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Utah Academy of Sciences, Arts, and Letters

History: Founded 3 April 1908, the Utah Academy of Sciences was organized "to promote investigations and diffuse knowledge in all areas of science." Beginning in 1923, the Academy started publishing the papers presented in its annual meetings in *Proceedings.* In June 1933 at the annual meeting, the Academy was enlarged to include arts and letters, and the name was changed to the Utah Academy of Sciences, Arts, and Letters. Articles of incorporation and non-profit organization status were accepted by the Academy membership at the spring meeting in April 1959. In 1977, the name of the journal of the Academy was changed from *Proceedings* to *Encyclia*. It became a refereed journal at this time. In the mid 1980s, the scope of the Academy was expanded further to include (1) business, (2) education, (3) engineering, (4) library information and instruction, and (5) health, physical education, and recreation. Beginning with the 1998 issue, the journal became *The Journal of the Utah Academy of Sciences, Arts, and Letters*.

Annual Meeting: The Academy's annual meetings are normally held in the spring on one of the Utah campuses of higher education. The plenary session is called the Tanner Lecture, endowed by Mr. O.C. Tanner in 1986.

Best Paper Awards: A best paper and a best poster presented in each division may be selected for cash award, which is presented at the Academy's "Awards Evening" held the following fall.

Distinguished Service Awards: The Academy recognizes outstanding contributions to teaching and scholarship by means of annual Distinguished Service Awards, alternating every other year between disciplines.

Membership: When the Academy was founded in 1908, membership was by nomination, ratified by the Council, and elected by a "three-fourths votes of members present." Today, the Academy's membership is available by application.

Institutional Members: All Utah institutions of higher education are members of the Utah Academy. The Academy appreciates their patronage.

Publication Policy

The Journal of the Utah Academy of Sciences, Arts, and Letters publishes works in all of the fields of study encompassed in the Academy's mission. Papers published in *The Journal of the Utah Academy* are drawn from papers presented by members in good standing at the annual conference of the Utah Academy. To qualify for publication, the papers must be recommended through a refereeing system.

Presenters are encouraged to publish their paper in *The Journal of the Utah Academy*. *The Journal*'s criteria are that a submission is (1) fresh, meaningful scholarly insight on its subject; (2) readable and well written; and (3) of general interest for an academic readership beyond the author's field.

If you wish your paper to be considered for publication in *The Journal*, please submit a Microsoft Word document to the division chair of the appropriate section by the indicated deadline. Contact information for the division chairs is available on the Utah Academy's website (www.utahacademy.org).

The Journal of the Utah Academy is a refereed journal. Editorial responses will be forthcoming after the resumption of school the following fall when referees have returned their comments to the division chairs.

Papers should be between 10 and 20 double-spaced pages. Detailed instructions to authors are available at http://www.utahacademy.org/ Instructions_for_Authors.pdf.

The Journal of the

Utah Academy of Sciences, Arts, & Letters 2024

AWARDS

ARTICLES

ARTS

BIOLOGICAL SCIENCES

ENGINEERING

HUMANITIES, PHILOSOPHY, & FOREIGN LANGUAGE

PHYSICAL SCIENCES

SOCIAL SCIENCES

DISTINGUISHED SERVICE AWARD

The Distinguished Service Award is given to to honor an individual for exceptional service to education or academic service to citizens in Utah.

Jean Tokuda Irwin

Utah Division of Arts and Museums

Jean Tokuda Irwin holds a B.A/M.A. from the University of Texas/Permian Basin. She is the Arts Education Program Manager for the Utah Division of Arts and Museums. She serves on NASAA/AE's Diversity, Equity, Access & Inclusion Group & NEA/POL Accessibility Working Group, Spy Hop Advisory Board, and Emerald Hills Institute Board. Her past service includes panelist for NEA, sister SAAs and President's Committee for Arts and Humanities Education; NASAA/AE Advisory Group & Leadership Taskforce, Coalition for Minorities Advisory Committee to the Utah State Board of Education; the Utah Indian Education Taskforce; National PTA Board of Directors (added dance & film/video to national Reflections Program); adjunct faculty - Odessa College, Galveston College, Western Texas College and Director of Museums (History & Art). She has received the Utah Human Rights award/Utah Counselors Association, Ruby Chacon Award for Arts and Social Justice, and the Sorensen Legacy Foundation Award for Lifetime Achievement in Arts Education, and is a Utahns for Culture Special Honoree. Her mixed media work appeared in the 2002 Cultural Olympiad featuring 20 works by Utahns and most recently in the Clay, Paper, Scissors Gallery in Laramie, WY. She is a serial fondler of books and crafts visual journals and is an independent world cinema addict who loves traveling, weird foreign foods, and squiggly ingredients. She abhors bottled water and plastics.

JOHN & OLGA GARDNER PRIZE

The Gardner Prize is awarded annually for exceptional achievement by an academic professional in Utah.

Loreen Allphin, PhD

Brigham Young University

Loreen Allphin, plant ecologist/conservation geneticist, received her doctorate in 1996 from the University of Utah (biology with an ecology and evolution emphasis). She has served on the faculty at Brigham Young University from 1996 to the present. She is currently a faculty member in the Department of Plant and Wildlife Sciences at Brigham Young University, where she serves as chair of the departmental graduate committee. Since 2003, she has also served as an adjunct curator of plants at the Utah Museum of Natural History in Salt Lake City. Dr. Allphin teaches undergraduate courses in conservation biology, genetics and reproduction in natural populations, ecology, and medicinal botany. Her research interests include: ecological and conservation genetics of rare plant populations; systematics of Brassicaceae, primarily the genera Boechera and Draba in western North America; phylogeography of rare plant genera and species in western North America; exploration of biogeographic patterns associated endemism and rarity in plants; plant population and community ecology; and plant reproductive ecology.

O.C. TANNER LECTURE 2024

The plenary session of the Annual Conference is called the Tanner Lecture, endowed by Mr. O.C. Tanner in 1986.

"Human life history evolution & sensitivity to social safety that shadows our lives"

Kristen Hawkes, PhD

University of Utah

A hunting/paternal provisioning hypothesis has long been central to ideas about what happened in human evolution. But challenges have been accumulating that point to an alternative grandmother hypothesis, initially aimed to explain why postmenopausal longevity increased and maturation slowed, yet birth intervals shortened in us compared with our closest living relatives, great apes. Now, more features that distinguish us from them are linked to the evolution of human life history, including our pair bonding habits, our big brains, and our distinctive sensitivity to social safety that begins with precocious agency for engagement in otherwise helpless human babies. Resulting lifelong appetites for mutual understanding and response to social context enrich our lives. They also sharpen "us versus them" divisions with high costs reported in today's alarming headlines. Other costs include stressful vigilance about uncertain social safety that amplifies health disparities for stigmatized and marginalized minorities.

Kristen Hawkes is a Distinguished Professor of Anthropology at the University of Utah. Hawkes received a bachelor's degree in Sociology and Anthropology from Iowa State University and a Masters in Anthropology from the University of Washington. She was awarded a PhD in Anthropology for her research into kinship and cooperation among the Binumarien—a highland community in New Guinea. Hawkes has pursued ethnographic fieldwork in highland New Guinea, Amazonia, and eastern and southern Africa. She is a member of the Scientific Executive Committee of the Leakey Foundation, the American Academy of Arts and Sciences, and the National Academy of Sciences. In 2021 she was elected to the American Philosophical Society.

ACADEMY FELLOW

"Fellow" is the title used to honor individuals who have, or have had, substantial involvement as members of the Academy and who have gained distinction through meritorious original research, scholarship, creative work, or extraordinary teaching within their academic field.

H. Laine Berghout

Weber State University

Henry Laine Berghout (Laine) currently serves as an associate dean in the College of Science at Weber State University, where he has been a member of the chemistry faculty since 2000, teaching General Chemistry and Quantum Chemistry courses. Interacting with students as they discover chemistry is the highlight of his career at Weber State. Laine is a native of Ogden and attended public schools, ultimately graduating from Ogden High School. Following service as a missionary for the Church of Jesus Christ of Latter-day Saints, he attended then Weber State College, choosing Chemistry as a major and Physics and German as minor areas of study. He attended the University of Wisconsin–Madison for graduate study, completing a PhD in Physical Chemistry. His thesis research involved controlling the reaction dynamics of small unimolecular decomposition processes by preparation of vibrational motions in the reactant molecule followed by photolytic dissociation. Laine's interest in understanding factors that influence the safety of energetic materials led him to pursue postdoctoral research at Los Alamos National Laboratory. Laine has authored more than 20 peer-reviewed publications and presented his work in numerous regional, national, and international meetings. During the 24+ years on the faculty of Weber State, Laine has regularly mentored undergraduate research projects, including computational investigations of factors that affect the rates of chemical reactions, developing a budget Raman spectrometer, and investigating the prevalence of environmental microplastics in Utah waters. The results from some of these projects have been presented in talks at the annual conference of the Utah Academy of Sciences, Arts, and Letters and published as papers in the *Journal of the Utah Academy of Sciences, Arts, and Letters*. The Annual Conference of the Utah Academy is among Laine's favorite conferences because of its multidisciplinary nature and undergraduate-research-friendly mission. Laine has been active in the Utah Academy since he joined the faculty at Weber State, serving as Physical Sciences Chair, President Elect, President, Past President, and member at large. His most enjoyable activities with the Academy include recognizing the outstanding

accomplishments of Academy members through its various awards and participating in and sometimes leading the Academy's Spring Excursion to places like the Mormon Pioneer National Historic Trail, the Escalante and Dominguez Trail, the Glen Canyon Dam, and Range Creek Canyon. Laine and Tamara Berghout recently celebrated forty years of marriage. They are the parents of four daughters and currently enjoy spending time with their five grandchildren. They enjoy traveling together and have recently taken up SCUBA diving.

HONORARY MEMBER

Any person who has given long service and gained unusual prominence and distinction in the sciences, arts or letters may be conferred honorary membership in the Academy by the Board of Directors.

Let Utah Read

Let Utah Read is a coalition of Utahns, educators, parents, librarians, and organizations dedicated to preserving Americans' freedom to read. We believe that all people in American have the right to access a wide range of literature in school and public libraries and to engage with diverse ideas, free from censorship or discrimination. We believe parents, not the government, should regulate and supervise their children's reading. We work to educate and activate our fellow citizens across Utah so that together, we can protect the right to read for ourselves, our children, and future generations.

2024 BEST PAPER/POSTER AWARDS

ARTS

Best Poster

Turning Towards the Lord: Latter-Day Saint Temple Astro-Architectural Orientation
Jake Wendt, Desiree Ritchie
Utah Valley University

BIOLOGICAL SCIENCES

Best Paper

Isolation of Multi-drug Resistant Serratia from Soil
Kaeson Severe, Landon Severe
Weber State University

Best Poster

Encoding and Proessing of Visual Information in the Leech
Belle Brown
Westminster University

BUSINESS

Best Paper

Is Personal Compulsive Social Media Use Affecting the Happiness of Employees?
Jeff Clements
Weber State University

EDUCATION

Best Paper

Collaborative Practices Between Utah Teachers and School Social Workers
Kristina Moleni, Andrea Garavito Martinez, Fangaafa Tu'ifua
Weber State University

ENGINEERING

Best Paper

Performance Analysis of a Spray-Type Passive Downdraft Evaporative Cooler

Avline Vega, Matt Lovell, JaydenPayne, Ali Syved Siahpush
Southern Utah University

HUMANITIES, PHILOSOPHY, & FORIGN LANGUAGES

Best Paper

Reframing Empathy

Emily Richael
Brigham Young University

Best Poster

The State of Student Media at HBCUs and HSIs

Mariana Lopez
Weber State University

KINESIOLOGY AND HEALTH SCIENCES

Best Poster

Perceived Motivators and Barriers to Facilitate Exercise Among Primary Care Clinic Patients

Kelsey Hansen, Saori Hanaki
Weber State University

PHYSICAL SCIENCES

Best Paper

Sacrificial Micropatterning of PDMS for Filtration and Hydrophobicity

Kylee M. Stoddard, J. Fielding Hokanson, Russell M. Bodily, Emma D. Monson, Christopher F. Monson
Southern Utah University

SOCIAL SCIENCES

Best Paper

Exposure to True Crime Media Changes Safety Behaviors

Tayla Bair, Sami Flanagan, Taesi Higgs, Lillian Binks, Seli Ha'angana
Snow College

Best Poster

College Students' and Professors' Perceptions of a Student with ADHD: Does the Gender Matter?

Jackson T. Anderson, Rick B. Anderson, Aonika M. Russell, Kathryn Sperry
Weber State University

Frederic Balazs and Ernst von Dohnányi: From Budapest to the American Southwest

Jackie Bodily Biggs
Brigham Young University

Abstract

Hungarian musician Ernst von Dohnányi (1877–1960) held most of the leading musical positions in Budapest during the 1930s. Although accounts abound regarding his efforts to help Jewish musicians at the advent of World War II, Dohnányi was accused in the press of being anti-Semitic, and this charge reverberates in Hungary even today. Dohnányi's associations with Hungarian American musician Frederic Balazs (1919–2018) provide an additional witness of Dohnányi's aid to musicians of Jewish heritage. Balazs was an ethnic Ashkenazi Jew. He emulated Dohnányi and associated with him frequently in his youth. Balazs enjoyed early success, receiving the prestigious Reményi prize and becoming, at age seventeen, the youngest concertmaster in the history of the Budapest Philharmonic Orchestra. Dohnányi conducted this orchestra and was also Director of the Franz Liszt Academy of Music, from which Balazs graduated in 1939. At the advent of World War II, Dohnányi helped Balazs emigrate to the United States. Once there, they performed in concert together on several occasions, receiving favorable reviews. Balazs defended Dohnányi's reputation and conveyed admiration for his musicianship and character. Their associations and

congenial relationship indicate a more nuanced view of Dohnányi's actions and character.

"Please, listen to us. Radio Budapest is speaking, the blue Danube, the radiant Hungarian grain fields, the pale green forests, the Radio of ardent Hungarian hearts. Listen to us, for we are celebrating Ernst von Dohnányi, who is ours, and whom we have given to the world."[1] It was July 1937 when this broadcast rang across Europe to announce the sixtieth birthday of famous Hungarian musician Ernst von Dohnányi (1877–1960). Yet only a few years later, this same Dohnányi would become *persona non grata* in his home country for nearly half a century following a deluge of accusations regarding his conduct during World War II.[2] Scholars have concluded that the official charges "were finally withdrawn as they were mostly unfounded," but it was not until 1990 that Dohnányi would receive a renewal of civic approval as the posthumous recipient of Hungary's highest cultural honor, the Kossuth Prize.[3]

Despite this recognition, suspicions and even outright condemnation persist in Hungary today because of Dohnányi's supposed anti-Semitism and alleged collaboration with right-wing extremists.[4] The details on the particulars of his charges and conduct are currently under scrutiny, and new research is forthcoming.[5] Many examples, however, illustrate Dohnányi's kindness—even heroism—towards Jewish musicians. Dohnányi wrote a letter that led to pianist Lajos Hernádi's release from labor service. He enabled violinist Carl Flesch and his family to escape to Switzerland. He also saved the pianist György Ferenczy, Ferenczy's wife, and several other Jewish musicians from the death trains.[6] Dohnányi's third wife, Ilona von Dohnányi, suggested there were many others: "People often visited our home to ask his help or protection. Without hesitation he signed every petition and application that was handed to him. He saved hundreds of people whose names he

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[1] *Pesti napló* (Budapest), 28 July 1937, Arcanum Newspapers: The Eastern European Newspaper Archive, quoted in Ilona von Dohnányi, *Ernst von Dohnányi: A Song of Life*, ed. James A. Grymes (Indiana University Press, 2002), 222–23.
[2] Veronika Kusz, "The Accusation of Dohnányi: The Legal Procedure in Hungary, 1945–1946," *Studia Musicologica* 63 nos. 1–2 (2022): 1. https://doi.org/10.1556/6.2022.00001.
[3] Kusz, "Accusation of Dohnányi," 1.
[4] Kusz, "Accusation of Dohnányi," 1–3, and James A. Grymes, "Ernst von Dohnányi and Communist Hungary in the Early Cold War," *Acta Musicologica* 84, no. 1 (2012): 86. http://www.jstor.org/stable/23343909.
[5] Kusz, "Accusation of Dohnányi," 1–3.
[6] Grymes, "Dohnányi and Communist Hungary," 67–69.

never even cared to know. To act in this way required not only generosity but also immense courage and even audacity. To express any contrary opinion could easily cost someone his life."[7]

Adding yet another name to the ostensible "hundreds," the associations and collaborations of Dohnányi with Hungarian American musician Frigyes Balázs (1919–2018) shed a humanistic light on the perhaps unfairly tarnished reputation of Dohnányi.[8] The American version of the name, Frederic Balazs, will be used here, in harmony with Balazs's adaptation of his name following emigration, which included removal of the diacritic and emphasis on the second syllable of Balazs rather than the first.[9] It is interesting to note, however, that this would not have been Balazs's last name at all, had he been born 20 years earlier. His father, Oskar Brust, changed his last name to Balázs (a common Hungarian name, like Smith in the United States) ca. 1900 because of Jewish persecution.[10] Because Oskar and his wife, Ilona, were ethnically Ashkenazi Jews (as well as practicing Catholics), Frederic Balazs was also an Ashkenazi Jew by birth.[11] His congenial relations with Dohnányi

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[7] Ilona von Dohnányi, *Ernst von Dohnányi: A Song of Life*, ed. James A. Grymes (Indiana University Press, 2002), 124.

[8] Frederic Balazs himself has yet to be the object of extensive scholarly attention; for example, his name appears in R. R. Bowker, *Who's Who in American Music: Classical* (R.R. Bowker Company, 1983) and E. Ruth Anderson, *Contemporary American Composers: A Biographical Dictionary* (G.K. Hall & Co., 1982), but not in Virgil Thomson, *American Music Since 1910* (Weidenfeld and Nicolson, 1971), Gyula Czigány, ed., *Contemporary Hungarian Composers* (Editio Musica, 1970), or David Nicholls, ed., *The Cambridge History of American Music* (Cambridge University Press, 1998).

[9] Frederic Balazs, "Frederic Balazs—composer interview, 2012," [interview by Gina Genova], American Composers Alliance, December 2012, posted May 27, 2013, YouTube video, 10:30, https://www.youtube.com/watch?v=oVPzYS8tN3w. The change of pronunciation occurred with time. Interviewer's name confirmed in email message to author, May 20, 2024. Balazs's family still pronounces the name in this manner, per relative Brent M. Kitchens, direct message to author, May 1, 2024.

[10] "Oskar Balazs (Born Brust)," accessed 28 August 2024, Ancestry, https://www.ancestry.com/family-tree/person/tree/25407418/person/26441951622/facts. Year and political influence confirmed by Brent M. Kitchens, direct message to author, May 1, 2024.

[11] "Oszkar Balazs," Conference on Jewish Material Claims Against Germany, comp, *Hungary, Jewish Names from the Central Zionist Archives* [database on-line], Provo, UT, USA: Ancestry.com Operations Inc, 2008. Original data derived from archival documents available at the Central Zionist Archives, Yad Vashem, and the United States Holocaust Memorial Museum; this data provided in partnership with JewishGen.org. https://www.ancestry.com/discoveryui-content/view/104844:1513?ssrc=pt&tid=25407418&pid=26441951622. Ilona's Jewish ethnicity confirmed by Brent M. Kitchens, direct message to author, May 1, 2024; "Frigyes Balazs," New York, U.S., Arriving Passenger and Crew Lists (including Castle Garden and Ellis Island), 1820-1957 [database on-line]. The National Archives in Washington, DC. Washington, DC, USA, *Passenger and Crew Lists of Vessels Arriving at New York, New York, 1897-1957*, Microfilm Serial

both before and after the war present an additional example of a Jewish musician aided by Dohnányi, indicating a nuanced view of Dohnányi's actions and character as well as expanding the biographical scholarship on the musicians' collaborative Southern and Western performances in the United States.

Born 12 December 1919 in Budapest, Balazs had numerous associations in his early years with Dohnányi.[12] At the time, Dohnányi was an iconic musical figure in Budapest. As a virtuoso pianist, he enjoyed an international career. He was conductor of the Budapest Philharmonic Orchestra beginning in 1919, Music Director of the Hungarian Radio from 1931, and Director General of the Franz Liszt Academy of Music from 1934.[13] In addition, a position in the Hungarian legislature was automatically allocated to him as Director of the Academy. Dohnányi's influence was such that these years have been historically categorized as an "era with the central power of Dohnányi."[14] Given Dohnányi's status at the time, it is natural that young Balazs would admire the prominent musician, as an American newspaper later reported:

> [Dohnányi] was conductor of the Budapest Philharmonic Society. It was in that capacity that he became the idol of a dark-visaged little boy who yearned to become a violinist, who followed the maestro like a shadow, and occasionally thrilled to the privilege of carrying Dohnányi's music case. This lad was Frederic Balazs of Budapest. Eventually, Balazs sat in that ensemble under the baton of Dohnányi.[15]

In fact, Balazs became not only part of the ensemble, but, at seventeen, the youngest concertmaster in the history of the Budapest

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or NAID: T715. RG Title: *Records of the Immigration and Naturalization Service, 1787-2004*, RG: 85, Lehi, UT, USA: Ancestry.com Operations, 2010, https://www.ancestry.com/discoveryui-content/view/1004664419:7488?tid=&pid=&queryid=a9bc1a4d-665f-4409-9205-0cbfd4dc00f9&_phsrc=eNf101&_phstart=successSource.

[12] Frederic Balazs, "Dohnányi in Texas," *The Southwestern Musician* 15 (February 1949): 21.

[13] Grymes, "Dohnányi and Communist Hungary," 65; Dohnányi, *Song of Life*.

[14] Rachel Beckles Willson, *Ligeti, Kurtág, and Hungarian Music during the Cold War* (Cambridge University Press, 2007), 2.

[15] Micheline Keating, quoted in "Tucson Acclaims Ernst Dohnányi," *Wichita Falls Times* (Texas), January 15, 1956, https://www.newspapers.com/image/780320089.

Philharmonic.[16] In addition, he was appointed as assistant director of the orchestra.[17] In short, Dohnányi inspired Balazs and recognized his talent by promoting him to high-profile positions.

This held true in the orchestra as well as at the Academy. Balazs was admitted to the Academy before the age of six, won the Reményi prize when only sixteen years old, and, in 1939, graduated with honors in violin, conducting, and composition.[18] In addition to studying composition with Dohnányi, he benefited from the tutelage of such greats as Béla Bartók, Zoltán Kodály, and Jenő Hubay.[19] Although some accusations claimed that Jewish students at the Academy experienced academic prejudice, Balazs disagreed, recalling Dohnányi as "the master in the conservatory showing a wide and gentle interest in the work of all the students."[20]

Following his graduation, Balazs embarked on a European tour, and hoped to book a tour in the United States as well.[21] This was challenging, however, because of the political climate at the advent of World War II. "I needed a lot of political help to be able to come." Balazs said, "The frontiers were closed; the Nazis were next door and right inside Hungary. The person who really helped me was Ernst von Dohnányi. … He had to do some political twisting around so I would officially be let out of the country."[22] Balazs's gratitude shines in his naturalization document, in which his newly American name, Frederic Balazs, proudly includes a middle name: Ernest.[23] It is unclear whether

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[16] Daniel Buckley, "Hungarian-Born Conductor Left His Mark on the Tucson Symphony Orchestra," *Tucson Citizen* (Arizona), October 23, 2003, accessed May 31, 2024, https://acacomposers.s3.amazonaws.com/balazs_by_buckley_2003.pdf.

[17] "Violinist Will Direct Wichita Falls Symphony," *Fort Worth Star-Telegram* (Texas), January 18, 1948, https://www.newspapers.com/image/637148177.

[18] "Young Violinist to Appear on Series Opening Program at Kinsloe House Monday," *Corsicana Daily Sun* (Texas), January 11, 1949, https://www.newspapers.com/image/13123622. See also Buckley, "Hungarian-Born Conductor."

[19] "Violinist Frederick Balazs to Present Concert Monday Evening at Kinsloe House," *Corsicana Daily Sun* (Texas), January 15, 1949, https://www.newspapers.com/image/13125884.

[20] "Even the most talented students were mercilessly failed in [their] examinations if they were the children of Jewish parents," [without author (Ferenc Göndör?)]: "We are waiting for Dohnányi in New York," *Az Ember*, 20 November 1948, quoted in Veronika Kusz, "Dohnányi megvádolása a magyarországi és a külföldi magyar nyelvű sajtóban 1945 és 1948 között (Charges against Dohnányi in the Hungarian press in Hungary and abroad between 1945 and 1948)" *Magyar Zene: Zenetudományi Folyóirat* 58, no. 3 (2020): 329. Translation by DeepL. John Maul, "Dohnányi to Instruct Piano Here," *Arizona Daily Star*, Jan. 1, 1956, https://www.newspapers.com/image/163813763.

[21] "Young Violinist."

[22] Balazs, "Frederic Balazs—composer interview, 2012," 2:24.

[23] Frederic Ernest Balazs, Naturalization Petition, The National Archives at Atlanta, Georgia, USA, NAI Number: 6091096, NARA NAID Title: *Naturalization Orders*,

this was a new addition; Balazs's Hungarian name is recorded as Frigyes Balazs, but "No change," is written under the petition for name change. The fact that Balazs included Ernest in his name, whether new or not, indicates his appreciation and admiration for Dohnányi.

The two musicians would meet again a decade later, but first, each left his home country behind. Balazs caught the last ship out of Bordeaux, France. "It was very moving to wake up at dawn," he said, "coming slowly, slowly from behind the Statue of Liberty with the sun coming up slowly over the skyscrapers. It was a very emotional experience."[24] All his luggage was lost when the freight ship was sunk by U-boats, such that Balazs arrived in America on 15 November 1939 with only twenty-one cents, the clothes on his back, his violin, and his umbrellas.[25] Initially, Balazs made a living as a concert violinist. He soloed with the New York Symphony Orchestra and toured the eastern United States, "winning ovations" for his "sensitive interpretations."[26] When the United States joined the war, Balazs enlisted, serving four years in a field artillery unit.[27] He also became an American citizen, enabling him to help bring his surviving family members to the U.S.[28] In 1948, Balazs took a position as head of the instrumental department at the School of Music of Hardin College and conductor of the newly reinstated Wichita Falls Symphony Orchestra, which had ceased operations during the war.[29]

Meanwhile, Dohnányi faced the changing political climate in Hungary. Although he had been able to ignore anti-Semitic quotas instituted in 1920 that would have limited Jewish enrollments to six percent, the 1939 enactment of the Second Anti-Jewish Law made observance compulsory. Dohnányi personally requested that current Jewish preparatory students be allowed to continue into college classes, but his request was denied.[30] When ordered to dismiss Jewish instructors at the Academy, Dohnányi resigned. In the Budapest Philharmonic, he

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Compiled 1931–91, Record Group Title*: Records of District Courts of the United States*, Record Group Number: 21, *Mississippi, U.S., Naturalization Records, 1907-2008*, Serial Number: 32201765, Lehi, UT, USA: Ancestry.com Operations, Inc., 2012, https://www.ancestry.com/discoveryui-content/view/10121:2502?tid=&pid=&queryid=b651c4d9-74c4-4a66-8855-2d01608de34d&_phsrc=eNf96&_phstart=successSource.

[24] Buckley, "Hungarian-Born Conductor."

[25] Balazs, "Frederic Balazs - composer interview, 2012," 1:25.

[26] "Young Violinist."

[27] Byrd Stanley, "Balazs' Career Ranges from Budapest to Bisbee," *Tucson Citizen* (Arizona), May 2, 1953, https://www.newspapers.com/image/18833475.

[28] Direct message, Brent M. Kitchens, May 1, 2024.

[29] "Orchestra Wins Topmost Praise," *Wichita Falls Times* (Texas), May 13, 1948, https://www.newspapers.com/image/774213425.

[30] Grymes, "Dohnányi and Communist Hungary," 66.

managed to keep on all Jewish orchestra members until May 1944, then disbanded the entire orchestra rather than dismissing only Jewish musicians.[31] In contrast, the Budapest Opera, one of the only musical organizations unaffiliated with Dohnányi, released its Jewish members directly in 1939, making it the first time in history that the orchestras maintained different rosters.[32]

In November 1944, as the Red Army approached Budapest after conquering eastern Hungary, Dohnányi, who believed he was on the list to be taken prisoner, fled to Austria.[33] Here he found refuge in a small Austrian village that later became part of the American Zone. In gratitude "for the security afforded him by the American forces," Dohnányi composed a piano work, his Six Pieces for Piano, op. 41.[34] The "elegiac" final movement he dedicated to the memory of his son, Hans, whom he discovered at this time had been executed by the Nazis for his involvement in the 20 July 1944 assassination attempt against Hitler.[35]

In 1945, the largely communist Provisional National Government in Hungary issued a list of war criminals.[36] Dohnányi's name was included on the list, and the press quickly amplified the news. Shockingly, some of these accusations—including on the BBC radio—went so far as to claim that Dohnányi personally delivered Hungarian artists to the Gestapo. Dohnányi did not respond to many accusations, but in this case, he wrote a letter of protest to the BBC program director, which reads in part:

> I do not know where such information came (surely not from any official place), but I have to declare it a calumny and a complete lie. I never had anything to do either with the Gestapo or with any similar organization. I never belonged to any political party, and nobody can prove that I ever committed an incorrect or unliberal action against anybody. My only fault was—it is strange enough that it should be a fault—that as a member of the Hungarian House of Lords, I signed (like other members of the House who were good patriots) the foundation of the "Nemzeti Szövetség (National Association) which was directed

[31] Grymes, "Dohnányi and Communist Hungary," 67.
[32] Grymes, "Dohnányi and Communist Hungary," 67.
[33] Grymes, "Dohnányi and Communist Hungary," 70.
[34] John Maul, "Dohnányi Plays Famed Concerto," *Arizona Daily Star*, Jan. 11, 1956, https://www.newspapers.com/image/163858920.
[35] Maul, "Famed Concerto." In 2003, Hans was honored as one of the Righteous Among the Nations for his aid to several Jewish lawyers.
[36] Grymes, "Dohnányi and Communist Hungary," 71–2.

> against Russia. I leave it to your kindness and your sense of what is right, to investigate this matter and to do me justice.[37]

It is clear why this would seem to be a particularly unfair claim when Dohnányi had been accomplishing precisely the opposite: *saving* the lives of Jewish musicians. As Dohnányi scholar James A. Grymes has written, "Ironically, many of these accusations were propagated by a man whom Dohnányi had anonymously saved from the concentration camps, as he had tirelessly done for numerous Hungarians."[38] The most important official charge seems to be that of intellectual collaboration with fascists in the programming of the Budapest Radio.[39] Although this charge was eventually dropped, its veracity is being researched. Whatever the outcome, it is worth noting that recently found documents indicate a communist plot against Dohnányi, to the point that the campaign may bear "the majority of the responsibility for Dohnányi's condemnation by his homeland and subsequent blacklisting by the music world."[40]

In 1946, Dohnányi's situation in Austria became increasingly precarious, and he resolved to exit the country. His damaged reputation and personal circumstances discouraged many countries from approving entry, but finally an offer came from Argentina for several concert engagements, and Dohnányi debuted there successfully on 25 April 1948.[41] He then accepted a position as director of a new music school at the Universidad Nacional in Tucumán, Argentina. The school, however, had yet to be built.

In the meantime, Dohnányi embarked on his first post-war tour of the United States. As part of the tour, Balazs and Dohnányi met again, this time in two joint recitals in Texas, booked by Dohnányi's agent, Andrew Schulhof. These recitals were held at Hardin College, Wichita Falls, and College of Mines, El Paso. Another recital was to be held at Scott Hall in Dallas in December 1948, but this seems not to have occurred.[42] Two other expected collaborations became solo recitals, one on Wednesday, 5 January 1949, at the University of Texas, Austin, the

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[37] James A. Grymes, ed. *Perspectives on Ernst von Dohnányi* (Scarecrow Press, 2005), 14.
[38] James A. Grymes, *Ernst von Dohnányi: A Bio-Bibliography* (Greenwood Press, 2001), 8.
[39] Veronika Kusz, "A Dohnányi-ügy első hulláma (1945–1946) (The first wave of Dohnányi's political case [1945–1946])," *Dohnányi-Tanulmányok* (2021): 47.
[40] Grymes, "Dohnányi and Communist Hungary," 70.
[41] Grymes, "Bio-Bibliography," 9. The following sentences reference this as well.
[42] Lynne A. Wortham, "Current Musical Events of Interest to Corsicanans in Local, State and U.S. Circles," *Corsicana Daily Sun* (Texas), Oct. 5, 1948, https://www.newspapers.com/image/10933743.

other at Texas Christian University, Fort Worth on Wednesday, 12 January 1949 at Paschal High School Auditorium.[43] In combination with a series of master classes, the latter recital made a large enough impression for Dohnányi to receive a job offer from the Dean of Music to become Professor and Composer-in-Residence.[44] (Later, he opted for an offer to be Professor of Piano and Composer-in-Residence at Florida State University in the fall of 1949, upon finding on his return to Argentina that construction had not even begun on the music school.)[45]

In conjunction with the tour, a wave of negative press regarding the accusations against Dohnányi swept through the United States.[46] Most of the press announcements in Texas remained somewhat oblivious, highlighting only Dohnányi's musicality and prestigious career; for example, Clyde Whitlock, music editor of the Fort Worth-Star Telegram, wrote that Dohnányi was "the greatest artist offered Fort Worth since Stravinsky."[47] A few announcements also attempted to redress possible prejudices. One article spends three quarters of its length assuring readers that Dohnányi had been certified as not collaborating with Nazis and that he was positively refusing Russian invitations to return to Hungary.[48] Many claim erroneously that Dohnányi was associated with the University of Brazil in Rio de Janeiro, rather than the Universidad Nacional in Tucumán, Argentina.[49] This could be a genuine mistake or possibly a distortion of unknown origin, as Argentina was then a place where those of "questionable background" could reside.[50] Dohnányi was

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[43] "Dohnányi Recital at UT Wednesday," *Austin American* (Texas), January 2, 1949, https://www.newspapers.com/image/52407928/; "Dohnányi Recital to be Rare Musical Experience," *Fort Worth Star-Telegram* (Texas), January 9, 1949, https://www.newspapers.com/image/636883523/. This performance was favorably reviewed: William J. Marsh, "Sterling Technique of Dohnányi, at 71, Unravels Artistic Works for Piano," *Fort Worth Star-Telegram* (Texas), January 13, 1949, https://www.newspapers.com/image/636716281/.

[44] Dohnányi, *Song of Life*, 183.

[45] Grymes, "Bio-Bibliography," 9.

[46] Kusz, "Dohnányi megvádolása." See also Dohnányi, "Song of Life," 177–84 and 226–31.

[47] "Ticket Sale Starts for Dohnányi Concert," *Times Record News* (Texas), January 5, 1949, https://www.newspapers.com/image/775034009.

[48] "Famous Pianist Shuns Homeland," *Times Record News* (Texas), January 6, 1949, https://www.newspapers.com/image/775034048. See also W.L. Underwood, "Curtain Currents," *Wichita Falls Record News* (Texas), Oct. 15, 1948, https://www.newspapers.com/image/775047570.

[49] For example, see Underwood, "Curtain Currents."

[50] One paper did list the correct country: "Dohnányi Back in America After 20 Years, Due Here," *Fort Worth Star-Telegram* (Texas), January 7, 1949, https://www.newspapers.com/image/636883117; Grymes, *Bio-Bibliography*, 9.

quoted in the press as discussing European musicians' emigrations to South America, but without elaboration on the city or country.[51]

Balazs apparently intended to publish his own announcement of the tour in the journal *The Southwestern Musician*. Although the article appeared belatedly (after the Texas tour had already occurred), the sentiments expressed were perhaps useful in promoting Dohnányi afterward. That Balazs would credit Dohnányi in the face of negative press bespeaks to his positive impressions of Dohnányi from his youth. He begins by stating his association with Dohnányi in Budapest and lists the anticipated locations of the then-upcoming concerts.[52] With admiration, he states, "Dohnányi achieved everything of which any musician would dream." His perspectives on Dohnányi as a person are particularly generous: "His youthful appearance belies his 71 years. He is always cheerful, full of humor, and interested in others. He is one of those rare specimens of the musical world who likes to converse on subjects other than himself."

Balazs provides a biographical sketch and comments on Dohnányi the pianist, teacher, composer, and conductor. Like many Hungarians, he came to the defense of his old mentor, although he did not mention the personal emigration assistance he received from Dohnányi here.[53] "During the change of the Austrian Government, attendant upon World War II," he wrote, "Dohnányi was reported as one who furthered the cause of music, and of artists, regardless of political affiliations. As the leading musician of his country, he was known many times to risk political disfavor for the sake of aiding his young artist friends." Balazs attests that Dohnányi had been cleared of all charges. Fascinatingly, he then adds that Dohnányi is "head of the music department at the University of Brazil in Rio de Janeiro, where he retains the honored title of Dean of Pianists and Composers." The article concludes with a statement of confidence in Dohnányi's ability to encourage artists of the Southwest:

> Although he is old in years, he is very young in spirit and in creativeness. At this age, he has been willing to select a new country, a different world from that which he knew all of his

[51] "Composer-Pianist in Concert Here," *El Paso Herald-Post* (Texas), January 8, 1949, https://www.newspapers.com/image/797388005/.
[52] Balazs, "Dohnányi in Texas," 21–22. For the next paragraphs as well.
[53] James A. Grymes, "'Dohnányi Was Not—And Could Not Have Possibly Been—A War Criminal' The Hungarian Defense of Ernő Dohnányi, 1945-1949," *Studia Musicologica* 54, no. 3 (2013): 301–17, https://doi.org/10.1556/6.2022.00001.

> life in his homeland. He will be very understanding to the musical problems in our own Southwest, although we are a very young territory for artistic backgrounds. His pioneer spirit will strike an encouraging note in all of us who have chosen to dedicate our knowledge and our lives towards the improvement of our musical status.[54]

Balazs's positive estimation demonstrates empathy and affection for Dohnányi, who reciprocated in a letter expressing his "'joyful anticipation' of reunion and joint performance and asking Balazs to select all numbers for their joint programs."[55] The program was to include sonatas by Brahms and Beethoven, as well as Dohnányi's Sonata in C-sharp Minor for Piano and Violin. Announcements highlighted the old teacher and student relationship: "When Ernst von Dohnányi and Frederic Balazs appear next Monday night at Hardin College in joint concert, it will be master and pupil again despite the fact that Balazs joined his former 'meister' in the ranks of professional concertists."[56]

As Dohnányi began his American tour in November 1948, several local Jewish agencies protested his concerts in Boston.[57] In later years, similar protests would hinder Dohnányi's ability to perform at major concert venues for a time.[58] Despite these protests, the joint recitals did occur. An 8 January 1949 recital in El Paso, Texas, was held in the Scottish Rite Auditorium at the College of Mines on a Saturday afternoon for an audience of about 200 people. Dohnányi opened the program with Beethoven's Piano Sonata in C Major, op. 53 ("*Waldstein*"). The reviewer stated that "all the distinctive marks of the great musical artist, poise, confidence, technical fluency, tonal balance and beauty, were apparent in Dohnányi's performance."[59] Also performed were Brahms's Sonata for Violin and Piano, op. 78, Dohnányi's "*Ruralia Hungarica*" for violin and piano, and Dohnányi's Six Pieces for Piano, op. 41. The reviewer compared Dohnányi with "the great Paderewski during his last tour of this country. Even in advanced age, there is the same proud carriage, straight back, gentlemanly calm

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[54] Balazs, "Dohnányi in Texas," 22.
[55] Underwood, "Curtain Currents."
[56] "Master and Pupil to Give Concert," *Wichita Falls Times* (Texas), January 6, 1949, https://www.newspapers.com/image/774216700.
[57] "Wellesly Manager, Pupil Defend von Dohnányi on Collaboration Charges," *The Boston Globe*, November 18, 1948, https://www.newspapers.com/image/433404126.
[58] Dohnányi, *Song of Life*, *192*–7.
[59] "Dohnányi Enthralls Audience," *El Paso Times* (Texas), January 10, 1949, https://www.newspapers.com/image/433204306.

and, above all, the same facile technique still in the fingers."[60] The comment that Balazs seemed "somewhat stiff and ill-at-ease in the presence of the master pianist" undoubtedly had more reference to musical presentation than personal relations, for later, the reviewer notes that in "*Ruralia Hungarica*," Balazs "seemed more 'at home' in this presentation than in the Brahms."[61]

The second performance was held on Monday, 1949 January 10 at 8:30 p.m. in the Hardin College auditorium, and was mentioned with fondness by Ilona von Dohnányi in her biography of Dohnányi: "On 10 January Dohnányi joined Frederic Balazs, who had once been a very talented student at the Budapest Academy, in giving a recital of violin sonatas in Wichita Falls, Texas."[62] It was an "obviously gratifying reunion for both Dohnányi and Balazs," noted a reviewer. "Dohnányi played, throughout the evening, with sublime assurance which never was in any measure demonstrative. His humility was born of exaltation derived from the music to which his heart was given."[63] Dohnányi opened with Beethoven's Piano Sonata in F Minor, op. 57 ("Appassionata"), which "abounded in rich feeling along with truly imposing technique. Probably no single facet of his art was more potent than the restraint, the pauses which were as natural as his breathing."[64] Once again, the Brahms violin sonata followed. The reviewer noted that Balazs played from the score and might have performed more persuasively with additional preparation. After intermission,

> [Balazs] and the intense, white-haired pianist literally sailed into Dohnányi's "*Ruralia Hungarica*" for violin and piano. As Balazs took fire on the presto, Dohnányi himself seemed lifted with a new animation, and the two final movements were an exciting display of fireworks. Technique and tone were highly gratifying. The stage was alive with ecstatically dancing peasants in gay attire, a vision induced by the fire of the music. To robust and prolonged applause, each artist responded by awarding major credit to his companion.[65]

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[60] "Dohnányi Enthralls."
[61] "Dohnányi Enthralls."
[62] Dohnányi, *Song of Life*, 183.
[63] "Wichita Music Lovers Defy Weather to Hear Dohnányi," *Times Record News* (Texas), January 11, 1949, https://www.newspapers.com/image/775034275.
[64] "Wichita Music."
[65] "Wichita Music."

Dohnányi then performed his Six Pieces for Piano, op. 41, once again.[66] He concluded by playing two encores, a Liszt consolation and one of his own marches.[67]

Balazs and Dohnányi's next association occurred about a year later, in 1950, when Balazs embarked on a 33-day tour through the Southern and Central states with his newlywed wife, Ann, a pianist. The Dohnányi family attended the Balazs's concert in Thomasville, Georgia, where Balazs had the opportunity to introduce his wife to Dohnányi for perhaps the first time. The Balazses were quoted as saying, "We made him take a bow from his seat with the audience after our performance of his violin piano suite '*Ruralia Hungarica*.'"[68] The newspaper article mentions that faculty of the Tallahassee State College and some of Dohnányi's Argentinian friends were also in attendance. Again, the two musicians' relations remained friendly and supportive.

Balazs became the conductor of the Tucson Symphony Orchestra in 1952 and, in this capacity, would invite Dohnányi to collaborate once more. In his new position, Balazs began "the practice of importing major guest artists as soloists, thus ending the established practice of featuring only local talent. This in turn brought about greater interest and support from the community."[69] Balazs would even follow Dohnányi's example of "aiding young artist friends" later in life, inviting several African American artists to perform with the Tucson Symphony during the tumultuous years of the Civil Rights Movement.[70] Singer Marian Anderson was booked twice, and composers William Grant Still and Ulysses S. Kay were invited to lead the orchestra. When a Southern-born player in the orchestra protested having to play with a Black conductor, Balazs insisted that he play, and in the end the player and Kay became lifelong friends.

In 1956, Balazs invited Dohnányi to perform as a guest artist with the orchestra in a performance of Beethoven's Piano Concerto No. 4 in G Major, op. 58. The announcements highlighted the relationship between the two musicians: "In [former] days, Dohnányi was the conductor and Balazs the instrumentalist. The tables will be turned at the Jan[uary] 10 concert when Balazs will conduct the Tucson Symphony and the soloist will be Dohnányi at the piano. It is a long and dear

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[66] "Dohnányi and Balazs to Present Concert," *Wichita Falls Times* (Texas), January 10, 1949, https://www.newspapers.com/image/774216785.
[67] "Wichita Music."
[68] "Balazs Tour Musical and Good Will Coup," *Wichita Falls Times* (Texas), April 9, 1950, https://www.newspapers.com/image/774294075.
[69] Charles W. King, "Arizona: Tucson Symphony Orchestra," in *Symphony Orchestras of the United States: Selected Profiles*, ed. Robert R. Craven (Greenwood Press, 1986), 10.
[70] Buckley, "Hungarian-Born Conductor."

friendship between the two Hungarian musicians that will be renewed here a week from next Tuesday."[71] Although a newspaper announcement mentioning the musicians' warm relations might seem distant, 1956 Tucson was a close community, and Balazs as symphony conductor likely had substantial influence on the rather extensive marketing and publicity of this event, as may be seen by the following reports of Dohnányi's visit.[72]

When Dohnányi and Ilona arrived in Tucson, they were very well received, acquiring almost celebrity status (Figure). Dohnányi's reunion with an old friend from Hungary, Louis Busch, made the papers, along with a large photo.[73] A chance run-in with vacationing Metropolitan Opera conductor, Fritz Stiedry, did as well, who was "delighted" to find Dohnányi here and remembered him from Vienna in 1903.[74] Stiedry was quoted as saying, "We had the same teachers, although he is a good deal older than I. His style of playing is something that you do not hear anymore. He is full of grace."[75] Even Dohnányi's master classes were featured in the newspaper, with a large photo of Dohnányi and a promising student.[76] In addition, a pre-concert lecture "Symphony Silhouette" was announced for 9 January, the day before the concert, held at a local home and featuring guest speakers.[77] James Anthony, professor of piano at the University of Arizona, was to discuss selections from the symphony program and several of Dohnányi's recordings. Balazs was also slated to discuss the symphony program, followed by Geraldine Saltzberg speaking about Dohnányi's life. A luncheon was to follow at 12:30 p.m., including attendance by the Dohnanyi's (following the morning master class), as well as a lecture by Ilona as writer and music critic. A reception was also planned to honor Dohnányi following the concert, with invitees including various sponsors and patrons of the

[71] Micheline Keating, "Renowned Musician Adds Luster to Musical Season," *Tucson Citizen* (Arizona), Dec. 31, 1955, https://www.newspapers.com/image/582506807 (originally "Jan.").
[72] Buckley, "Hungarian-Born Conductor."
[73] Bernie Roth, "Dohnányi Meets Old-Time Friend," *The Arizona Daily Star*, January 7, 1956, https://www.newspapers.com/image/163839480.
[74] John Maul, "Met Conductor 'Taking Break' From Opera Season to Relax in Tucson," *The Arizona Daily Star*, January 13, 1956, https://www.newspapers.com/image/163872310.
[75] Maul, "Met Conductor."
[76] "Maestro Impressed with Tucson Artist," *Tucson Citizen* (Arizona), January 9, 1956, https://www.newspapers.com/image/581899992.
[77] "Silhouette to Discuss Symphony," *Tucson Citizen* (Arizona), January 7, 1956, https://www.newspapers.com/image/581899147.

Symphony.[78] Balazs apparently spared no effort to honor his mentor and to create a memorable experience for the community.

Figure. Thursday, 5 January 1956: The Dohnányi's were met at the airport by the Balazses. *Left to right:* Frederic Balazs, Ernst von Dohnányi, Ilona von Dohnányi, Ann Balazs. ("No Post-Holiday Lull on Entertainment Scene," Photo by Lou Raizk for Sutton, Arizona Daily Star, January 8, 1956, https://www.newspapers.com/image/163844988.)

The night of the concert arrived. Even here, in the far-flung region of Arizona cactus and desert, accusations followed Dohnányi. A Tucson resident, Eugene Deutsch, distributed a circular to the waiting crowd in front of the University of Arizona auditorium. Deutsch was reported as having been imprisoned in a concentration camp in Hungary during the war. The flier read, "Ask Ernest Dohnányi where he was and what he was doing in Hungary on Oct. 15, 1944?"[79] The date has reference to the

[78] "Reception to Fete Dohnanyi," *Arizona Daily Star*, January 3, 1956, https://www.newspapers.com/image/163821025.
[79] "Where Was Dohnányi?" *The Arizona Post*, January 20, 1956, *Chronicling America: Historic American Newspapers*, Library of Congress, https://chroniclingamerica.

Nazi regime's *coup d'etat* in Hungary, following which Ferenc Szálasi, a radical anti-Semite, was installed as leader.

Still, the concert went on, opening with Samuel Barber's *Adagio for Strings* and followed by Haydn's "Farewell" Symphony, in which Balazs adhered to the original scoring for a small orchestra.[80] The orchestra followed the tradition of musicians exiting the stage throughout the piece.[81] Reviewer Guy Thackeray suggested the orchestra was lacking in its usual "singing quality" in the Barber and had difficulty with the technical requirements of the Haydn.[82] Next, the "spirited, white-thatched" Dohnányi, nearly 80 years old, entered the stage and performed his Six Pieces for Piano.[83] After intermission, Dohnányi and the orchestra performed Beethoven's Fourth Concerto. Dohnányi included his own cadenza. Balazs was again faithful to the original scoring for a small orchestra. Reviewer John Maul recorded, "In the concerto the pattern of unfoldment came across with an incisiveness that only a lifetime of devoted consideration could achieve. … Dohnányi exhibited wonderful subtlety of shading. He employed the finest distinction of Beethoven's masterwork in every pure style."[84] Thackeray praised the orchestral performance of the Beethoven concerto and enthusiastically reviewed Dohnányi's pianism,

> The Beethoven Concerto and the Andante which he played as an encore were both things of tenuous beauty highlighted by flashes of brilliant technical accomplishment, yet never did the master give the impression of pyrotechnic display as his fingers swept the keyboard. Any member of the audience might well have been content to watch the artist, for here was no showman who hurled himself at the piano and, summoning his might [and] lifting his brawny shoulders, thundered the forte passages of the work. A quiet man, who learned the dynamics of his art when most of us were still unborn, Dohnányi sits erect at the

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loc.gov/lccn/sn82000867/1956-01-20/ed-1/seq-2. The article attempts to partially answer the question, stating that Dohnányi was presumably in Budapest.

[80] "Orchestra Sets Double Treat," *Tucson Citizen*, January 9, 1956, https://www.newspapers.com/image/581900068.

[81] Dorothy Kalil, "Dottie Has Chip on Her Shoulder Today—from New License Plate," *Arizona Daily Star*, January 15, 1956, https://www.newspapers.com/image/163881924.

[82] Guy Thackeray, "Dohnányi's Playing at UA Bring Salute, 'Great Artist,'" *Tucson Citizen*, January 11, 1956, https://www.newspapers.com/image/581900723/.

[83] "Tucson Acclaims Ernst Dohnányi," *Wichita Falls Times* (Texas), January 15, 1956, https://www.newspapers.com/image/780320089.

[84] Maul, "Famed Concerto."

> keyboard, and makes it speak. His sensitive touch, his use of pedal, his velvet tone marks him as a great artist.[85]

At the conclusion of the concert, Dohnányi graced the audience with an encore, Beethoven's *Andante favori* in F Major. The audience of 2,500 enthusiastically offered a standing ovation.[86] It was a magnificent final collaboration between the two artists.

The old teacher and his student had maintained a congenial relationship over the course of 30 years and thousands of miles, from Balazs's childhood in Budapest as an admiring pupil and star student to the triumphant appearance of Dohnányi as guest artist with the Tucson Symphony. Balazs's defense of accusations against Dohnányi and determined collaborations demonstrate respect and trust for Dohnányi. In addition, Dohnányi's willingness to collaborate with Balazs indicates a reciprocal affability. Although their mutual support may have been typical of that found in immigrant communities, it also stands as a Hungarian testament to a Dohnányi who not only rescued his Jewish pupil but was remembered and honored by that student throughout his life.

Bibliography

Ancestry. "Oskar Balazs (Born Brust)." Accessed 28 August 2024. https://www.ancestry.com/family-tree/person/tree/25407418/person/26441951622/facts.

Balazs, Frigyes. New York, U.S., Arriving Passenger and Crew Lists (including Castle Garden and Ellis Island), 1820-1957 [database on-line]. The National Archives in Washington, DC. Washington, DC, USA. Passenger and Crew Lists of Vessels Arriving at New York, New York, 1897-1957. Microfilm Serial or NAID: T715. RG Title: Records of the Immigration and Naturalization Service 1787-2004. RG: 85. Lehi, UT, USA: Ancestry.com Operations, 2010. https://www.ancestry.com/discoveryui-content/view/1004664419:7488?tid=&pid=&queryid=a9bc1a4d-665f-4409-9205-0cbfd4dc00f9&_phsrc=eNf101&_phstart=successSource.

[85] Thackeray, "Dohnányi's Playing."
[86] Maul, "Famed Concerto."

Balazs, Frederic. “Dohnányi in Texas.” *The Southwestern Musician*, 15 (February 1949): 21–22.

Balazs, Frederic. “Frederic Balazs—composer interview, 2012.” [By Gina Genova.] *American Composers Alliance*. YouTube video. December 2012, posted May 27, 2013. https://www.youtube.com/watch?v=oVPzYS8tN3w.

Balazs, Frederic Ernest. Naturalization Petition. The National Archives at Atlanta, Georgia, USA. NAI Number: 6091096. NARA NAID Title: Naturalization Orders Compiled 1931–91. Record Group Title: Records of District Courts of the United States. Record Group Number: 21. Mississippi, U.S., Naturalization Records, 1907-2008. Serial Number: 32201765. Lehi, UT, USA: Ancestry.com Operations, Inc., 2012. https://www.ancestry.com/discoveryui-content/view/10121:2502?tid=&pid=&queryid=b651c4d9-74c4-4a66-8855-2d01608de34d&_phsrc=eNf96&_phstart=successSource.

Balazs, Oszkar. Hungary, Jewish Names from the Central Zionist Archives [database on-line]. Conference on Jewish Material Claims Against Germany, comp. Provo, UT, USA: Ancestry.com Operations Inc, 2008. Original data derived from archival documents available at the Central Zionist Archives, Yad Vashem, and the United States Holocaust Memorial Museum; this data provided in partnership with JewishGen.org. https://www.ancestry.com/discoveryui-content/view/104844:1513?ssrc=pt&tid=25407418&pid=26441951622.

“Balazs Tour Musical and Good Will Coup.” *Wichita Falls Times* (Texas), April 9, 1950. https://www.newspapers.com/image/774294075.

Buckley, Daniel. “Hungarian-Born Conductor Left His Mark on the Tucson Symphony Orchestra.” *Tucson Citizen Newspaper*, October 23, 2003. https://acacomposers.s3.amazonaws.com/balazs_by_buckley_2003.pdf.

“Dohnányi and Balazs to Present Concert.” *Wichita Falls Times* (Texas), January 10, 1949. https://www.newspapers.com/image/774216785.

“Dohnányi Back in America After 20 Years, Due Here.” *Fort Worth Star-Telegram* (Texas), January 7, 1949. https://www.newspapers.com/image/636883117.

"Dohnányi Enthralls Audience." *El Paso Times* (Texas), January 10, 1949, https://www.newspapers.com/image/433204306.

Dohnányi, Ilona Von. *Ernst von Dohnányi: A Song of Life*. Edited by James A. Grymes. Indiana University Press, 2002.

"Dohnányi Recital at UT Wednesday." *Austin American* (Texas), January 2, 1949. https://www.newspapers.com/image/52407928.

"Dohnányi Recital to be Rare Musical Experience." *Fort Worth Star-Telegram* (Texas), January 9, 1949. https://www.newspapers.com/image/636883523.

"Famous Pianist Shuns Homeland." *Times Record News* (Texas), January 6, 1949. https://www.newspapers.com/image/775034048.

[Göndör, Ferenc?]. "We are waiting for Dohnányi in New York." *Az Ember*, 20 November 1948.

Grymes, James A. "'Dohnányi Was Not—And Could Not Have Possibly Been—A War Criminal' The Hungarian Defense of Ernő Dohnányi, 1945-1949." *Studia Musicologica* 54, no. 3 (2013): 301–17. http://www.jstor.org/stable/43290141.

Grymes, James A., ed. *Ernst von Dohnányi: A Bio-Bibliography*. Greenwood Press, 2001.

Grymes, James A. "Ernst von Dohnányi and Communist Hungary in the Early Cold War." *Acta Musicologica* 84, no. 1 (2012), 65–86. http://www.jstor.org/stable/23343909.

Grymes, James A., ed. *Perspectives on Ernst von Dohnányi*. Scarecrow Press, 2005.

Kalil, Dorothy. "Dottie Has Chip on Her Shoulder Today—from New License Plate." *Arizona Daily Star*, January 15, 1956. https://www.newspapers.com/image/163881924.

Keating, Micheline. "Renowned Musician Adds Luster To Musical Season." *Tucson Citizen* (Arizona), December 31, 1955. https://www.newspapers.com/image/582506807.

King, Charles W. “Arizona: Tucson Symphony Orchestra.” In *Symphony Orchestras of the United States: Selected Profiles*, edited by Robert R. Craven. Greenwood Press, 1986.

Kusz, Veronika. “The Accusation of Dohnányi: The Legal Procedure in Hungary, 1945–1946.” *Studia Musicologica* 63, nos. 1–2 (2022): 1–15. https://doi.org/10.1556/6.2022.00001.

Kusz, Veronika. “Dohnányi megvádolása a magyarországi és a külföldi magyar nyelvű sajtóban 1945 és 1948 között (Charges against Dohnányi in the Hungarian press in Hungary and abroad between 1945 and 1948).” *Magyar zene: Zenetudományi folyóirat* 58, no. 3 (2020): 318–335. https://real.mtak.hu/129284.

Kusz, Veronika. “A Dohnányi-ügy első hulláma (1945–1946) (The first wave of Dohnányi’s political case [1945–1946]).” *Dohnányi-Tanulmányok* (2021): 37–50.

Kusz, Veronika. *A Wayfaring Stranger: Ernst von Dohnányi’s American Years, 1949–1960*. University of California Press, 2020.

“Maestro Impressed with Tucson Artist.” *Tucson Citizen* (Arizona), January 9, 1956. https://www.newspapers.com/image/581899992.

Marsh, William J. “Sterling Technique of Dohnányi, at 71, Unravels Artistic Works for Piano.” *Fort Worth Star-Telegram* (Texas), January 13, 1949. https://www.newspapers.com/image/636716281.

“Master and Pupil to Give Concert.” *Wichita Falls Times* (Texas), January 6, 1949. https://www.newspapers.com/image/774216700.

Maul, John. “Dohnányi Plays Famed Concerto.” *Arizona Daily Star*, January 11, 1956. https://www.newspapers.com/image/163858920.

Maul, John. “Dohnányi to Instruct Piano Here.” *Arizona Daily Star*, January 1, 1956. https://www.newspapers.com/image/163813763.

Maul, John. “Met Conductor ‘Taking Break’ from Opera Season to Relax in Tucson.” *The Arizona Daily Star*, January 13, 1956. https://www.newspapers.com/image/163872310.

“Orchestra Sets Double Treat.” *Tucson Citizen* (Arizona), January 9, 1956. https://www.newspapers.com/image/581900068.

"Orchestra Wins Topmost Praise." *Wichita Falls Times* (Texas), May 13, 1948, https://www.newspapers.com/image/774213425.

Pesti napló (Budapest). 28 July 1937. Arcanum Newspapers: The Eastern European Newspaper Archive. Quoted in Ilona von Dohnányi. *Ernst von Dohnányi: A Song of Life*. Edited by James A. Grymes (Indiana University Press, 2002).

"Reception to Fete Dohnányi." *Arizona Daily Star*, January 3, 1956. https://www.newspapers.com/image/163821025.

"Renowned Hungarian Pianist to Play Here." *Wichita Falls Times*, January 7, 1949. https://www.newspapers.com/image/774216611.

Roth, Bernie. "Dohnányi Meets Old-Time Friend." *The Arizona Daily Star*, January 7, 1956. https://www.newspapers.com/image/163839480.

"Silhouette to Discuss Symphony." *Tucson Citizen* (Arizona), January 7, 1956. https://www.newspapers.com/image/581899147.

Stanley, Byrd. "Balazs' Career Ranges from Budapest to Bisbee." *Tucson Citizen* (Arizona), May 2, 1953. https://www.newspapers.com/image/18833475.

Thackeray, Guy. "Dohnányi's Playing at UA Bring Salute, 'Great Artist.'" *Tucson Citizen*, January 11, 1956. https://www.newspapers.com/image/581900723.

"Ticket Sale Starts for Dohnányi Concert," *Times Record News* (Texas), January 5, 1949, https://www.newspapers.com/image/775034009.

"Tucson Acclaims Ernst Dohnányi." *Wichita Falls Times* (Texas), January 15, 1956. https://www.newspapers.com/image/780320089.

Underwood, W. L. "Curtain Currents," *Wichita Falls Record News* (Texas), October 15, 1948. https://www.newspapers.com/image/775047570.

"Violinist Frederick Balazs to Present Concert Monday Evening at Kinsloe House." *Corsicana Daily Sun* (Texas), January 15, 1949. https://www.newspapers.com/image/13125884.

"Violinist Will Direct Wichita Falls Symphony." *Fort Worth Star-Telegram* (Texas), January 18, 1948. https://www.newspapers.com/image/637148177.

"Wellesly Manager, Pupil Defend von Dohnányi on Collaboration Charges." *The Boston Globe*, November 18, 1948. https://www.newspapers.com/image/433404126.

"Where Was Dohnányi?" *The Arizona Post*, January 20, 1956. *Chronicling America: Historic American Newspapers*. Library of Congress. https://chroniclingamerica.loc.gov/lccn/sn82000867/1956-01-20/ed-1/seq-2.

"Wichita Music Lovers Defy Weather to Hear Dohnányi." *Times Record News* (Texas), January 11, 1949. https://www.newspapers.com/image/775034275.

Willson, Rachel Beckles. *Ligeti, Kurtág, and Hungarian Music during the Cold War*. Cambridge University Press, 2007.

Wortham, Lynne A. "Current Musical Events of Interest to Corsicanans in Local, State and U.S. Circles." *Corsicana Daily Sun* (Texas), October 5, 1948. https://www.newspapers.com/image/10933743.

"Young Violinist to Appear on Series Opening Program at Kinsloe House Monday." *Corsicana Daily Sun* (Texas), January 11, 1949. https://www.newspapers.com/image/13123622.

Antibiotic Bioprospecting from Soil Bacteria against Safe Relatives of ESKAPE Pathogens

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Abstract

Antibiotic resistance represents a growing global crisis, particularly in the context of nosocomial infections, where the escalation of antibiotic resistance poses a significant threat. This makes it essential to focus our efforts on discovering new antibiotics. Soil, as a reservoir of diverse microbial communities, presents a promising source for the discovery of these compounds, given the tendency of soil microorganisms to produce antibiotics as a defense mechanism against competing bacterial species. In the 1940s, Streptomycin was discovered in a sample of New Jersey soil. Malacidins were discovered in 2018 by researchers studying gene clusters from DNA extracted from environmental samples. These malacidins are active against methicillin-resistant Staphylococcus aureus (MRSA). The number of new antibiotics is about 60% lower than in the mid-1980s, hence the need for bioprospecting soil bacteria for antibiotic production. In this research, we tested soil for the presence of bacteria with antibiotic properties against relatives of ESKAPE pathogens, a group of microbes that exhibit antibiotic resistance. Three promising colonies were isolated. Colony 7 showed antibiotic activity against Bacillus subtilis, being able to clear a 5×4-mm area. Colonies 6

and 13 inhibited Mycobacterium smegmatis, clearing 22×26 mm and 9×9 mm, respectively. Colonies 6 and 13 also inhibited Staphylococcus aureus, clearing 12×14-mm and 12×20-mm areas, respectively. Chemical analysis is being done to help us characterize these microorganisms. These findings have the potential to help us identify new antibiotics to treat common infections.

Introduction

Antibiotic resistance occurs when infectious bacteria become less susceptible to the antibiotic treatments that have been developed to fight them off. This resistance arises from the swift evolution of bacterial pathogens, which continually generate robust strains that evade conventional antibiotic treatments. Many of these will end up becoming resistant to more than one antibiotic, which, according to the Institute of Medicine Forum on Microbial Threats (2010), creates "multidrug-resistant 'superbugs' [that] have become a global challenge, aided and abetted by the use, misuse, and overuse of once highly effective anti-infective drugs." Factors such as the overprescription of antibiotics and certain available over-the-counter drugs further fuel this escalation (Llor & Bjerrum 2014). Consequently, the efficacy of common antibiotics diminishes, which can create a necessity to use other drugs for treatment, worsening the situation. This can be seen in multidrug-resistant tuberculosis (MDR-TB), a major contributor to antimicrobial resistance. Strains of TB that are extensively drug-resistant (XDR-TB) are an even bigger problem, with higher rates of mortality due to an inability to treat them with current antibiotics. Second-line drugs such as bedaquiline, clofazimine, pyrazinamide, levofloxacin, and linezolid are effective against MDR-TB, but they are toxic and expensive (World Health Organization, 2023). In addition, drug resistance has been already observed with the use of some second-line drugs (Shah et al., 2011). In some instances, the options for treatment are severely limited, which can result in more debilitating and life-threatening bacterial infections.

The escalating severity of antibiotic resistance is a growing concern, resulting in a rising incidence of fatalities (Institute of Medicine, 2010). In the U.S., approximately 2.8 million antibiotic-resistant infections occur, with more than 35,000 people dying as a result of these infections (CDC, 2019). The report highlights the heavy impact of the COVID-19 pandemic on this predicament, describing the disruption it brought to research and development endeavors because of overwhelmed healthcare facilities. Consequently, the pace of antibiotic discovery and production stagnated, failing to match the swift evolution

of pathogens. Historically, pathogens have been shown to rapidly develop resistance shortly after an antibiotic is introduced (Figure 1). This shows how imperative it is to continue the effort to discover novel antibiotics. Despite the pressing need, the number of antibiotics that have been approved for clinical use has steadily declined over the past three decades (Ventola, 2015). Should this trend continue, antibiotics could become unreliable or entirely ineffectual.

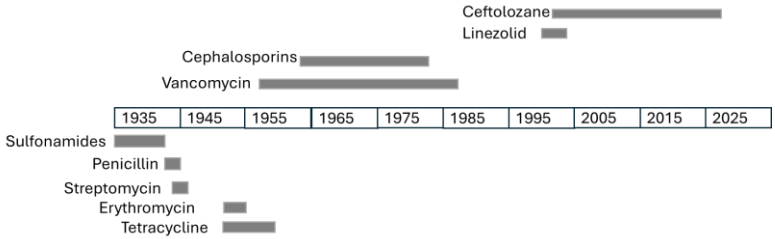

Figure 1. Timeline showing the year that an antibiotic was introduced and the length of time it took for resistance to emerge.

The pathogens exhibiting the highest levels of antibiotic resistance are collectively referred to as the ESKAPE pathogens, encompassing *Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* species (De Oliveira et al., 2020). These pathogens are the leading cause of hospital-acquired infections globally, and most of them are multidrug resistant. This study aimed to isolate bacteria from soil samples and ascertain their potential for antibiotic production against the less pathogenic ESKAPE pathogens. The soil is an ideal source for sample collection because many bacteria have developed the ability to produce antibiotics in order to survive in such a competitive environment (Van Goethem et al., 2018). This competition is a potential driver of antibiotic production because predation by protists creates selective pressures. The identification of such bacteria holds promise for future antibiotic development, with a particular emphasis on addressing these prevalent hospital-acquired infections. This research seeks to contribute to the ongoing efforts of the Tiny Earth project to combat antibiotic resistance (Hernandez et al., 2022).

Materials and Methods

Safe relatives of ESKAPE pathogens

To ensure safety while doing these experiments, nonpathogenic organisms similar to the ESKAPE pathogens were used in the laboratory setting (Table 1).

Table 1. List of ESKAPE pathogens used

ESKAPE and other pathogens	Safe relatives (less pathogenic)	Gram stain
Enterococcus faecium	Enterococcus raffinosus	Gram-positive
Staphylococcus aureus	Staphylococcus epidermidis	Gram-positive
Klebsiella pneumoniae	Escherichia coli	Gram-negative
Acinetobacter baumannii	Acinetobacter baylyi	Gram-negative
Pseudomonas aeruginosa	Pseudomonas putida	Gram-negative
Enterobacter species	Enterobacter aerogenes	Gram-negative
Model organism	Bacillus subtilis	Gram-positive
Model organism	Erwinia carotovora	Gram-negative
Model organism	Mycobacterium smegmatis	Gram-positive

Sample collection, serial dilutions, and colony selection

The soil sample was collected from the Provo Canyon in Springville, Utah, about two meters from a river and on the surface level (40.34757 N, -111.54653 W). Serial dilutions were performed, up to 1:10,000. Each dilution was plated twice on trypticase soy agar (TSA) plates. One set of plates was left at room temperature, in the dark, and the other set was placed in an incubator at 37°C. Bacterial colonies from these plates were then chosen based on their differing appearance as well as their ability to be collected as single colonies. These were transferred to create TSA master plates A, B, and C, each containing 14 different colonies (Figure 2).

Pathogen preparation and antibiotic production testing

Frozen samples of all pathogens and safe models to be tested were inoculated under a sterile hood on TSA (Thermo Scientific R455002) to create fresh streak plates. These were placed in the incubator at 37°C, after which each was checked to ensure single colonies were present.

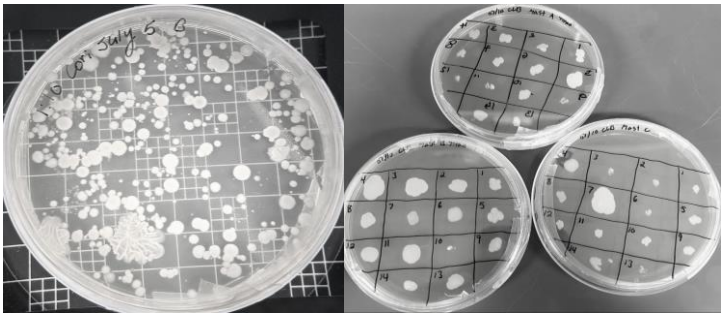

Figure 2. An example plate from the 1:10 serial dilution (left), and the three master plates with selected colonies to study (right).

Liquid cultures were then made by placing a single colony of each in approximately 3 ml of Luria broth (LB) (BD 244620) and left in a shaking incubator for 24 hours or until the broth became visibly clouded. These liquid cultures were then used to test each bacterial colony for antibiotic production against each of the safe relatives selected. Using a micropipette, 100 µL of liquid culture was spread evenly across a TSA plate using a glass spreader. Samples of the bacterial colonies from the master plates were then transferred with sterilized toothpicks to a corresponding TSA plate containing the ESKAPE or safe relatives. All plates were then placed in the incubator for 24-72 hours depending on their speed of growth. Each experiment was repeated twice.

Selection of colonies of interest and chemical testing for characterization

Bacterial colonies that exhibited growth inhibition during the antibiotic activity testing were selected as isolates of interest. Each of these isolates was tested again against the pathogens they interacted with to ensure that the results observed were reliable. When confirmation was complete, chemical testing was started so that categorization of the isolates could begin. Before any tests were performed, fresh streak plates of each selected bacterial colony were created. Gram staining was done on each isolate to see whether the bacteria was Gram negative or Gram positive. Each colony was also inoculated on blood agar (BD 279240) to determine its interaction with red blood cells. A sulfide, indole, motility (SIM) test was performed using BD BBL SIM media (Fisher Scientific BB21010) to test the ability of the microorganisms to reduce sulfur, produce indole, and demonstrate motility. The media was boiled and then cooled before samples of each colony were punctured into it with

an inoculating needle. All test tubes were placed in a shaking incubator for approximately 48 hours. Two test tubes were made for each isolate to confirm the results. The last chemical test performed was a fermentation test using BD BBL Phenol red broth (Fisher Scientific BB21677) to determine fermentation reactions. Samples of each colony were added into the broth using an inoculating loop and were then observed over several days. Three versions of this were done, the first with added dextrose, the second with sucrose, and the third with lactose.

Results

Antibiotic production

Out of the 42 original colonies tested, 3 showed positive results for one or more of the safe relatives. Colony 7 from master plate A (A7) showed antibiotic production against *B. subtilis,* clearing a 5×4-mm area (Figure 3, left). Colonies 6 and 13 from master plate B (B6 and B13, respectively), showed antibiotic production for both *S. epidermidis* (Figure 3, center) and *M. smegmatis* (Figure 3, right). Against *S. epidermidis,* B6 cleared 12×14 mm and B13 cleared 12×20 mm. Against *M. smegmatis,* B6 cleared 22×26 mm and B13 cleared 9×9 mm.

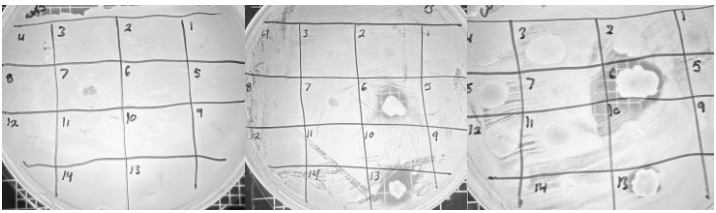

Figure 3. The positive results of antibiotic activity. Colony A7 showing antibiotic activity against *B. subtilis* (left). The center figure shows the areas of antibiotic resistance around colonies B6 and B13 against *S. epidermidis.* Colonies B6 and B13 showed antibacterial activity against *M. smegmatis (right).*

Gram stain and blood agar tests

All three isolates were Gram-negative with rod-shaped structures. The inoculation of the colonies on the blood agar plates resulted in two positive results and one negative. Colony A7 showed γ-hemolysis (Figure 4), indicating that the isolate is not able to break down red blood cells. Colonies B6 and B13 showed β-hemolysis (Figure 4), indicating

that both isolates exhibited the complete breakdown of red blood cells, shown by the cleared areas.

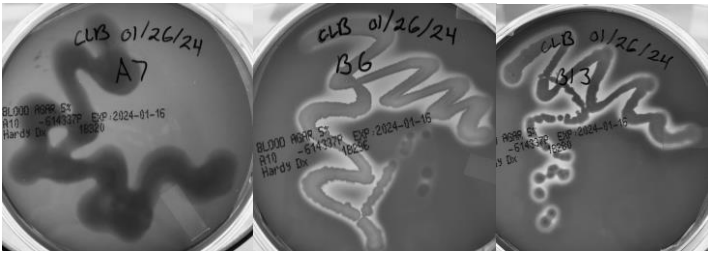

Figure 4. Colony A7, showing γ-hemolysis, with no clearing of the blood agar (left). Colony B6 showing β-hemolysis (middle). Colony B13 showing β hemolysis (right).

SIM and fermentation

All three colonies tested negative for hydrogen sulfide production, as well as for the ability to break down tryptophan and produce indole (not shown, summarized in Table 2). As for motility, colony A7 tested negative while colonies B6 and B13 tested positive. Both test tubes of A7 showed 0 mm of motility. The first tube for B6 showed 1.3 cm of motility, while the second showed 5 mm, for an average of 9 mm. The first tube for B13 showed 1 cm of motility, while the second showed 8 mm, for an average of 9 mm (not shown, summarized in Table 2).

The fermentation tests showed that none of the three colonies could break down the carbohydrate lactose. Colony A7 could also not break down dextrose or sucrose. Colonies B6 and B13 broke down both, turning the phenol red broth into a bright yellow coloring (not shown, summarized in Table 2).

Table 2. Sulfide indole motility and fermentation test result summary for antibiotic-producing colonies A7, B6, and B13

Test	Colonies		
	A7	**B6**	**B13**
Sulfide	Negative	Negative	Negative
Indole	Negative	Negative	Negative
Motiliy	Negative	Positive	Positive
Lactose	Negative	Negative	Negative
Sucrose	Negative	Positive	Positive
Dextrose	Negative	Positive	Positive

Discussion

The results of the antibiotic production testing confirm what other studies have shown, that soil is an ideal source for bacteria of interest. One such study discovered a new class of antibiotics, called malacidins, by analyzing the DNA of the bacteria living in more than 2,000 soil samples (Hover et al., 2018). These malacidins were able to kill methicillin-resistant *S. aureus* (MRSA). Looking at the results of this study, it is clear to see the potential for developing novel antibiotics. The three isolates identified here comprised approximately 7% of the colonies tested. The scaling of this study, such as the 2,000 samples tested to identify malacidins as well as the efforts of the other participants in the Tiny Earth project, could increase the rate of discovery by a significant amount.

Of the three bacteria that were killed by the isolates, only one was found to be a safe relative of the ESKAPE pathogens. *S. epidermidis* is the safe relative of *S. aureus*, a highly infectious pathogen that causes infections in the skin, soft tissues, bones, and joints (Tong et al., 2015). Despite it being the only one related to the ESKAPE pathogens, the other two that were affected by the isolates are also worth examining. *B. subtilis* is widely known to be nonpathogenic and considered a probiotic (Garvey et al., 2022). However, it can be used as a model organism for several other species in the *Bacillus* genus that can affect animals and humans by causing diseases and producing toxins (Bhunia, 2018). *M. smegmatis* is also not considered a human pathogen but is related to others in the *Mycobacterium* genus that are pathogenic such as *M. fortuitum, M. leprae*, and *M. tuberculosis. M. fortuitum* can cause people who are immunocompromised to get infections in the skin, bones, and joints (Okamori et al., 2018). *M. leprae* and *M. tuberculosis* are also highly infectious pathogens.

A Gram stain provided an effective way to begin the classification of these microorganisms, and all three being Gram-negative is an intriguing result. This is because most current antibiotics have come from Gram-positive bacteria, but Gram-negative bacteria have been an underexplored source with great potential (Masschelein et al., 2017). Many antibiotics could likely be produced from Gram-negative bacteria that have been ignored in favor of Gram-positive sources.

Determining whether the isolated colonies produced hemolysins was an important step in deciding the potential safety of these bacteria if used as antibiotics. Other than the general damage to red blood cells, hemolysins being present in an infection could contribute to its resistance as well as damage tissues or increase lethality (Elliott et al., 1998). Colonies B6 and B13 showing complete hemolysis is an indication that

they may not be a viable option for use. This could, however, depend on whether the antibiotic produced by these colonies continued to induce hemolysis when isolated from the bacteria.

The SIM and fermentation testing provided a variety of information on the isolates, mainly as another method of grouping these colonies, but also to collect broader knowledge on the functions of these bacteria. Sulfate-reducing bacteria are not known to be harmful to humans, and all of them are strictly anaerobic. Because none of the colonies showed positive sulfide results, this left the possibility of them being either aerobic or facultatively anaerobic. However, the results of the fermentation test provided more information on this. Colonies B6 and B13 were able to ferment 2 of the carbohydrates, showing that they must be facultative anaerobes. Testing the production of indole was important because indole has been shown to reduce antibiotic resistance (Dou et al., 2023; Lepri et al., 2016) ,with indole reversing the intrinsic antibiotic resistance of some bacterial species (Wang et al., 2019). However, this potential relation could be discarded when production was not detected. It was important to determine the mode of transportation for these colonies as well because cell motility can influence many aspects of cell function (Piskovsky & Oliveira, 2023). The difference in motility between colony A7 and the others is important for categorization.

The colonies could not be 16S sequenced because of the time constraints of this study. For this reason, it should be noted that it is not confirmed whether colonies B6 and B13 are the same type of bacteria. Considering that all their responses to the antibiotic production tests as well as chemical tests were identical, it is possible that they could also be identical. All colonies were taken from the same small soil sample, and two single colonies of the same bacteria could have been taken from the serial dilution plates. It is also a possibility that one or more of these colonies could be an already known antibiotic-producing species; however, future studies will elucidate this when the 16S sequencing is processed.

Conclusion

Bioprospecting from soil samples is an ideal method for the discovery of novel antibiotics to combat the growing antibiotic resistance crisis. The inoculation of colonies on agar plates containing pathogens helps identify bacteria with potential antibiotic activity. By using the results of chemical tests to categorize the isolates it is possible to obtain an idea of which ones may be viable for antibiotic use. This study identified three bacterial colonies that showed antibiotic activity and three pathogens susceptible to these colonies. Additional research should

be done to genetically identify these isolates, extract the antibiotics produced for additional analysis, and characterize those potential antibacterial compounds. If determined to be safe, the produced antibiotics could be developed for clinical use. Increasing the number of studies such as this would be instrumental in the fight against antibiotic resistance.

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References

Bhunia, A.K. (2018). *Bacillus cereus* and *Bacillus anthracis.* In: Foodborne Microbial Pathogens. Food Science Text Series. New York: Springer. https://doi.org/10.1007/978-1-4939-7349-1_11

Centers for Disease Control and Prevention. (2019). Antibiotic resistance threats in the United States, 2019. Atlanta, GA: U.S. Department of Health and Human Services, CDC; 2019. http://dx.doi.org/10.15620/cdc:82532.

Dam, S. (2018) Post-transcriptional regulation of porin expression in *Escherichia coli* and its impact on antibiotic resistance. PhD dissertation, Aix-Marseille Université, 2018.

De Oliveira, D.M.P., Forde, B.M., Kidd, T.J., Harris, P.N.A., Schembri, M.A., Beatson, S.A., et al. (2020). Antimicrobial resistance in ESKAPE pathogens. Clin. Microbiol. Rev., 33(3): e00181-19. https://doi.org/10.1128/CMR.00181-19

Dou, Q., Zhu, Y., Li, C., Bian, Z., Song, H., Zhang, R., et al. (2023). 4F-indole enhances the susceptibility of *Pseudomonas aeruginosa* to aminoglycoside antibiotics. Microbiol. Spectr. 11: e04519-22. https://doi.org/10.1128/spectrum.04519-22

Elliott, S.J., Srinivas, S., Albert, M.J., Alam, K., Robins-Browne, R.M., Gunzburg, S.T., et al. (1998). Characterization of the roles of hemolysin and other toxins in enteropathy caused by alpha-hemolytic *Escherichia coli* linked to human diarrhea. Infect. Immun., 66(5): 2040–2051. https://doi.org/10.1128/IAI.66.5.2040-2051.1998

Garvey, S.M., Mah, E., Blonquist, T.M., Kaden, V.N., Spears, J.L. (2022). The probiotic *Bacillus subtilis* BS50 decreases gastrointestinal symptoms in healthy adults: a randomized, double-blind, placebo controlled trial. Gut Microbes 14(1): 2122668. https://doi.org/10.1080/19490976.2022.2122668

Hernandez, S., Tsang, T., Bascom-Slack, C., Broderick, N., Handelsman, J. (2022). Tiny Earth: A Research Guide to Studentsourcing Antibiotic Discovery. Livonia, MI: XanEdu

Hover, B.M., Kim S.H., Katz, M., Charlop-Powers, Z., Owen, J.G., Ternei, M.A., et al. (2018). Culture-independent discovery of the malacidins as calcium-dependent antibiotics with activity against multidrug-resistant Gram-positive pathogens. Nat. Microbiol. 3(4): 415-422. https://doi.org/10.1038/s41564-018-0110-1

Institute of Medicine (US) Forum on Microbial Threats. (2010). Antibiotic Resistance: Implications for Global Health and Novel Intervention Strategies: Workshop Summary. Washington (DC): National Academies Press (US). https://doi.org/10.17226/12925

Lepri, S., Buonerba, F., Goracci, L., Velilla, I., Ruzziconi, R., Schindler, B.D., et al. (2016). Indole based weapons to fight antibiotic resistance: A structure-activity relationship study. J. Med. Chem. 59: 867-891. https://doi.org/10.1021/acs.jmedchem.5b01219

Llor, C., & Bjerrum, L. (2014). Antimicrobial resistance: risk associated with antibiotic overuse and initiatives to reduce the problem. Ther. Adv. Drug Saf., 5(6): 229–241. https://doi.org/10.1177/2042098614554919

Masschelein, J., Jenner, M., Challis, G.L. (2017). Antibiotics from Gram-negative bacteria: a comprehensive overview and selected biosynthetic highlights. Nat. Prod. Rep., 34(7): 712–783. https://doi.org/10.1039/c7np00010c

Okamori, S., Asakura, T., Nishimura, T., Tamizu, E., Ishii, M., Yoshida, M., et al. (2018). Natural history of *Mycobacterium fortuitum* pulmonary infection presenting with migratory infiltrates: a case report with microbiological analysis. BMC Infect. Dis., 18(1): 1. https://doi.org/10.1186/s12879-017-2892-9

Piskovsky, V., and Oliveira, N.M. (2023) Bacterial motility can govern the dynamics of antibiotic resistance evolution. Nat. Commun. 14: 5584. https://doi.org/10.1038/s41467-023-41196-8

Shah, N.S., Richardson, J., Moodley, P., Moodley, S., Babaria, P., Ramtahal, M., et al. (2011). Increasing drug resistance in extensively drug-resistant tuberculosis, South Africa. Emerg. Infect. Dis. 17(3): 510-513. https://doi.org/10.3201/eid1703.101363

Tong, S.Y.C., Davis, J.S, Eichenberger, E, Holland, T.L, Fowler, V.G. (2015). *Staphylococcus aureus* infections: epidemiology, pathophysiology, clinical manifestations, and management. Clin. Microbiol. Rev. 28(3): 603-661. https://doi.org/10.1128/cmr.00134-14

Van Goethem, M.W., Pierneef, R., Bezuidt, O.K.I., De Peer, Y.V., Coqwan, D.A., Makhalanyane, T.P. (2018). A reservoir of 'historical' antibiotic resistance genes in remote pristine Antarctic soils. Microbiome 6: 40. https://doi.org/10.1186/s40168-018-0424-5

Ventola, C.L. (2015) The antibiotic resistance crisis: part 1: causes and threats. P T 40(4): 277-283.

Wang, Y., Tian, T., Zhang, J., Jin, X., Yue, H., Zhang, Z.H., et al. (2019). Indole reverses intrinsic antibiotic resistance by activating a novel dual-function importer. MBio 10(3): e00676-19. https://doi.org/10.1128/mBio.00676-19

World Health Organization. (2023). Antimicrobial resistance. Retrieved October 18, 2023, from https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance.

Isolation of Multidrug-resistant *Serratia* from Suburban Soil

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Abstract

Antibiotic resistance has been a rising global and public health threat for years and has increased since the COVID-19 pandemic. Antibiotic resistance is conferred by bacterial genes, which bacteria are able to share with other bacteria through horizontal gene transfer. This allows antibiotic resistance to spread in natural environments. We aimed to quantify and isolate antibiotic-resistant bacteria from suburban soil as part of a course-based undergraduate research project. We isolated three multidrug-resistant strains of bacteria from the genus Serratia. For the three isolates, 3A-UT belongs to the species Serratia ureilytica and 3B-UT and 3C-UT both belong to Serratia quinivorans, although whole genome analysis confirms they are genetically distinct strains. Both of these species are more commonly found as pathogens of invertebrates, rather than humans. Despite this, all three isolates are resistant to

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tetracycline, ampicillin, and erythromycin. This study highlights the significance of soils for the potential spread of antibiotic resistance.

Introduction

During the early 1900s, the discovery and then synthesis of antibiotic medications to treat bacterial infections greatly shifted the primary cause of death from infectious diseases, which could now be treated, to chronic diseases, such as heart disease or cancer (1, 2). However, in response to constant use of antibiotics in medical, veterinary, and agricultural sectors, bacteria have evolved to resist antibiotics (2, 3). The rate at which bacteria acquire antibiotic resistance—whether via horizontal gene transfer or de novo evolution—is of critical concern for the continued ability of modern society to treat infections. Antibiotic resistance has been a global public health and economic threat for over a decade (4) with more than 35,000 related deaths in the U.S. annually (5); rates have increased further since the COVID-19 pandemic, both within the U.S. (6) and worldwide (4). The growing threat of antibiotic-resistant bacteria is causing significant declines in therapeutic efficacy of antibiotics and poses the potential that we will face a post-antibiotic world where there are limited treatments for bacterial infections.

Society commonly tends to think about the impact of antibiotic resistance in medical settings, such as with multidrug-resistant nosocomial infections (5, 7, 8); however, antibiotic residues and antibiotic-resistant bacteria can be found in a multitude of other environments, including soil (9, 10), agricultural runoff (11, 12), freshwater (13), and wastewater (14). Antibiotic resistance genes can be shared among members of the same generation, although different species, via horizontal gene transfer mechanisms (15). This means that antibiotic resistance can spread to nonclinical bacteria and amplify in natural environments, where opportunistic pathogens may reside.

Serratia is a genus within the order Enterobacterales often found in soils (16-19), in water (20, 21), on plants (16, 22, 23), and on insects (16, 24-26). Our understanding of the genus *Serratia* has undergone a complicated evolution over the past two centuries, from a rare, harmless component of the natural biosphere to a frequent treatment-resistant nosocomial pathogen (27, see also references therein). Although there are presently 10 known species of *Serratia* (27, 28), the most well studied and understood is the type-species, *Serratia marcescens* (27). *S. marcescens* was originally discovered as a food contaminant because of the “blood red” pigment of colonies growing on polenta (29). Because

of its bright color and assumed innocuous nature, *S. marcescens* has been used as a tracer in medical treatments (30, 31) and public health experiments (31-33). This changed in the early 1950s, when the first *Serratia* infections were described following the large-scale release of *S. marcescens* in San Francisco by the U.S. Navy to assess how vulnerable large U.S. cities were to biowarfare attacks (31, 34). More recently, *S. marcescens* has emerged as an opportunistic and nosocomial pathogen causing urinary tract and wound infections, with increasing reports of multidrug resistance (35-38).

This study was developed from a course-based undergraduate research experience modeled after the Prevalence of Antibiotic Resistance in the Environment (PARE) project, a citizen-science module developed by the Tufts University Center for Science Education (10). Here we describe the isolation and antibiotic resistance of three *Serratia* isolated from a residential soil sample. To our knowledge, this study is only the second undergraduate-driven publication to result from the ongoing PARE project exploring the ubiquity of antibiotic resistant bacteria in environmental soils around the United States (39) and represents some of the first descriptions of multidrug-resistant *S. ureilytica* and *S. quinivorans*.

Materials and Methods

Sample site and collection

In January 2022, a soil sample was collected from a residential leach field in Eden, Utah (41.301376° N, -111.8620329° W) from a depth of approximately 10 cm using a garden trowel that had been sanitized with 70% isopropyl alcohol, with care taken to remove plant material. The soil sample was stored in a 50-mL sterile tube at 4°C for 48 h until laboratory investigation.

Culturing and isolation

Serial dilutions of the soil sample (1×10^{1}-1×10^{5}) were made using sterile water. Two hundred microliters of each diluted sample were spread onto the corresponding MacConkey agar plate (40), amended with varying levels of tetracycline: no antibiotics (NA) as a control; 3 μg/mL (Tet3) as a low concentration of antibiotics; and 30 μg/mL (Tet30) as a high concentration of antibiotics) (10). The plates were individually sealed with parafilm and incubated at 28°C for 72 h. Colonies grown on all three types of media were quantified and described. Three tetracycline-resistant colonies, two from a Tet3 plate

and one from a Tet30 plate, were selected for downstream analysis and were transferred to fresh media via the streak plate method and incubated at 28°C for 72 h.

Testing for multidrug resistance

Although colonies isolated from Tet3 and Tet30 media were assumed to be resistant to tetracycline, the Kirby-Bauer disk diffusion susceptibility test was used to assess their resistance to other antibiotics (41, see also references therein). Briefly, each colony was selected with a sterile cotton swab and grown overnight in tryptic soy broth (TSB). The following day, each TSB culture was spread on a Mueller-Hinton agar plate and allowed to sit for 10 min at room temperature. Disks containing the following antibiotics were then placed onto the surface of the agar using flame-sterilized forceps: ampicillin (10 units), ciprofloxacin (5 µg), chloramphenicol (30 µg), erythromycin (15 µg), and sulfamethoxazole/trimethoprim (25 µg). Antibiotic resistance was assessed by measuring the zone of inhibition of the bacterial culture surrounding the antibiotic-infused disk after incubation at 30°C for 24 h.

Resistance to an antibiotic is assessed by zone of clearing around the antibiotic disk. Large zones indicate that the bacterium is susceptible to the antibiotic (–); intermediate zones indicate some resistance to the antibiotic (X); no zone of clearing indicates full resistance to the antibiotic (XXX). The size of a zone of clearing indicating resistance to an antibiotic varies depending on the antibiotic. Details of the ranges of zone clearing used to define susceptibility, intermediate, and resistant are defined in Table 1.

Table 1. Zones of inhibition (in mm) for determining resistance of three bacterial soil isolates of the genus *Serratia* to antibiotics via Kirby-Bauer disk diffusion assay (41)

Antibiotic	Resistant	Intermediate	Susceptible
Ampicillin (10 µg)	≤11	12-13	≥14
Ciprofloxacin (5 µg)	≤15	16-20	≥21
Chloramphenicol (30 µg)	≤12	13-17	≥18
Erythromycin (15 µg)	≤13	14-22	≥23
Sulfamethoxazole/ trimethoprim (5 µg)	≤10	11-15	≥16

Molecular analyses of isolates

Each of the three tetracycline-resistant colonies was selected with sterile loops and deposited into sterile tubes containing molecular-grade

water. DNA was then extracted from the colonies using the Qiagen DNeasy PowerSoil Pro Kit following the manufacturer's instructions. Resulting DNA was quantified via a Qubit 3.0 Fluorometer using the high-sensitivity reagents and DNA purity was assessed via a Nanodrop spectrophotometer.

Polymerase chain reaction (PCR) of the bacterial 16S rRNA gene was performed using the universal bacterial primers 27F and 1492R (42) with GoTaq G2 Hot Start Master Mix reagents on an Applied Biosystems SimpliAmp Thermocycler. Successful amplification was confirmed by gel electrophoresis. Amplicons were submitted to the Idaho State Molecular Research Core Facility for Sanger sequencing on an AB 3130xl Genetic Analyzer. AB1 chromatogram files were edited for quality control using the free software 4Peaks (RRID: SCR_000015) and exported as FASTA files. FASTA files of the isolates were searched against the NCBI Sequence Read Archive (SRA) database using the blastn function of BLAST+ (43).

A reference file of full-length 16S rRNA genes from *Serratia* species was exported from the SILVA r138.1 database (44), with *E. coli* as an outgroup, and used to construct a multiple-sequence alignment with the Sanger sequences from the isolates in UGENE software with the ClustalW algorithm (45, 46). A neighbor-joining tree with 1000 bootstrap replicates was created from the multiple-sequence alignment (data not shown).

Following characterization of isolates, whole-genome sequencing and analysis were performed as described in Markert *et al*. (47). A phylogeny of concatenated ribosomal proteins of our isolates, all known *Serratia* genomes in NCBI and rooted with Enterobacteriaceae genus *Shimwellia* was created with RAaxML (48) after aligning sequences with MUSCLE software (49). Figure 1 illustrates the phylogenetic context of our isolates. The antibiotic resistance genes in these genomes were searched to find genes conferring resistance to tetracycline, ampicillin, and erythromycin. The identified antibiotic genes (see Table 2) were then looked up in the Comprehensive Antibiotic Resistance Database (CARD; 50).

Molecular analyses of soil sample

A 0.25-gram aliquot of the original soil sample underwent DNA extraction, using the same methods described above, and was sequenced for whole community 16S rRNA amplicon sequencing on an Oxford Nanopore MinION Mk1C sequencing device using the 16S Barcoding kit (SQK-RAB204) on a MinION flow cell (R9.4.1) in house to identify

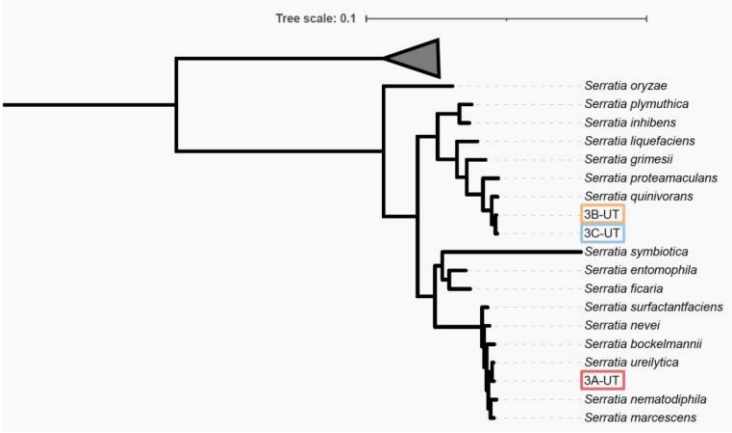

Figure 1. Concatenated ribosomal protein tree built using our genomes and other complete *Serratia* genomes from NCBI, covering all recognized species in this genus according to the Genome Taxonomy Database. Rooted with members of the Enterobacteriaceae genus *Shimwellia*. Modified, with permission, to highlight our isolate genomes (3A-UT, 3BUT, and 3C-UT). Copyright Markert EX, Severe K, Severe L, Twing KI, Ward LM. 2024. Genomes of novel *Serratia* strains from suburban soil. Microbiol Resource Announc. 2024 Dec 4: e0086624. doi: 10.1128/ mra.00866-24. Online ahead of print. Licensed under Creative Commons Attribution 4.0 International license.

the diversity of all bacteria within the original sample. Real-time base calling was conducted using the built-in Oxford Nanopore MinKNOW software. A Krona plot depicting alpha-diversity was created using the Oxford Nanopore EPI2ME wf-16S workflow with the default options.

Results

Tetracycline-resistant colonies

The no-antibiotic (NA) agar plates were used as a control to quantify the total number of bacteria culturable on the MacConkey agar without the selection by antibiotics. A total of 2.35×10^5 CFUs/g of soil were cultured on the NA plates. Two concentrations of tetracycline were added to MacConkey media to assess the resistance of bacteria to low (3-µg/mL) and high (30-µg/mL) tetracycline pressure. Approximately 10.6% of bacterial colonies (49 CFUs grown from a 1×10^2 dilution) were resistant to the 3-µg/mL concentration of tetracycline, whereas only 0.02% of bacterial colonies (a single CFU grown from a 1×10^1 dilution) was resistant to the higher 30-µg/mL concentration of tetracycline.

Three tetracycline-resistant colonies were selected based on different appearance, including shape, deep purple color, and size of colonies for downstream analyses, one from a Tet30 plate (3A-UT) and two from a Tet3 plate (3B-UT and 3C-UT). 3A-UT, isolated from a 1×10^{1} dilution on a Tet30 plate, was a shiny, pink colony, measuring 2 mm in diameter, grown near the side of the plate (Fig. 2A). Both 3B-UT and 3C-UT were isolated from a 1×10^{2} dilution on a Tet3 plate and were growing within microns of each other with nearly identical morphologies of pink, convex colonies measuring 3 mm in diameter (Fig. 2B). MacConkey agar is selective for Gram-negative bacteria and allows for differentiation based on lactose metabolism, with lactose-fermenting colonies appearing pink in color, whereas colonies unable to ferment lactose will form whitish colonies (40). The pink color of the selected colonies (Fig. 2) suggests that they are all capable of lactose fermentation.

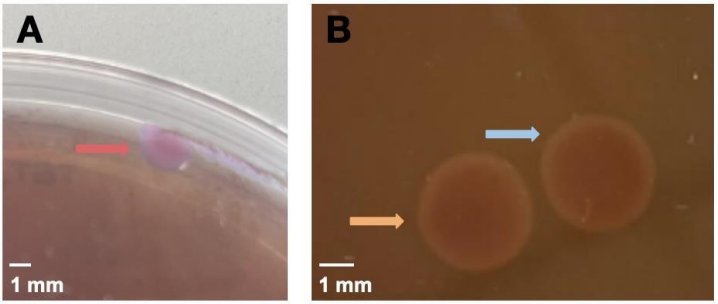

Figure 2. Photographs of tetracycline-resistant colonies. (A) Colony 3A-UT isolated on MacConkey agar with 30 μg/mL tetracycline (Tet30), highlighted with pink arrow. (B) Colonies 3B-UT (orange) and 3C-UT (blue) isolated on MacConkey agar with 3 μg/mL tetracycline (Tet3).

Multidrug resistance of isolates

To assess resistance to additional antibiotics, the Kirby-Bauer disk diffusion assay was performed with each of the three isolates. All three exhibited susceptibility to ciprofloxacin, chloramphenicol, and sulfamethoxazole/trimethoprim, as indicated by culture clearing around the respective antibiotic disks. However, all three were resistant to ampicillin and erythromycin (Table 2, Fig. 3).

Table 2. Measured zone of inhibition (in mm) of bacterial soil isolates of the genus *Serratia* to antibiotics			
Antibiotic	**3A-UT**	**3B-UT**	**3C-UT**
Ampicillin (10 µg)	0 (R)	12 (I)	10 (R)
Ciprofloxacin (5 µg)	34 (S)	31 (S)	28 (S)
Chloramphenicol (30 µg)	20 (S)	21 (S)	20 (S)
Erythromycin (15 µg)	10 (R)	10 (R)	10 (R)
Sulfamethoxazole/trimethoprim (5 µg)	30 (S)	26 (S)	26 (S)

Levels of resistance to antibiotic: R=resistant; I=intermediate; S=susceptible.

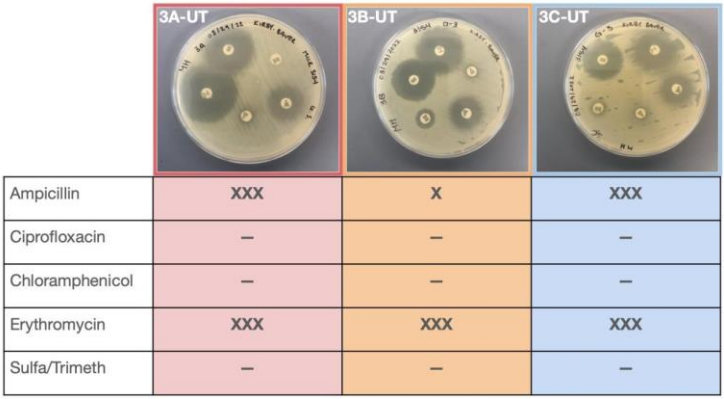

Figure 3. Multidrug resistance of colonies as assessed by Kirby-Bauer disk diffusion assay.

Antibiotic resistance genes for tetracycline, ampicillin, and erythromycin were detected in the whole genomes of isolates (Table 3; 47), providing genetic support for the laboratory-derived antibiotic resistance assays reported here.

Table 3. Relevant antibiotic resistance genes observed in whole genomes of three bacterial soil isolates of the genus *Serratia* (47)					
Antibiotic	**Resistance gene**	**3A-UT**	**3B-UT**	**3C-UT**	**Reference**
Tetracycline	*adeF*	+	+	+	51
	kpnF	+	+	+	52
Ampicillin	*ftsI*	+	+	+	53
Erythromycin	*kpnF*	+	+	+	52
	kpnH	+	+	+	54
	bla_{CRP}	+	+	+	55

Taxonomy and phylogeny of isolates

BLAST analysis of the 16S rRNA gene sequences generated via Sanger sequencing identified both 3B-UT and 3C-UT as belonging to *Serratia quinivorans*, with the same best hit sequence for both (Table 4). BLAST analysis of 3A-UT was able to identify the sequence as belonging to the genus *Serratia* but not further to the species level (Table 3). Given the inability to assign species-level taxonomy to the sequence via BLAST, we attempted to construct a phylogeny of 16S rRNA genes of *Serratia* to better characterize 3A-UT; however, bootstrap attempts failed, placing the sequence within *S. profundis* during some attempts and *S. marcescens* during others (data not shown). Subsequent whole genome sequencing was used to better assess the identity of the isolates (47). A concatenated ribosomal gene phylogeny (Fig. 1) and taxonomic assignment with GTDB-Tk (47) confirmed 3B-UT and 3C-UT as belonging to *S. quinivorans* and identified 3A-UT as belonging to *S. ureilytica* (Fig. 1; 47).

Table 4. BLAST results of 16S rRNA genes from bacterial soil isolates via Sanger sequencing

Isolate	Best hit	Query coverage	E value	% identity	Best hit accession	Ref.
3A-UT	*Serratia* sp. strain EB341	100%	0	99.51	MH127792	56
3B-UT	Serratia quinivorans strain D73_SO3R	100%	0	99.84	MK883176	57
3C-UT	Serratia quinivorans strain D73_SO3R	100%	0	99.81	MK883176	57

Relative abundance of Serratia in whole soil community

Amplicon sequencing (16S rRNA gene) of the whole soil community on an Oxford Nanopore MinION device yielded 207,903 high-quality (mean read quality 9.9) long (>1.5 kb) sequence reads. Of those, only nine sequence reads were classified as belonging to the genus *Serratia* (Fig. 4), which equates to only 4×10^{-5}% of the total microbial community.

Figure 4. Krona plot representing the taxonomy and relative abundance of 16S rRNA amplicon diversity assessed by Oxford Nanopore MinION sequencing. A Krona plot is a dynamic way of interactively exploring the taxonomic composition of DNA sequencing data from a sample. The figure was generated automatically using the Oxford Nanopore Epi2me Labs wf-16S workflow. The rings of the chart represent taxonomic levels, with domain (Bacteria) at the center and genus at the outermost ring. The inset focuses on the genus *Serratia*, which belongs to the order Enterobacterales and Family Yersiniaceae. The colors (blue to green) represent the relative abundance of that taxon in comparison with the total number of reads. The grayed and light-green portions of the inset represent taxa that fall within the order but are not our focus.

Discussion

Serratia ureilytica and soil isolate 3A-UT

S. ureilytica is very closely related to *S. marcescens* (98.3% 16S rRNA gene sequence similarity) and therefore is sometimes misidentified as *S. marcescens* (26, 38); however, it is recognized as a separate species based on its divergent DNA-DNA hybridization measure of 43.7% (typically, the species threshold for the method is >70%; 49). This is just one example of the convoluted and changing taxonomy that has plagued the genus *Serratia* over the years, where the total number of species within the genus has ranged from 10 to 32, depending on the data used to define "species" (26-28). This may explain some of the initial challenges we had identifying the species of our 3A-UT isolate (Table 4). Our data (Fig. 1; 47) support the findings of Williams *et al.* (28) that a whole genome (or at least multigene) approaches may be necessary to untangle the taxonomy of genera originally described before the advent of molecular methods.

As its name suggests, *S. ureilytica* can use urea as its sole nitrogen source for growth by hydrolyzing it to form ammonia if needed (58). *S. ureilytica* has a feature that allows it to enter a dormant state by forming a cyst-like structure and appearance, allowing it to survive in poly-extreme environments (59), which could include those of high antibiotic load, as one might find in wastewater. Additionally, the species is known to produce serrawettins, a biosurfactant considered a biocide against many other bacteria and fungi (60), and other novel secondary metabolites (61, 62). Further, our genomic analysis revealed that ~65% of genes in the 3A-UT genome encode hypothetical proteins of unknown function (47), potentially masking other antibiotic resistance and other adaptive traits.

To our knowledge, *S. ureilytica* has only been implicated in human infection in one report to date, which was related to an outbreak of gastrointestinal distress in neonates in a hospital setting in 2018-2019 (38). One study detected *S. ureilytica* in veterinary infections, but it was specifically noted that their presence could have been due to sample contamination and not necessarily pathogenesis (63). Otherwise, reports of *S. ureilytica* pathogenicity have been constrained to parasites such as nematodes (64) and plasmodia (65). Given this, there are very few data for *S. ureilytica* in clinical settings where it would potentially obtain antibiotic resistance through direct selection.

Our 3A-UT isolate was resistant to high concentrations (30 μg/mL) of tetracycline and also exhibited full resistance to ampicillin and erythromycin during Kirby-Buaer disk diffusion assays (Table 2; Fig. 3). The following genes conferred resistance to the corresponding antibiotics: *adeF* and *kpnF* to tetracycline, *ftsI* to ampicillin, and *kpnF*, *kpnH*, and bla_{CRP} to erythromycin (Table 3) in all three isolates and were also observed in conspecific genomes (47). No resistance to ciprofloxacin, chloramphenicol, or sulfamethoxazole/trimethoprim were detected by laboratory (Fig. 3) or genomic methods in any of the three isolates.

Serratia quinivorans and Soil Isolates 3B-UT and 3C-UT

Isolates 3B-UT and 3C-UT were both identified as *S. quinivorans* via BLAST (Table 4) and phylogenetic analyses (Fig. 1). However, despite matching to an identical best hit using BLAST (Table 4), displaying similar colony morphology (Fig. 2B) and exhibiting the same antibiotic resistance profiles (Fig. 3), whole genome analysis (47) demonstrates that these are in fact divergent strains. This divergence is further supported by the differing sizes of genome assemblies for these strains (5.54 Mb consisting of 5305 coding sequences in 3B-UT versus

5.55 Mb and 5350 coding sequences in 3C-UT) despite 100% estimated completeness in both (47).

Similar to *S. ureilytica*, *S. quinivorans* has a complicated taxonomic history. It was initially described as a subspecies of the *Serratia liquefaciens* complex (21, 27); however, more recently it has been determined to be a separate species using DNA-DNA hybridization (16) and comparative phylogenomics (28).

S. quinivorans is not typically associated with human infections, with the exception of a care of pneumonia reported in the 1990s (31, 66), although this could be in part due to the taxonomic confusion described above. *S. quinivorans* can be found in a range of environments, including soils, plants, invertebrates (16), wild rodents, and water (21). This species is also commonly associated with parasitic nematodes that cause pine tree wilting (67).

Despite the fact that *S. quinivorans* has yet to be found in association with clinical diseases in humans, strains of *S. quinivorans* have been observed to be resistant to a range of antibiotics. For example, *S. quinivorans* strain BFX1 is resistant to antibiotics including tetracycline, ampicillin, kanamycin, chloramphenicol, rifampicin, and streptomycin (67). Analysis of the genomes of the three strains described here as compared with conspecific reference genomes suggests recent horizontal gene transfer, including of antibiotic resistance genes (47). The ability of *S. quinivorans* to resist such a wide variety of antibiotics may contribute to its overall fitness and ability to survive in a wide range of environments (68).

Serratia *in whole soil community*

It has been long accepted that there is a discrepancy between the diversity of bacteria grown via traditional culturing methods and those detected by culture-independent methodologies such as environmental DNA sequencing (62-64). This anomaly is reinforced by this study, where all three of the selected isolated colonies belonged to the same genus (Table 4, Fig. 1), while that genus made up only 9 out of the total 207,000 sequence reads generated from amplicon sequencing of the same soil samples from which isolates were cultured (Fig. 2). Nonetheless, the presence of multidrug-resistant bacteria even at very low relative abundance can pose an environmental and public health risk. Horizontal gene transfer also poses a threat as antibiotic selection can lead to resistant strains rapidly coming to dominate bacterial populations (72).

Conclusion

This study highlights the adaptive capabilities of *Serratia* species that have not traditionally been associated with human infections but show increasing antibiotic resistance due to environmental pressures. The complex taxonomy of *Serratia* requires more than traditional 16S rRNA methods to accurately identify the species, which when diving deeper into whole-genome sequencing allows for a more precise understanding of the presence of antibiotic resistance in these nonclinical, environmentally derived colonies. *S. ureilytica*, closely related to the clinically significant *S. marcescens*, demonstrated resistance to high concentrations of tetracycline and other antibiotics. Similarly, *S. quinivorans* exhibited resistance to multiple antibiotics, despite its historically limited association with human disease. This resistance may be attributed to recent horizontal gene transfer, enhancing their survival in diverse environments. Although they are found in low abundance in the environment, these isolates highlight the role that environmental reservoirs play in the spread of antibiotic resistance genes from one species to another. Understanding the mechanisms and spread of resistance genes in nonclinical settings is essential for developing comprehensive strategies to diminish the growing threat of antibiotic-resistant infections in both human and animal populations. If left unaddressed, the silent pandemic of antibiotic resistance will only continue to worsen, as seen in the trend in recent years.

Data availability

16S amplicon Sanger sequencing data can be accessed in the NCBI SRA database under the accession numbers SRR29267537 (3A-UT), SRR29267536 (3B-UT), and SRR29267535 (3C-UT). Raw and assembled whole genome sequencing data, described in detail in Markert *et al*. 2024 (47), are available in the NCBI SRA and WGS databases under accession numbers SRR28911882 and JBFQXS000000000 (3A-UT), SRR28911881 and JBFQXR000000000 (3B-UT), and SRR28911880 and JBFQXQ000000000 (3C-UT).

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References

1. Jones DS, Podolsky SH, Greene JA. 2012. The burden of disease and the changing task of medicine. N Engl J Med. 366:2333-2338.

2. Martens E, Demain AL. 2017. The antibiotic resistance crisis, with a focus on the United States. J Antibiot. 70:520-526.

3. Davies J, Davies D. 2010. Origins and evolution of antibiotic resistance. Microbiol Mol Biol Rev. 74(3):417433.

4. World Health Organization. Global Antimicrobial Resistance and Use Surveillance System (GLASS) Report 2022. Geneva: World Health Organization; 2022.

5. Centers for Disease Control and Prevention. Antibiotic Resistance Threats in the United States, 2019. Atlanta, GA: U.S. Department of Health and Human Services, CDC; 2019.

6. Centers for Disease Control and Prevention. Antimicrobial Resistance Threats in the United States, 2021-2022. Atlanta, GA: U.S. Department of Health and Human Services, CDC; 2024.

7. Solomon SL, Oliver KB. 2014. Antibiotic resistance threats in the United States: stepping back from the brink. Am Fam Physician. 89(12):938-941.

8. Sousa SA, Feliciano JR, Pita T, et al. 2021. Bacterial nosocomial infections: multidrug resistance as a trigger for the development of novel antimicrobials. Antibiotics. 10(8):942.

9. Thiele-Bruhn S. 2003. Pharmaceutical antibiotic compounds in soils—a review. J Plant Nutr Soil Sci. 166:145-167.

10. Genné-Bacon EA, Bascom-Slack CA. 2018. The PARE Project: A short course-based research project for national surveillance of antibiotic-resistant microbes in environmental samples. J Microbiol Biol Educ. 19(3):19.3.97.

11. Sarmah AK, Meyer MT, Boxall AB. 2006. A global perspective on the use, sales, exposure pathways, occurrence, fate and effects of veterinary antibiotics (VAs) in the environment. Chemosphere. 65:725-759.

12. Woolhouse M, Ward M, van Bunnik B, Farrar J. 2015. Antimicrobial resistance in humans, livestock and the wider environment. Philos Trans R Soc Lond B Biol Sci. 370:20140083.

13. Kummerer K. 2009. Antibiotics in the aquatic environment—a review—part II. Chemosphere 75:435-441.

14. Segura PA, Francois M, Gagnon C, Sauve S. 2009. Review of the occurrence of anti-infectives in contaminated wastewaters and natural and drinking waters. Environ Health Perspect. 117:675-684.

15. Allen HK, Donato J, Wang HH, Cloud-Hansen KA, Davies J, Handelsman J. 2010. Call of the wild: antibiotic resistance in natural environments. Nat Rev Microbiol. 8:251-259.

16. Ashelford KE, Fry JC, Bailey MJ, Day MJ. 2002. Characterization of *Serratia* isolates from soil, ecological implications and transfer of *Serratia proteamaculans* subsp. quinovora grimont *et al*. 1983 to *Serratia quinivorans* corrig., sp. nov. Int J Syst Evol Microbiol. 52(6):2281-2289.

17. Bai F, Bai B, Jin T, Zhang G, Ren J. 2023. Selection and validation of reference genes for quantitative realtime polymerase chain reaction analyses of *Serratia ureilytica* DW2. Biocell. 47(3):647-656.

18. Cao X, Ye Y, Li P. 2023. Genome sequence resource of *Serratia ureilytica* HNU47: a strain with biocontrol potential against bacterial wilt pathogen *Ralstonia solanacearum*. Plant Dis. 107(3):919-921.

19. Baker IR, Colston SM, Hervey WJ, Bird LJ. 2023. Complete genome of a *Serratia* species isolated from PFAS-impacted soil. Microbiol Resour Announc. 12(12):e0064023.

20. Gavini F, Ferragut C, Izard D, et al. 1979. *Serratia fonticola*, a new species from water. Int J Syst Evol Microbiol. 29(2):92-101.

21. Grimont PAD, Grimont F, Irino K. 1982. Biochemical characterization of *Serratia liquefaciens* sensu stricto, *Serratia proteamaculans*, and *Serratia grimesii* sp. nov. Curr Microbiol. 7:69-74.

22. Grimont PAD, Grimont F, Starr MP. 1981. *Serratia* species isolated from plants. Curr Microbiol. 5, 317-322.

23. Matilla MA, Udaondo Z, Krell T, Salmond GPC. 2017. Genome sequence of *Serratia marcescens* MSU97, a plant-associated bacterium that makes multiple antibiotics. Genome Announc. 5(9):e01752-16.

24. Ishii K, Adachi T, Hara T, Hamamoto H, Sekimizu K. 2014. Identification of a *Serratia marcescens* virulence factor that promotes hemolymph bleeding in the silkworm, *Bombyx mori*. J Invertebr Pathol. 117:61-67.

25. Raymann K, Coon KL, Shaffer Z, Salisbury S, Moran NA. 2018. Pathogenicity of *Serratia marcescens* strains in honey bees. mBio. 9:e01649-18.

26. Allen JL, Dolge NP, Cheng C, et al. 2022. Genomic characterisation of an entomopathogenic strain of *Serratia ureilytica* in the critically endangered phasmid *Dryococelus australis*. PLoS One. 17(4):e0265967.

27. Grimont F, Grimont PA. 2006. The genus *Serratia*. Prokaryotes. 6:219-644.

28. Williams DJ, Grimont PAD, Cazares A, et al. 2022. The genus *Serratia* revisited by genomics. Nat Commun. 13:5195.

29. Merlino CP. 1924. Bartolomeo Bizio's letter to the most eminent priest, Angelo Bellani, concerning the phenomenon of the red-colored polenta [translated from the Italian]. J Bacteriol. 9:527-543.

30. Kleef R, Hager ED. 2006. Fever, pyrogens and cancer, p. 276-337 *In* Baronzio G.F., Hager E.D. (ed.), Hyperthermia in Cancer Treatment: A Primer. Springer Science, New York, NY

31. Mahlen SD. 2011. *Serratia* infections: from military experiments to current practices. Clin Microbiol Rev. 24(4):755-791.

32. Cumming JG. 1920. Sputum-borne disease transmission with epidemiologic and bacteriologic research. Mil Surg. 46:150-165

33. Burket LW, Burn CG. 1937. Bacteremias following dental extraction: demonstration of source of bacteria by means of a non-pathogen (*Serratia marcescens*). J Dent Res. 16:521-530

34. Thompson H. 2015. In 1950, the U.S. released a bioweapon in San Francisco. Smithsonian Magazine. Smithsonian Institution, Washington, DC. Accessed June 23, 2024, at https://www.smithsonianmag.com/smart-news/1950-us-released-bioweapon-san-francisco-180955819/.

35. Khanna A, Khanna M, Aggarwal A. 2013. Serratia marcescens—a rare opportunistic nosocomial pathogen and measures to limit its spread in hospital patients. J Clin Diagn Res. 7:243-246.

36. Iguchi A, Nagaya Y, Pradel E, et al. 2014. Genome evolution and plasticity of *Serratia marcescens*, an important multidrug-resistant nosocomial pathogen. Genome Biol Evol. 6(8):2096-2110.

37. Moradigaravand D, Boinett CJ, Martin V, Peacock SJ, Parkhill J. 2016. Recent independent emergence of multiple multidrug-resistant *Serratia marcescens* clones within the United Kingdom and Ireland. Genome Res. 26(8):1101-1109.

38. Dahdouh E, Lázaro-Perona F, Ruiz-Carrascoso G, Sánchez García L, Saenz de Pipaón M, Mingorance J. 2021. Intestinal dominance by *Serratia marcescens* and *Serratia ureilytica* among neonates in the setting of an outbreak. Microorganisms. 9(11):2271.

39. Brock OD, Larson LR. 2019. The prevalence and identification of multidrug resistant bacteria in adjacent ecological systems in the Hocking Hills region of Appalachia. Fine Focus 6:54-75.

40. Jung B, Hoilat GJ. 2022. MacConkey medium. In: StatPearls [Internet]. StatPearls Publishing, Treasure Island, FL. https://www.ncbi.nlm.nih.gov/books/NBK557394/

41. Hudzicki J. 2009. Kirby-Bauer disk diffusion susceptibility test protocol. American Society for Microbiology protocols. Accessed June 23, 2024, at https://asm.org/getattachment/2594ce26-bd44-47f6-8287-0657aa9185ad/Kirby-Bauer-Disk-Diffusion-Susceptibility-Test-Protocol-pdf.pdf.

42. Weisburg WG, Barns SM, Pelletier DA, Lane DJ. 1991. 16S ribosomal DNA amplification for phylogenetic study. J Bacteriol. 173(2):697-703.

43. Camacho C, Coulouris G, Avagyan V, Ma N, Papadopoulos J, Bealer K, Madden TL. 2009. BLAST+: architecture and applications. BMC Bioinformatics. 10:421.

44. Pruesse E, Quast C, Knittel K, Fuchs BM, Ludwig W, Peplies J, Glöckner FO. 2007. SILVA: a comprehensive online resource for quality checked and aligned ribosomal RNA sequence data compatible with ARB. Nucleic Acids Res. 35:7188-7196.

45. Okonechnikov K, Golosova O, Fursov M, UGENE team. 2012. Unipro UGENE: a unified bioinformatics toolkit. Bioinformatics. 28(8):1166-1167.

46. Thompson JD, Higgins DG, Gibson TJ. 1994. CLUSTAL W: improving the sensitivity of progressive multiple sequence alignment through sequence weighting, position-specific gap penalties and weight matrix choice. Nucleic Acids Res. 22(22):4673-4680.

47. Markert EX, Severe K, Severe L, Twing KI, Ward LM. 2024. Genomes of novel *Serratia* strains from suburban soil. Microbiol Resource Announc. 2024 Dec 4: e0086624. doi: 10.1128/mra.00866-24. Online ahead of print.

48. Stamatakis, A., 2014. RAxML version 8: a tool for phylogenetic analysis and post-analysis of large phylogenies. Bioinformatics. 30(9):1312-1313.

49. Edgar, R.C., 2004. MUSCLE: multiple sequence alignment with high accuracy and high throughput. Nucleic Acids Res. 32(5):1792-1797.

50. McArthur AG, Waglechner N, Nizam F, et al. 2013. The comprehensive antibiotic resistance database. Antimicrob Agents Chemother. 57(7):3348-57.

51. Coyne S, Rosenfeld N, Lambert T, Courvalin P, Périchon B. 2010. Overexpression of resistance-nodulationcell division pump AdeFGH confers multidrug resistance in *Acinetobacter baumannii*. Antimicrob Agents Chemother. 54(10):4389-4393.

52. Srinivasan VB, Rajamohan G. 2013. KpnEF, a new member of the Klebsiella pneumoniae cell envelope stress response regulon, is an SMR-type efflux pump involved in broad-spectrum antimicrobial resistance. Antimicrob Agents Chemother. 57(9):4449-4462.

53. Misawa K, Tarumoto N, Tamura S, et al. 2018. Single nucleotide polymorphisms in genes encoding penicillin-binding proteins in β-lactamase-negative ampicillin-resistant *Haemophilus influenzae* in Japan. BMC Res Notes. 11(1):53

54. Srinivasan VB, Singh BB, Priyadarshi N, Chauhan NK, Rajamohan G. 2014. Role of novel multidrug efflux pump involved in drug resistance in *Klebsiella pneumoniae*. PLoS One. 13;9(5):e96288.

55. Nishino K, Senda Y, Yamaguchi A. 2010. CRP regulator modulates multidrug resistance of *Escherichia coli* by repressing the mdtEF multidrug efflux genes. J Antibiot. 61(3):120-127.

56. Lui Y, Ponpandian LN, Kim H, et al. 2019. Distribution and diversity of bacterial endophytes from four Pinus species and their efficacy as biocontrol agents for devastating pine wood nematodes. Sci Rep. 9:12461.

57. Muñoz PA, Arismendi MJ, Cárdenas SF, Cifuentes Bachmann DE, Venegas FA, Sepúlveda-Chavera GF. 2020. Diversity of culturable bacteria isolated from ancestral crops of Arica and Parinacota Region, Atacama Desert. Antonie Van Leeuwenhoek. 13(12):2123-2137.

58. Bhadra B, Roy P, Chakraborty R. 2005. *Serratia ureilytica* sp. nov., a novel urea-utilizing species. Int J Syst Evol Microbiol. 55(5):2155-2158.

59. Filippidou S, Junier T, Wunderlin T, et al. 2019. Adaptive strategies in a poly-extreme environment: Differentiation of vegetative cells in *Serratia ureilytica* and resistance to extreme conditions. Front Microbiol. 10:102.

60. Marques-Pereira C, Neves Proença D, Morais PV. 2020. Genome sequences of *Serratia* strains revealed common genes in both serratomolides gene clusters. Biology. 9(12):482.

61. Kuo YH, Hsu HC, Chen YC, Liang TW, Wang SL. 2012. A novel compound with antioxidant activity produced by *Serratia ureilytica* TKU013. J Agric Food Chem. 60(36):9043-9047.

62. Petersen LM, Tisa LS. 2013. Friend or foe? A review of the mechanisms that drive *Serratia* towards diverse lifestyles. Can J Microbiol. 59:627-640.

63. Allen JL, Doidge NP, Bushnell RN, Browning GF, Marenda MS. 2022. Healthcare-associated infections caused by chlorhexidine-tolerant *Serratia marcescens* carrying a promiscuous IncHI2 multi-drug resistance plasmid in a veterinary hospital. PLoS One. 17(3):e0264848.

64. Wong-Villarreal A, Méndez-Santiago EW, Gómez-Rodríguez O, et al. 2021. Nematicidal activity of the endophyte *Serratia ureilytica* against *Nacobbus aberrans* in chili plants (*Capsicum annuum* L.) and identification of genes related to biological control. Plants. 10:2655.

65. Gao H, Bai L, Jiang Y, et al. 2021. A natural symbiotic bacterium drives mosquito refractoriness to Plasmodium infection via secretion of an antimalarial lipase. Nat Microbiol. 6:806-817.

66. Bollet C, Grimont P, Gainnier M, Geissler A, Sanity JM, De Micco P. 1993. Fatal pneumonia due to *Serratia protomaculans* subsp. *Quinovora*. J Clin Microbiol. 31(2):444-445.

67. Nascimento FX, Espada M, Barbosa P, Rossi MJ, Vicente CS, Mota M. 2016. Non-specific transient mutualism between the plant parasitic nematode, *Bursaphelenchus xylophilus*, and the opportunistic bacterium *Serratia quinivorans* Bxf1, a plant-growth promoting pine endophyte with antagonistic effects. Environ Microbiol. 18(12):5265-5276.

68. Venkatesh R, Agarwal M, Singh S, Mayor R, Bansal A. 2017. Scleral buckle infection by *Serratia* species. Oman J Ophthalmol. 10(1):36-37.

69. Staley JT, Konopka A. 1985. Measurement of in situ activities of non-photosynthetic microorganisms in aquatic and terrestrial habitats. Annu Rev Microbiol. 39:321-346.

70. Handelsman J. 2004. Metagenomics: application of genomics to uncultured microorganisms. Microbiol Mol Biol. 68(4):669-685.

71. Donachie SP, Foster JS, Brown MV. 2007. Culture clash: challenging the dogma of microbial diversity. ISME J. 1(2):97-99.

72. Hughes D, Andersson DI. 2012. Selection of resistance at lethal and non-lethal antibiotic concentrations. Curr Opin Microbiol. 15(5):555-5560.

Equisetum bogotense: Still Phylogenetically Labile After All These Years

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Abstract

The genus Equisetum is recognized as having 15–18 species in 2–3 subgenera. Previous studies have found strong support for both subg. Equisetum (minus the previously included E. bogotense) and subg. Hippochaete and discussed the lability of E. bogotense in terms of its phylogenetic relationships. Recently, the monotypic subg. Paramochaete (E. bogotense) has been proposed. The present study reexamines rps4 gene and rps4-trnS spacer data for this genus using midpoint rooting. Data matrices representing rps4 gene plus rps4-trnS spacer, rps4 only, and rps4-trnS spacer only sequences were evaluated using maximum parsimony (MP) and maximum likelihood (ML) optimality criteria. Two partitions (the rps4 gene and the rps4-trnS spacer) were examined using partition homogeneity tests to evaluate possible incongruence but no significant incongruence was found ($p>0.05$). The utility of midpoint rooting was evaluated and determined to be appropriate. MP and ML consistently separated both subg. Equisetum and subg. Hippochaete, although placement of E. bogotense was variable. MP results placed E.

bogotense in a sister relationship with the rest of the genus. ML results differed noticeably, with E. bogotense in a sister relationship with subg. Equisetum or clearly embedded in it, which was not obtained in previous studies. A smaller set of RPS4 protein sequences were evaluated also, which generated results comparable with the ML nucleotide data with respect to E. bogotense. Genetic distance analyses were also conducted. These results, although sometimes differing with previous studies, continue to confirm the lability of E. bogotense.

Introduction

Based on the morphological treatment by Hauke (1963, 1978), the eusporangiate fern genus *Equisetum* L. was recognized as having 15 species placed in two subgenera: 1) subg. *Equisetum* (*E. arvense L.*, *E. bogotense* Kunth, *E. diffusum* D. Don, *E. fluviatile* L., *E. palustre* L., *E. pratense* Ehrh., *E. sylvaticum* L., and *E. telmateia* Ehrh.) and 2) subg. *Hippochaete* (J. Milde) Baker (*E. giganteum* L., *E. hyemale* L., *E. laevigatum* A. Braun, *E. myriochaetum* Schltdl. & Cham., *E. ramosissimum* Desf., *E. scirpoides* Michx., and *E. variegatum* Schleich. ex Weber & Mohr). It should also be noted that there are also several recognized hybrid taxa within, but not between, subgenera (Duckett 1979; Des Marais et al. 2003). It has also been noted that there are not any known hybrids between *E. bogotense* and any of the other horsetail taxa (Elgorriaga et al. 2018).

Subsequently, several chloroplast gene-based phylogenetic studies have supported the placement of *Equisetum* taxa into one of these two subgenera, with one notable and consistent exception: the South American species *E. bogotense* (Des Marais et al. 2003, Guillon 2004, Guillon 2007). On the basis of both *rbcL* and *trnL–trnF* nucleotide data, Des Marais et al. (2003) first established that the placement of this taxon was outside subg. *Equisetum*. Furthermore, they observed that its phylogenetic affinities varied according to the phylogenetic methodology employed, being either in a sister position to subg. *Hippochaete* or as a sister to the rest of the genus (Des Marais et al. 2003). Similarly, Guillon's (2004) *rps4* gene study indicated that *E. bogotense* was a sister taxon to the rest of the genus and not in subg. *Equisetum*. In contrast, the *atpB* study of Guillon (2007) nested *E. bogotense* within subg. *Hippochaete*, although the same study also presented a combined plastid gene dataset using *trnL–trnF*, *rbcL*, *rps4*, and *atpB* sequences that generated phylogenetic results consistent with Des Marais et al. (2003) and Guillon (2004). More recently, Christenhusz et al. (2019) recognized the monotypic subg.

Paramochaete Christenh. & Husby, in which is placed *E. bogotense*. Additionally, their study also splits three of Hauke's (1963, 1978) taxa to arrive at 18 species for the genus: *E. praealtum* Raf. (the North American *E. hyemale* var. *affine*) from *E. hyemale*, *E. xylochaetum* Mett. from *E. giganteum*, and *E. braunii* Milde (the western North American *E. telmateia* subsp. *braunii* (Milde) Hauke) from *E. telmateia* (Christenhusz et al. 2019).

The study presented here reexamines intrageneric phylogenetic relationships within *Equisetum*, and those particularly of *E. bogotense*, using sequences for both the ribosomal protein small subunit 4 (*rps4*) gene and the *rps4–trnS* intergenic spacer. Phylogenetic inferences using *rps4* and/or *rps4–trnS* intergenic spacer sequences, either alone or with other genes, have been conducted at various taxonomic levels and for many plant groups, including ferns (e.g., Pryer et al. 2004, Thomson et al. 2005, Speer 2008, Li et al. 2008, W. Wang et al. 2015, de Gasper et al. 2017). Guillon (2004) also used *rps4*, as well as data from flanking "upstream and downstream noncoding DNA regions," although in separate analyses, for his examination of *Equisetum*. The inclusion of these contiguous noncoding regions is here understood to include the *trnT–rps4* intergenic spacer (not included in the present study) and, of course, the *rps4–trnS* intergenic spacer. Although he ultimately used an outgroup approach in his two nucleotide-based analyses, Guillon (2004) did discuss the problems of identifying potential, usable outgroups and the difficulties of ambiguous alignment with non-*Equisetum* sequences for both coding and noncoding regions. Similar difficulties were also noted by Des Marais et al. (2003) for the *trnL–trnF* alignment in their study. This raises the question of whether it may be useful to try an alternative to outgroup rooting such as a midpoint rooting, especially because these are congeneric taxa and presumably closely related.

Midpoint rooting, one of the oldest rooting methodologies, determines pairwise distances between taxa and then places the root in the middle of the longest distance between taxa in the resulting tree (Farris 1972, Swofford et al.1996, Kinene et al. 2016). This approach assumes that there is a more or less constant rate of evolution between sequences (i.e., no rate heterogeneity) and that the tree will have a balanced topology, which may be not as useful if these assumptions are violated (Stavrinides and Guttman 2004, Kinene et al. 2016). However, case studies and direct evaluations of midpoint rooting by itself or with other rooting methodologies have determined it to be often a robust and valuable tool in phylogenetic analyses, especially when an outgroup cannot be clearly determined (Tarrío et al. 2000, Schuettpelz and Hoot 2006, Hess and de Morales Russo 2007, Wade et al. 2020). Although it did not always outperform all rooting methods for all categories

evaluated, Wade et al. (2020) point out that midpoint rooting is often effective at rooting even when there is significant gene tree reconstruction error, although as already previously noted, it was sensitive to variation in the nucleotide substitution rates.

The primary objectives of this study are to reevaluate *rps4*/*rps4–trnS* spacer phylogenies of the genus by using a larger data set and evaluating combined *rps4* and *rps4–trnS* spacer sequence data, in addition to the individual *rps4* and *rps4–trnS* spacer sequences. This approach will also include examination of the phylogenetic congruency between these two adjoining nucleotide regions. To provide an additional avenue of comparison, RPS4 protein data will be phylogenetically assessed. Furthermore, midpoint rooting will be employed, and its phylogenetic results compared with previous outgroup rooted *Equisetum* phylogenies.

Materials and Methods

Taxon selection

Taxa, both orthospecies (primary species) and, in a small number of cases, nothospecies (hybrids) were included to cover the taxonomic and geographic diversity within the genus *Equisetum*. Following Christenhusz et al. (2019), multiple representations of *Equisetum* taxa were used, here for purposes of more adequately determining phylogenetic affinities of between species and genetic distances between subgenera. Both nucleotide and protein sequences were used. These were either downloaded from GenBank or generated by the author (nucleotide only). Sequences generated by the author were obtained from either plant material that he personally collected or from material that was provided to him. All sequences are listed in Appendix 1 (nucleotide) and Appendix 2 (protein) by taxon and GenBank accession number.

DNA extraction, PCR, and sequencing

For plant material collected by the author or others, total genomic DNA was extracted using the Doyle and Doyle (1987) cetyltrimethyl-ammonium bromide method. Each 100-µl PCR reaction mixture had 100 ng of DNA. PCR reaction mixtures were amplified using forward (5′-AT GTCCCGTTATCGAGGACCT-3′) and reverse (5′-TACCGAGGGTTC GAATC-3′) primers. Thermocycling involved heating the PCR reaction mixtures to 95°C for 5 min, followed by 30 cycles of 95°C (1 min), 42°C (1.5 min), and 72°C (1 min), then by a final extension of 72°C for 10 min, and storage at 4°C in a GeneAmp PCR System 2400 (Perkin-Elmer,

Norwalk, CT). A Wizard PCR Prep Purification System (Promega, Madison, WI) was used to purify the PCR products before sequencing.

Sequencing reactions used BigDye Terminator Cycle Sequencing Ready Reaction (PE Applied Biosystems, Foster City, CA). Sequencing reactions were heated to 96°C for 1 s, followed by 30 cycles of 96°C (1 s), 47°C (5 s), and 60°C (4 min), and then stored at 4°C. Reactions were cleaned using Sephadex columns, loaded onto an acrylamide gel, and electrophoresed on an ABI Prism 377 DNA Sequencer (PE Applied Biosystems). Sequences that were generated as described here were deposited in GenBank and assigned accession numbers.

Data matrices and sequence alignment

The intent of this study was to evaluate phylogenetic relationships within the genus *Equisetum* using *rps4* gene (coding) and the *rps4–trnS* intergenic spacer (noncoding) sequences. However, although contiguous, these represent distinct nucleotide regions, and the possibility that they each are under different evolutionary constraints should be considered. For this reason, nucleotide sequences were put in one or more groups (data matrices) for phylogenetic examination. Data matrix 1 consisted of sequences spanning both the *rps4* gene and the *rps4–trnS* intergenic spacer regions. Data matrix 2 was *rps4* only, while data matrix 3 was the *rps4–trnS* intergenic spacer only. It should be noted that all sequences used were in all three data matrices, mostly because of differences in sequence length. BLAST (http://blast.ncbi.nlm.nih.gov/Blast.cgi) search results for potential outgroup taxa found low similarity with *Equisetum* taxa and with numerous gaps, even for *rps4* only (data matrix 2) and, so, matrices were composed of *Equisetum* sequences only. As previously noted, downloaded *RPS4* protein data were also utilized as a fourth data matrix. In each matrix, sequences were aligned using MAFFT (Katoh and Standley 2013) at the EMBL-EBI website (Madeira et al. 2022, https://www.ebi.ac.uk/jdispatcher/msa/mafft).

Disparity index for rate homogeneity assessment

As noted previously, the reliability of midpoint rooting assumes, in part, that there should not be substitution rate variation between sequences. To assess this, disparity indices (IDs) (Kumar and Gadagkar 2001) were pairwise calculated using the "Disparity Index Test of Pattern Homogeneity" and "Compute Pattern Disparity Index," both available under the "Models" tab in MEGA11. The former option uses a Monte Carlo test (500 replicates) to estimate the p-values. Following Sheffield et al. (2009), the probability of rejecting the null hypothesis that sequences have evolved with the same pattern of substitution was

assessed at the $p<0.01$ level. All positions containing gaps and missing data were removed using the complete deletion option. An index of ID=0 indicates that the criterion of homogeneity has been met, whereas a value ID>0 may indicate a statistically significant rate of heterogeneity (Kumar and Gadagkar 2001). For each data matrix, the numbers of pairwise sequence comparisons agreeing with or rejecting the null hypothesis were compared and the overall average disparity evaluated.

Transition/transversion ratios

To further evaluate the relationships within *Equisetum*, the transition to transversion ratio (ti/tv) of the DNA nucleotide nitrogenous bases was examined. In terms of nucleotide substitutions, a transition would be either purine-to-purine (A↔G) or pyrimidine-to-pyrimidine (C↔T) mutation, whereas a transversion would be either substitution from purine to pyrimidine or vice versa (A↔C, A↔T, G↔C, or G↔T). Assuming random mutation and that all possible pairwise substitutions occur at an equal rate, then ti/tv=0.5 (J. Wang et al. 2015, Duchêne et al. 2015). The reality is, however, that there can be considerable observed variation between observed ti/tv ratios between, for example, different genes or different taxa, with transitions usually occurring at a higher rate than transversions (Yang and Yoder 1999, Amselem et al. 2015, Zhong et al. 2021, Høy Hansen et al. 2022). Because the *rps4–trnS* spacer contained numerous indels, only data matrix 2 (just *rps4* sequences) were used to evaluate ti/tv for the genus as a whole and for each subgenus using the "Estimate Transition/Transversion Bias (ML)" option available under the "Models" tab in MEGA 11. The Tamura (1992) 3-parameter model with gamma distribution (i.e., T92+G model) was also used. Gaps/missing data were treated using the "Complete Deletion" option. Results recorded are R (in MEGA 11, R=ti/tv). The nucleotide frequencies reported were obtained using the "Compute MCL Transition/Transversion Bias," also available under the "Models" tab. MCL is the abbreviation for the maximum composite likelihood method and is defined as the sum of related log-likelihoods, which is often used to estimate evolutionary distances (Tamura et al. 2004).

Partition homogeneity test and phylogenetic analyses

It should be noted that whereas Guillon's (2004) study separately evaluated the *rps4* and flanking *trnT-rps4* spacer and *rps4–trnS* spacer regions, the present study evaluates the *rps4–trnS* spacer sequence, both concatenated with *rps4* (data matrix 1) and separately (data matrix 3). Because these are two distinct kinds of regions (coding and noncoding), they may be evolving at different rates and, therefore, could possibly

provide distinctly incongruous phylogenetic results. Guillon (2004) does not appear to have directly evaluated congruity between these different genetic regions. Therefore, prior to the maximum parsimony (MP) analysis of data matrix 1 (i.e., the *rps4* gene plus the *rps4–trnS* intergenic spacer region), a partition homogeneity test (PHT) was performed using PAUP* 4.0b10 (Swofford 2002) to evaluate phylogenetic heterogeneity between these distinct data partitions. PHT is the PAUP* version of the incongruence length difference test (Farris et al. 1994, 1995). Incongruence refers to the difference between the lengths of the most parsimonious tree for the complete dataset and the sum of the lengths of the most parsimonious trees from each partition. It is considered an indication of the degree to which the two partitions will result in different trees (Mickevich & Farris 1981, Farris et al. 1994). To perform this test, a paup block was written into the Nexus data file that defined each data partition (i.e., specified their respective nucleotide positions) and was carried out using parsimony settings, 100 replicates for each partition, and with a maximum possible of 100 trees saved for each replicate.

Both MP and maximum likelihood (ML) were used to analyze the data matrices. The four MP analyses were conducted using PAUP* 4.0b10 (Swofford 2002). Phylogenetic analyses were performed with default settings, including ACCTRAN optimization. Gaps were treated as missing data. The data were unordered and equally weighted. Because of difficulties in finding suitable outgroup taxa (see also Guillon 2004), a midpoint rooting (Kinene et al. 2016) approach was used. The heuristic algorithm was used in tree construction. For tree evaluation, the following statistics were compiled: consistency index (CI), retention index (RI), rescaled consistency index (RC), number of most parsimonious trees, tree length, and numbers of parsimony informative and variable characters. The CI, RI, and RC are different measures of homoplasy/goodness of fit, where 1.0 is no homoplasy (Kluge and Farris 1969, Farris, 1989, Klassen et al. 1991). A 50% majority rule consensus tree was generated prior to bootstrapping to identify the midpoint, because PAUP* does not allow for a midpoint-rooted bootstrap tree. Bootstrapping (Felsenstein 1985) was performed using a heuristic search with 100 random addition sequences with simple-addition sequence and TBR swapping. All generated majority rule consensus trees and the bootstrap trees were saved in Newick format (see Cardona et al. 2008) and uploaded to MEGA11 (see below) for midpoint placement of MP bootstrap trees. All branches with <50% bootstrap support (BS) were collapsed.

MEGA11 ver. 11.0.13 (Tamura et al. 2021) was used for all four ML analyses. Prior to each phylogenetic analysis, the "find best DNA/protein models (ML)" option (under the "Models" tab) was used

to determine the best substitution model for that data matrix. The Tamura (1992) 3-parameter model with gamma distribution was selected for data matrix 1 (G=0.2296) and data matrix 2 (G=0.1662). The Tamura (1992) 3-parameter model without a gamma distribution (i.e., T92 model) was selected for data matrix 3. The general reversible chloroplast model (Adachi et al. 2000) (i.e., cpREV model) was chosen for the protein data matrix. For all ML analyses, the partial deletion option was used (i.e., all positions with <95% site cover were eliminated), and bootstrapping was performed to assess branch support. MEGA11 results generated the tree with the highest log likelihood, which by default is midpoint rooted and is designated the "original tree." Conversely, bootstrap trees are initially unrooted and, therefore, are not midpoint rooted. However, MEGA11 does allow for the interactive placement of a root (i.e., the midpoint rooted original tree was used to determine the placement of the midpoint for the bootstrap tree). As with MP, all branches with BS <50% support were collapsed.

It should be noted that the MEGA program uses a midpoint approach for some available phylogenetic methodologies where an outgroup is not specified (https://www.megasoftware.net/mega1_manual/Phylogeny.html), but this option can also be selected in MEGA. As to phylogenetic tree output, it treats the basal branch containing the midpoint containing as a single bent segment and not as two linked branches and will show only one (not two) bootstrap value (Cunningham 2012). Similar examples of this are the midpoint rooted trees of Birks and Edwards (2002, see branch lengths in Fig. 6) and Wolf et al. (2018, see bootstrap values in Fig. 1).

Determination of genetic distances

The mean genetic distances between subgenera were calculated using MEGA11. First, all sequences were placed into one of the three subgenera using the "Select Taxa and Groups" option under the "Data" tab. Next, the "Compute Group Mean Distance" option under the "Distance" tab was used to compute distances between subgenera for each data matrix and optimality criterion (i.e., MP or ML). To evaluate MP results, p-distances were calculated for each matrix. For ML, distances were calculated based on the substitution model employed in the corresponding phylogenetic analysis: T92+G for data matrices 1 and 2 and T92 for data matrix 3. However, because cpREV was not an option in MEGA11 for protein distances, the Jones-Taylor-Thornton (JTT) model (Jones et al. 1992) was used instead. This was deemed appropriate because, although the model selection results identified cpREV as the best substitution model for the protein data matrix, the second-best

model was JTT. Furthermore, in the cpREV phylogeny, initial trees were obtained, in part, using a JTT pairwise distance matrix.

Results

Nucleotide data matrices and sequence alignment

Sequence alignment for matrices was mostly straightforward, although there were missing data and/or gaps (indel positions) in all three. Data matrix 1 (*rps4*+*rps4–trnS* spacer) comprised 55 downloaded nucleotide sequences. The alignment length was 774 nucleotide positions. Approximately 5.7% of this matrix had missing data (including gaps).

Data matrix 2 (complete *rps4* only) was made up of 70 sequences (55 downloaded from GenBank and 15 generated by the author). The length of the alignment was 624 bp. Missing data (no gaps) accounted for approximately 3.3% of the dataset.

There were 55 sequences in data matrix 3 (incomplete *rps4–trnS* spacer only), which had a length of 150 bp. Although its alignment was relatively straightforward, it had numerous gaps. Gap (indel) positions accounted for 34.1% of this matrix, and another 2.5% was missing data.

Some indel positions appeared to be potentially useful phylogenetically by consistently separating taxa, for example, 1) *E. bogotense* from the rest of the genus, 2) subg. *Hippochaete* and *E. bogotense* from subg. *Equisetum*, and 3) *E. xylochaetum* from the rest of the genus (Figs. 1 and 2). Beyond reporting these observations, however, indels were not further evaluated.

```
Eq_hyemale        AAACGATAAT----------------------------AAAAAA
Eq_ramosissimum-a AAACGATAAT----------------------------AAAAAA
Eq_ramosissimum-b AAACGATAAT----------------------------AAAAAAA
Eq_myriochaetum   AAACGATAAG----------------------------CAAAAA
Eq_laevigatum     AAACGATAAG----------------------------CAAAAA
Eq_xylochaetum    AAACGATAAG--------------------------AAAAAAAAA
Eq_giganteum      AAACGATAAG------------------------AAAAAAAAAA
Eq_scirpoides-a   AAACGAAAAG----------------------------AAAAA
Eq_scirpoides-b   AAACGAAAAG----------------------------AAAAAA
Eq_variegatum     AAACGAGAAG----------------------------AAACA
Eq_sylvaticum     ACATG---------------------------------AAAA
Eq_palustre       ACACA---------------------------------AAAA
Eq_arvense        ACATG---------------------------------AAAA
Eq_diffusum       ACATG---------------------------------AAAA
Eq_fluviatile     ACATG---------------------------------AAAA
Eq_telmateia      AAACG---------------------------------AAAAA
Eq_pratense       ACACG---------------------------------AAAAA
Eq_bogotense      ACACGATTTTTAAATGAGTTTTTTTATTTCTGTTAGGTAATAAACT
```

Figure 1. Indels in the *rps4–trnS* intergenic spacer corresponding to positions 57771–57786 of GenBank accession KC117177 (*E. hyemale* complete chloroplast genome). Note that two indel variants (designated “a” and ‘b”) were observed for both *E. ramosissimum* and *E. scirpoides*.

```
Eq_hyemale        GTCTCT----------------CTTTTAGATAGTATCT
Eq_ramosissimum-  GTCTCT----------------CTTTTAGATAGTATCT
Eq_myriochaetum   GTCTCT----------------CTTTTAGATAGTATCT
Eq_laevigatum     GTCTCT----------------CTTTTAGATAGTATCT
Eq_xylochaetum    GTTTCTCTTTTAGATCGTTTCTCTTTTAGATAGTATCT
Eq_giganteum      GTTTCT----------------CTTTTAGATAGTATCT
Eq_scirpoides     GTCTCT----------------ATTTTAGATAGTATCT
Eq_variegatum     GTCTCT----------------ATTTTAGATAGTATCT
Eq_sylvaticum     TTCTCG----------------ATTTTAGATAGTATCT
Eq_palustre       TTCTCG----------------ATTTTATATAGTATCT
Eq_arvense        TTCTTG----------------ATTTTATATAGTATCT
Eq_diffusum       TTCTCG----------------ATTTTATATAGTAGAT
Eq_fluviatile     TTCTCG----------------ATTTTATATAGTATCT
Eq_telmateia      TTCTCG----------------ATTTTAGAAAGTATCT
Eq_pratense       TTCTCG----------------ATTTTAGATAGTATCT
Eq_bogotense      TTTTCG----------------ATTTTAGCTAGTATCT
```

Figure 2. Indels in the *rps4–trnS* intergenic spacer corresponding to positions 57732–57753 of GenBank accession KC117177 (*E. hyemale* complete chloroplast genome).

Rate homogeneity assessment

The results of the disparity index tests indicate that significant rate substitution heterogeneity, depending on the matrix, is nonexistent to negligible at the $p<0.01$ level of significance. Data matrices 1 and 3, as well as the protein data matrix, did not have any values that differed significantly from ID=0. Data matrix 2, however, had three significantly different ID values, all of which were significant at p=0.008. These involved a pairwise comparison of an *E. telmateia* sequence with a sequence for either *E. scirpoides* or *E. palustre*. The overall average ID values for each matrix were very low with ID=0.0077 (data matrix 1), ID=0.0122 (data matrix 2), ID=0.0003, and ID=0.0095 (protein data matrix). Disparity index results are summarized in Table 1. To properly assess these ID values, they were compared with those obtained in other studies (see Discussion).

Table 1. Summary of disparity index tests

Matrix	# pairwise comparisons	ID range	% of ID significantly higher than ID=0.000	Overall average ID
1	1485	0.000-0.024	0.00%	0.0077
2	2415	0.000-0.081	0.12%	0.0122
3	1485	0.000-0.027	0.00%	0.0003
Protein	465	0.000-0.078	0.00%	0.0095

Comparison of rate for transitions/transversions and nucleotide frequencies

The R (ti/tv rates) and nucleotide frequency data results are shown in Table 2. With the exception of subg. *Hippochaete*, ti/tv rates were very comparable for the overall group of sequences (R=2.05), subg. *Equisetum* (R=2.02), and subg. *Paramochaete* (R=2.04), with transitions having occurred at a higher rate than that of transversions. In comparison, transversions occurred at a higher rate than transitions for subg. *Hippochaete* (R=0.91) (i.e., the rate of transitions is still higher than the rate of transversion, although much lower than for these other three categories). A similar observation for *Equisetum* has been made previously but using *rbcL* sequences (see Discussion). The observed nucleotide frequencies for the overall, subg. *Hippochaete*, subg. *Equisetum*, and subg. *Paramochaete* categories each fell into a narrow range of variation with A=34.31–36.95%, T=32.25–34.74%, C=15.02–15.87%, and G=15.08–16.40%.

Table 2. Summary of R (ti/tv) and nucleotide frequencies

Group	R	A%	T%	C%	G%
Overall	2.05	34.75	34.46	15.75	15.04
subg. Hippochaete	0.91	34.31	34.74	15.87	15.08
subg. Equisetum	2.02	36.95	32.46	15.02	15.57
subg. Paramochaete	2.04	35.69	32.25	15.66	16.4

Partition homogeneity test

Because the *rps4* gene and *rps4–trnS* spacer, although contiguous, represent a protein coding gene and a noncoding region and potentially may be evolving at different rates, a PHT was conducted in PAUP* for data matrix 1 (*rps4*+*rps4–trnS* spacer). The concatenated sequence data was divided into two partitions for analysis. However, the results of this test indicated that the *rps4* and spacer partitions showed phylogenetic homogeneity and were not statistically incongruous at p=0.55 (i.e., p>0.05).

Phylogenetic analyses: MP

The three nucleotide MP phylogenetic sets of results differed in varying degrees in terms of resolution but were otherwise in general agreement. The phylogenetic trees, with CI, RI, RC statistics and the numbers of parsimony informative and variable characters, are shown in Figures 3–5. The nucleotide data matrix 1 (Fig. 3) generated 12 equally

parsimonious trees of length 12, data matrix 2 (Fig. 4) produced 100 trees of length 109, and data matrix 3 (Fig. 5) resulted in 100 trees of length 73. Analysis of all three nucleotide data matrices placed *E. bogotense* (subg. *Paramochaete*) as a sister group to the rest of the genus

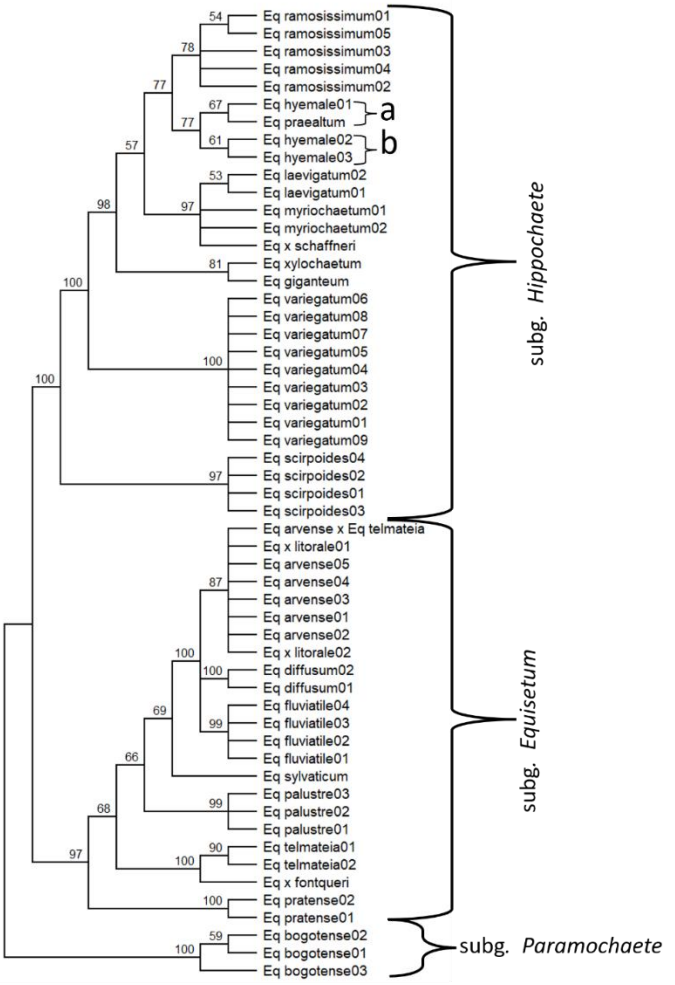

Figure 3. MP bootstrap consensus tree for data matrix 1 (*rps4+rps4–trnS* spacer) for 55 sequences. The MP analysis generated 12 equally parsimonious trees of length 183, with CI=0.825, RI=0.976, and RC=0.805. In the hyemale–praealtum clade, "a" corresponds to *E. hyemale* subsp. *affine* (=*E. praealtum*) and "b" corresponds to *E. hyemale* subsp. *hyemale*.

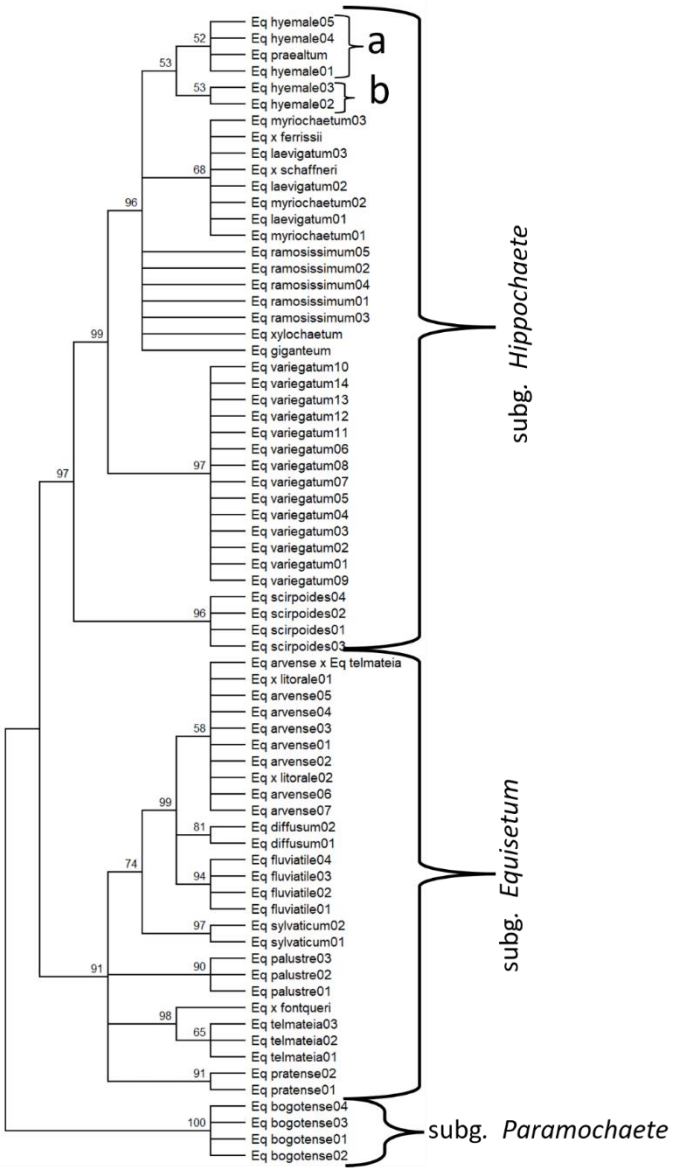

Figure 4. MP bootstrap consensus tree for data matrix 2 (*rps4* only) for 70 sequences. The MP analysis generated 100 equally parsimonious trees of length 109, with CI=0.817, RI=0.980, and RC=0.800. In the hyemale–praealtum clade, "a" corresponds to *E. hyemale* subsp. *affine* (=*E. praealtum*) and "b" corresponds to *E. hyemale* subsp. *hyemale*.

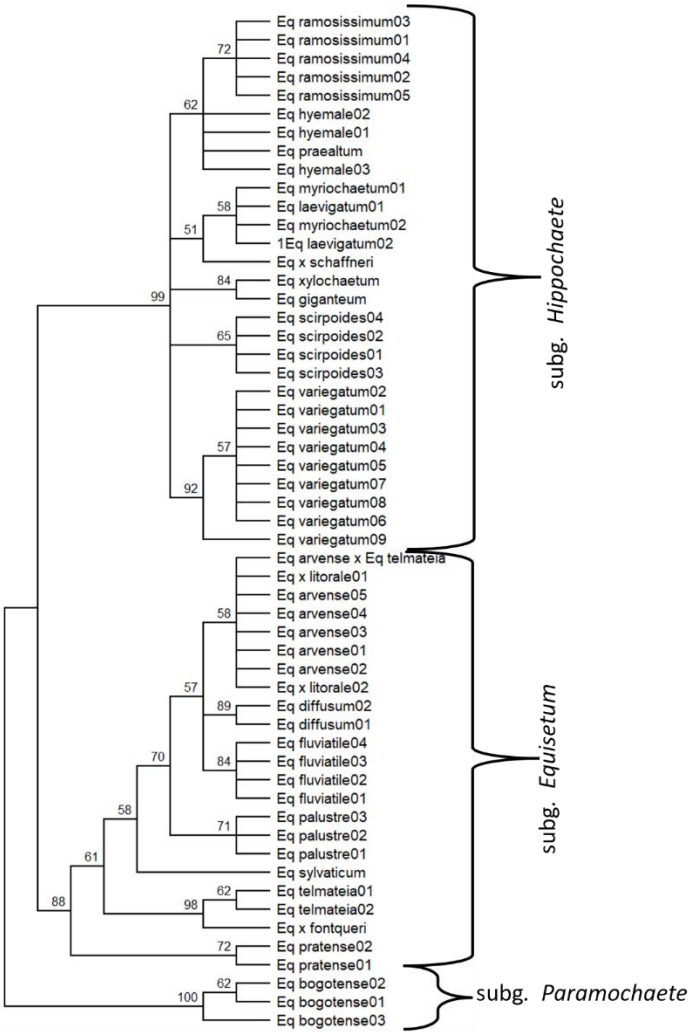

Figure 5. MP bootstrap consensus tree for data matrix 3 (*rps4–trnS* spacer) for 55 sequences. The MP analysis generated 100 equally parsimonious trees of length 73, with CI=0.849, RI=0.978, and RC=0.830.

in all three. Subg. *Equisetum* was supported in data matrix 1 with BS=97%, in data matrix 2 with BS=91%, and in data matrix 3 with BS=88%. Similarly, subg. *Hippochaete* was supported in data matrix 1 with BS=100%), in data matrix 2 with BS=97%, and in data matrix 3 with BS=99%. Within each phylogenetic tree, an *E. arvense*/*E.*

diffusum/*E. fluviatile* clade appeared, although with varying degrees of support. It had a BS=100% in data matrix 1 and a BS=99% for data matrix 2, but it in data matrix 3 it was BS=57%. Likewise, an *E. laevigatum*/*E. myriochaetum* clade received a BS=97% for data matrix 1, BS=68% for data matrix 2, and BS=51% for data matrix 3. This clade was often closely associated with *E. hyemale* and *E. ramosissimum*. *E. scirpoides*, followed by *E. variegatum*, was the most basal taxon in subg. *Hippochaete*, although their relationship is poorly resolved in data matrix 3. In subg. *Equisetum*, *E. pratense*, followed by *E. telmateia*, was the basal most taxon, although this relationship is not well resolved for data matrix 2. As will be noted again, the MP nucleotide results are in general agreement with previous studies (see Discussion). One final observation for the nucleotide analyses, the results for data matrices 1 and 2, but not data matrix 3, bifurcated the *E. hyemale* clade into groups corresponding to the European *E. hyemale* subsp. hyemale and the North American *E. hyemale* subsp. *affine* (=*E. praealtum*) (Figs. 3 and 4). The first two data matrices include the *rps4* protein coding gene, while data matrix 3 is the spacer only.

The analysis of the protein data matrix resulted 100 equally parsimonious trees of length 46. The bootstrap tree, with CI, RI, RC statistics and the numbers of parsimony informative and variable characters, is shown in Figure 6. The MP tree results generated from the protein data, however, differed noticeably from the nucleotide trees by placing *E. bogotense* in a sister relationship with subg. *Equisetum*. Similar to the nucleotide results, subg. *Hippochaete* (BS =94%) and subg. *Equisetum* (BS=74%) groups were obtained. Also, *E. arvense*/*E. diffusum*/*E. fluviatile* (BS=85%) and *E. laevigatum*/*E. myriochaetum* (BS=64%) clades were recovered. Relationships in the protein results, although mostly in agreement with the nucleotide trees (except for *E. bogotense*), were not always as well resolved and were sometimes not as well supported.

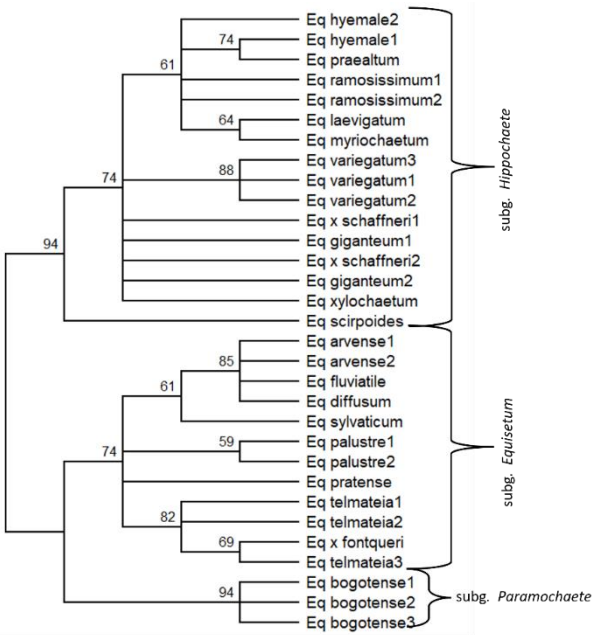

Figure 6. MP bootstrap consensus tree for protein data for 31 sequences. The MP analysis generated 100 equally parsimonious trees of length 46, with CI=0.848, RI=0.956, and RC=0.811.

Phylogenetic analyses: ML

Results of the ML analyses of the three nucleotide data matrices differed most noticeably from the MP results in terms of their placement of *E. bogotense*, which was not in a sister position with the rest of the genus. All nucleotide ML trees are shown in Figures 7–9. The best tree generated by data matrix 1 was log-likelihood=-1757.50 (Fig. 7). *E. bogotense* grouped with subg. *Equisetum*. Subg. *Hippochaete* was supported at BS=100% and subg. *Equisetum* (minus *E. bogotense*) was supported at BS=88%. The *E. arvense*/*E. diffusum*/*E. fluviatile* clade was supported with BS=100%. As previously observed, *E. scirpoides* was the most basal taxon in subg. *Hippochaete* with BS=100%. The *E. laevigatum*/*E. myriochaetum* clade received BS=91% support. Data matrix 2 resulted in an obtained original (best) tree of log-likelihood=-1290.54 (Figure 8). The *E. bogotense* plus subg. *Equisetum* clade was supported with BS=99%. A support of BS=97% was also observed for the *E. arvense*/*E. diffusum*/*E. fluviatile* clade. In subg. *Hippochaete*, however, the *E. laevigatum/E. myriochaetum* clade was

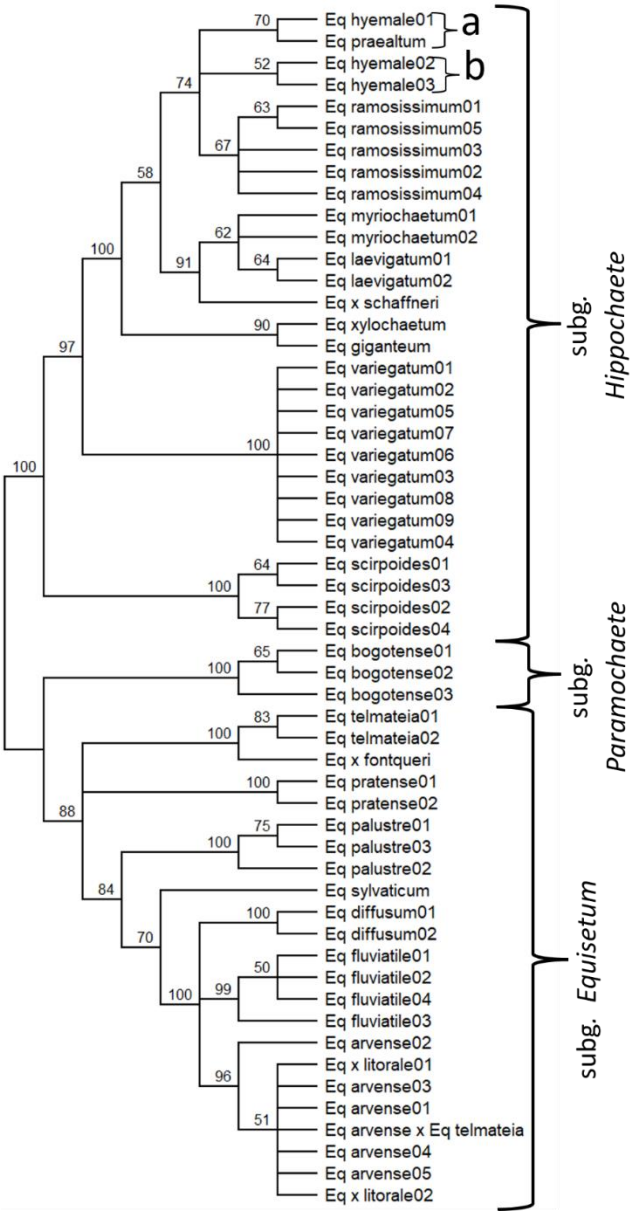

Figure 7. ML bootstrap consensus tree for data matrix 1 (*rps4*+*rps4–trnS* spacer) for 55 sequences (log likelihood=-1757.50). In the hyemale–praealtum grade, "a" corresponds to *E. hyemale* subsp. *affine* (= *E. praealtum*) and "b" corresponds to *E. hyemale* subsp. *hyemale*.

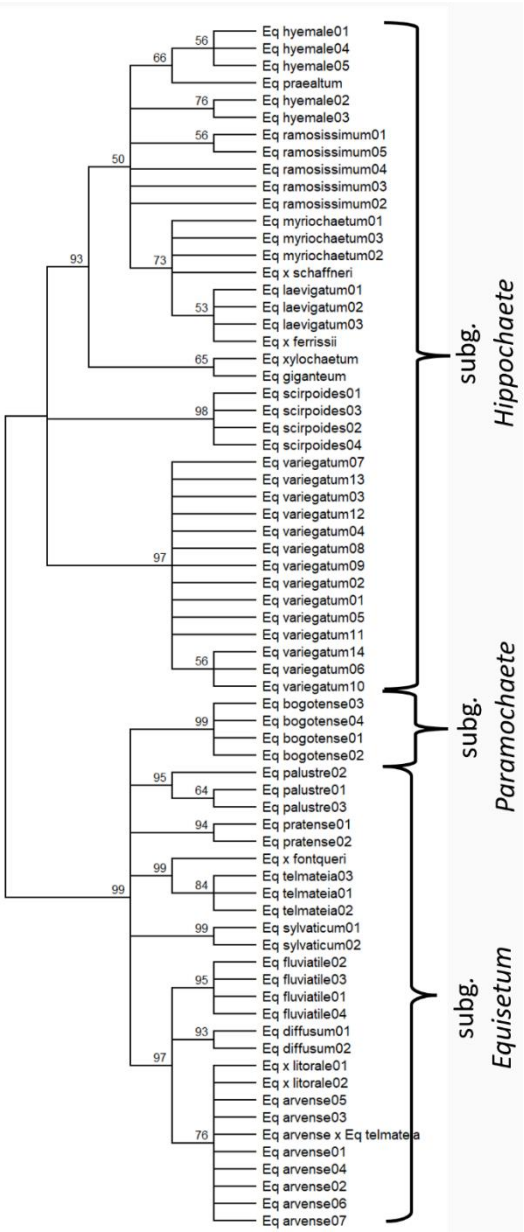

Figure 8. ML bootstrap consensus tree for data matrix 2 (*rps4* only) for 70 sequences (log likelihood=-1290.54).

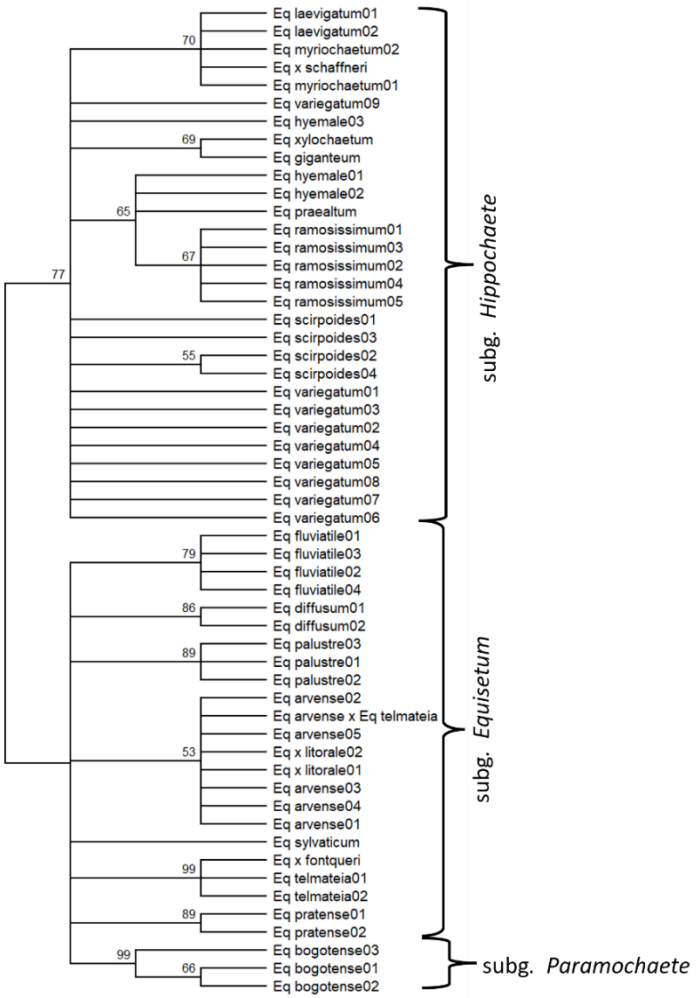

Figure 9. ML bootstrap consensus tree for data matrix 3 (*rps4–trnS* spacer) for 55 sequences (log likelihood=-287.49).

supported at BS=73% and the relationships of both *E. scirpoides* and *E. variegatum* with the rest of the subgenus were not well resolved. Analysis of nucleotide data matrix 3 resulted in a best tree of log likelihood=-287.49 (Fig. 9). In general, this tree was less well resolved than the previous ML trees. Nevertheless, taxa were segregated into two major clades consistent with subg. *Hippochaete* and subg. *Equisetum*

plus *E. bogotense* groups, as was seen with the previous two ML analyses. In contrast to the previous nucleotide phylogenetic results obtained in this study, there was not an *E. arvense*/*E. diffusum*/*E. fluviatile* grouping obtained. However, an *E. laevigatum*/*E. myriochaetum* group did appear in subg. *Hippochaete* (BS=70%). Similar to the MP results, data matrices 1 and 2, but, again, not data matrix 3, split *E. hyemale* into two groups corresponding to *E. hyemale* subsp. *hyemale* and *E. hyemale* subsp. *affine* (=*E. praealtum*). The difference, however, is that whereas MP had *E. hyemale* as a single bifurcating clade, ML placed these into distinct clades for each subspecies for data matrix 1 (Fig. 7).

ML analysis of the protein data matrix generated an original tree of log likelihood=-759.87. Two large groups corresponding to subg. *Hippochaete* and subg. *Equisetum* plus *E. bogotense* appeared in the protein bootstrap tree (Fig. 10), with *E. bogotense* clearly nesting within subg. *Equisetum* and not in a sister position to it. Consistencies with other phylogenetic results obtained include an *E. arvense*/*E. diffusum*/*E. fluviatile* clade (BS=53%), an *E. laevigatum*/*E. myriochaetum* group (BS=71%), and *E. scirpoides* in a basal position within subg. *Hippochaete*.

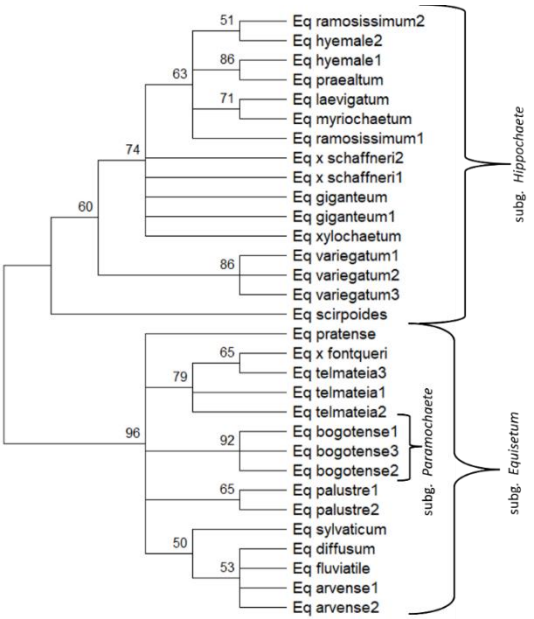

Figure 10. ML bootstrap consensus tree for protein data for 31 sequences (log likelihood=-759.87).

Subgeneric genetic distances

The subgeneric mean genetic distances obtained for each data matrix are shown in Table 3. In most cases these values were low. The highest set of overall distances was obtained for data matrix 3 (*rps4–trnS* spacer only). In general, the results show close relatedness between subgenera. For the nucleotide data (data matrices 1, 2, and 3), subgenera *Equisetum* and *Hippochaete* had the lowest pairwise distances (i.e., were more closely related), although subg. *Paramochaete* (*E. bogotense*) appeared to have more genetic relatedness to subg. *Equisetum* than to subg. *Hippochaete*. In contrast, the protein data indicate that subgenera *Equisetum* and *Paramochaete* are more closely related to each other than either is to subg. *Hippochaete*.

Table 3. Mean group genetic distance between subgenera

Data matrix	Distance used	Subgenera pairwise comparison		
		P-H*	P-E*	E-H*
1	T92+G	0.0912	0.0809	0.0739
1	p-distance	0.0799	0.0711	0.0663
2	T92+G	0.0717	0.0603	0.0567
2	p-distance	0.0640	0.0543	0.0521
3	T92	0.2920	0.2850	0.2550
3	p-distance	0.2380	0.2300	0.2070
Protein	JTT	0.0757	0.0489	0.0722
Protein	p-distance	0.0740	0.0486	0.0704

*For subgeneric pairwise comparisons, *P-H*=subgenera *Paramochaete–Hippochaete*, *P-E*=subgenera *Paramochaete–Equisetum*, and *E-H*=subgenera *Equisetum–Hippochaete*.

Discussion

Rate homogeneity, ti/tv bias, and nucleotide frequencies

Midpoint rooting assumes, in part, that there is not significant substitution rate homogeneity. As indicated by the disparity index tests, rate substitution heterogeneity between the sequences examined here was, for the most part, overwhelmingly nonexistent. Only three pairwise comparisons for data matrix 2 showed statistically significant deviations from the null hypothesis of I_D=0, which represent a negligible 0.12% of the total pairwise combinations for that data matrix. None of these three pairwise comparisons involved *E. bogotense*. Cautiously offered here to provide some comparison with other taxa for other plant genera are the range of disparity indices for 1) the genus *Piper* for the genes *rbcL*:

0.0000–0.0329 and *rpoC1*: 0.0000–0.0949 (Naim and Mahboob 2020) and 2) the genus *Salvia* for *ITS* sequences: 0.0000–0.4526 (Khal 2020). In contrast, the ranges obtained in the present student are much narrower, and the I_D values, including the three statistically significant I_D, were very small (Table 1). Consistent with the observation of rate homogeneity was the fact that the frequencies for each nucleotide appeared to be more or less consistent for the groups evaluated with, at most, minor variation. The I_D values and nucleotide frequencies obtained in this study would seem to agree with the appropriateness of a midpoint rooting approach for these data. It should be noted that although there was overall rate homogeneity and agreement of nucleotide frequencies within the genus and between subgenera, the transition–transversion (ti/tv) bias for subg. *Hippochaete* (R=0.91) differed from the values otherwise obtained (R=2.02–2.05). As noted previously, an assumption that transitions and transversion occur at equal rate would give ti/tv=0.5 (J. Wang et al. 2015, Duchêne et al. 2015). However, it has been long observed that transitions occur at higher rates than transversion (e.g., Yang and Yoder 1999), so that ti/tv (or R) values are usually greater than this (i.e., R>0.5). Although this was indeed the case in all four R values obtained, the R value for subg. *Hippochaete* suggests a lower transition rate relative to transversions than is otherwise found in this study. It should be noted that a somewhat similar result was reported by Des Marais et al. (2003) for *rbcL*, where the ti/tv ratio was 1.87 for subg. *Hippochaete* but 3.40 for subg. *Equisetum*.

PHT

The PHT result indicates that there is not any statistically significant phylogenetic incongruity between the *rps4* coding and *rps4–trnS* noncoding regions. As far as this study could determine, the observed lability of *E. bogotense* cannot be explained by any differences between these two data partitions.

Phylogenetic lability of E. bogotense and genetic distances

Des Marais et al. (2003) were first to point out the phylogenetic lability of *E. bogotense* by noting that the position of this taxon varied according to the phylogenetic methodology employed. Similarly, the analyses of Guillon (2004) and Guillon (2007) reported similar variability in the phylogenetic placement of *E. bogotense*. Christenhusz et al. (2019) subsequently proposed the placement of *E. bogotense* in the monotypic subg. *Paramochaete*. In his more recent analysis of sequence data from the P8 region of the *trnL*-UAA intron, Speer (2024) used two different ML approaches to evaluate *Equisetum* relationships

and obtained two different placements for this species: 1) using the HKY+G +I substitution model, as implemented in the program PhyML (Guindon et al. 2010), *E. bogotense* was placed in a sister group to subg. *Hippochaete*, whereas 2) the JC+I substitution model, as employed in the MEGA X program (Kumar et al. 2018), nested it within subg. *Hippochaete*, although in a very different clade as reported in the *atpB* only phylogeny of Guillon (2007). These previous studies demonstrate that, not only do the subgeneric relationships of *E bogotense* vary according to optimality criterion used, as noted by Des Marais et al. (2003), but they can differ also in terms of the particular molecular data set used and, at least in some cases, the substitution model used. This is in contrast to the other *Equisetum* taxa, which consistently grouped according to recognized subgenus. It should also be noted that the midpoint rooting approach used in this study generated results similar, and sometimes identical, to those obtained in previous studies, with the exception, as previously noted, of those results presented suggesting a closer phylogenetic relationship with subg. *Equisetum*.

The nucleotide MP analyses of the present study agree with several of the previous phylogenetic examinations in that *E bogotense* was placed in a sister group relationship with subg. *Hippochaete*. In contrast, the protein analyses and the nucleotide ML analyses presented here suggest a closer relationship with subg. *Equisetum*, which appears contradictory to all the previous molecular studies. Interestingly, and as previously noted, the recovered relationships in this study for the other *Equisetum* taxa did not exhibit any lability and were in general agreement with earlier studies. Hence, the phylogenetic results obtained in the present study are consistent with the notion of phylogenetic ambiguity for *E. bogotense* but not for the other taxa within the genus.

The results of the nucleotide subgeneric mean distances suggest a closer genetic relationship between subgenera *Equisetum* and *Hippochaete* than what was seen for either with subg. *Paramochaete* (*E. bogotense*). This would be consistent with the observation of Des Marais et al. (2003) that *E. bogotense* is the most isolated species among existing *Equisetum* species. It would also be in possible agreement with those studies (e.g., Des Marais et al. 2003, Guillon 2004) that suggested a possible basal position for this species followed by divergence of the clades representing subgenera *Equisetum* (minus Hauke's (1978) *E. bogotense*) and *Hippochaete*, but in disagreement with studies (e.g., Guillon 2007, Speer 2024) suggesting that it is in a sister position to subg. *Hippochaete*. However, the nucleotide distances also seem to indicate that *E. bogotense* has a closer genetic relationship with subg. *Equisetum* than with subg. *Hippochaete*, whereas the protein-based distances suggest the closest relationship is between subgenera

Paramochaete and *Equisetum*. The genetic distance results do not align with previous phylogenetic studies but are congruous with the nucleotide ML and protein results obtained in the present study.

Concluding remarks and a possible explanation for lability

This study provides additional information underscoring the uncertain position of *E. bogotense* within the genus *Equisetum*. This study and others have placed *E. bogotense* at different positions relative to the other members of the genus. These, including the present study, have evaluated only extant horsetails. However, at least one study of the genus *Equisetum* has incorporated fossil specimens in their study. While commenting on the phylogenetically ambiguous molecular relationships with other taxa, Elgorriaga et al. (2018) noted that in terms of modern horsetails, although *E. bogotense* is morphologically most like members of subg. *Equisetum*, it appears to be even much more related morphologically to fossil species than to currently living taxa. In fact, all fossil specimens from the Mesozoic appear to be intermediate between *E. bogotense* and the other extant taxa, suggesting that it is the most phylogenetically distinct species within the genus (Elgorriaga et al. 2018). If it is indeed the most ancient of living horsetail taxa and the lineage leading to subgenera *Hippochaete* and *Equisetum* arose much later, this would go a long way in explaining its ambiguous phylogenetic relationships with the rest of the genus. Although the usage of plesiomorphic (ancestral traits) and apomorphic (derived traits) terminology appears to be used only infrequently in molecular studies (Wägele 1996, Zhong et al. 2011, Kück and Wägele 2016), the determination of plesiomorphic sites in aligned sequences would be useful in avoiding events such as the symplesiomorphy trap, a type of long branch attraction where symplesiomorphies (shared plesiomorphies) are incorrectly considered as apomorphic (Wägele and Mayer 2007, Zhong et al. 2011). With a symplesiomorphy trap, a paraphyletic set of taxa may be joined together to appear as monophyletic. If the conjectures of Elgorriaga et al. (2018) are correct that *E. bogotense* is distantly related to all other extant *Equisetum* taxa, its inconsistent phylogenetic positions can be explained in this manner. This could very possibly explain why, for example, *E. bogotense* has shown a close (sister) relationship with subg. *Hippochaete* in some studies. Identification of potential symplesiomorphies in sequence data may be of use in clarifying the relationships of *E. bogotense*. Although great strides have been made in elucidating the relationships within the genus *Equisetum*, there remains phylogenetic work to be done.

Literature Cited

Adachi J, Waddell PJ, Martin W, Hasegawa M. 2000. Plastid genome phylogeny and a model of amino acid substitution for proteins encoded by chloroplast DNA. *J Mol Evol* 50:348-358.

Amselem J, Lebrun MH, Quesneville H. 2015. Whole genome comparative analysis of transposable elements provides new insight into mechanisms of their inactivation in fungal genomes. *BMC Genomics* 16:141.

Birks SM, Edwards SV. 2002. A phylogeny of the megapodes (Aves: Megapodiidae) based on nuclear and mitochondrial DNA sequences. *Mol Phylogenet Evol* 23:408-421.

Cardona G, Rosselló F, Valiente G. 2008. Extended Newick: it is time for a standard representation of phylogenetic networks. *BMC Bioinformatics* 9:532.

Christenhusz MJM, Bangiolo L, Chase MW, Fay MF, Husby C, Witkus M, Viruel J. 2019. Phylogenetics, classification and typification of extant horsetails (*Equisetum*, Equisetaceae). *Bot J Linn Soc* 189:311–352.

Cunningham M. (2012). Re: Why are some nodes in Mega5 NJ tree shown without bootstrap values? Retrieved September 9, 2024, from https://www.researchgate.net/post/Why_are_some_nodes_in_Mega5_NJ_tree_shown_without_boostrap_values/4fd1efefe4f076f005000000/citation/download.

de Gasper AL, Almeida TE, Dittrich VA, Smith AR, Salino A. 2017. Molecular phylogeny of the fern family Blechnaceae (Polypodiales) with a revised genus-level treatment. *Cladistics* 33:429–446.

Des Marais DL, Smith AR, Britton DM, Pryer KM. 2003. Phylogenetic relationships and evolution of extant horsetails, *Equisetum*, based on chloroplast DNA sequence data (*rbcL* and *trnL–F*). *Int J Plant Sci* 164:737–751.

Doyle JJ, Doyle JL. 1987. A rapid DNA isolation procedure for small quantities of fresh leaf tissue. *Phytochem Bull* 19:11-15.

Duchêne S, Ho SY, Holmes EC. 2015. Declining transition/transversion ratios through time reveal limitations to the accuracy of nucleotide substitution models. *BMC Evol Biol* 15:36.

Duckett JG. 1979. An experimental study of the reproductive biology and hybridization in the European and North American species of *Equisetum*. *Bot J Linn Soc* 79:205–229.

Elgorriaga A, Escapa IH, Rothwell GW, Tomescu AMF, Rubén Cúneo N. 2018. Origin of *Equisetum*: Evolution of horsetails (Equisetales) within the major euphyllophyte clade Sphenopsida. *Am J Bot* 105:1286-1303.

Farris JS. 1972. Estimating phylogenetic trees from distance matrices. *Am Nat* 106:645–668.

Farris JS. 1989. The retention index and the rescaled consistency index. *Cladistics* 5:417-419.

Farris JS, Källersjö M, Kluge AG, Bult C. 1994. Testing significance of incongruence. *Cladistics* 10:315-319.

Farris JS, Källersjö, M, Kluge AG, Bult C. 1995. Constructing a significance test for incongruence. Syst Bot 44:570-572.

Felsenstein J. 1985. Confidence limits on phylogenies: an approach using the bootstrap. *Evolution* 39:783-791.

Guillon J-M. 2004. Phylogeny of horsetails (*Equisetum*) based on the chloroplast *rps4* gene and adjacent noncoding sequences. *Syst Bot* 29:251–259.

Guillon J-M. 2007. Molecular phylogeny of horsetails (*Equisetum)* including chloroplast *atpB* sequences. *J Plant Res* 4:569–574.

Guindon S, Dufayard JF, Lefort V, Anisimova M, Hordijk W, Gascuel O. 2010. New algorithms and methods to estimate maximum-likelihood phylogenies: assessing the performance of PhyML 3.0. *Syst Biol* 59:307–321.

Hauke RL. 1963. A taxonomic monograph of the genus *Equisetum* subgenus *Hippochaete*. *Nova Hedwigia* 8:1–123.

Hauke RL. 1978. A taxonomic monograph of *Equisetum* subgenus *Equisetum*. *Nova Hedwigia* 30:385–455.

Hess PN, De Moraes Russo CA. 2007. An empirical test of the midpoint rooting method. Biol J Linn Soc 92:669-674.

Høy Hansen M, Steensboe Lang C, Abildgaard N, Nyvold CG. 2022. Comparative evaluation of the heterozygous variant standard deviation as a quality measure for next-generation sequencing. J Biomed Inform 135:104234.

Jones DT, Taylor WR, Thornton JM. 1992. The rapid generation of mutation data matrices from protein sequences. *Comput Appl Biosci* 8:275-282.

Katoh K, Standley DM. 2013. MAFFT multiple sequence alignment software version 7: improvements in performance and usability. *Mol Biol Evol* 30:772–780.

Khal LH. 2020. Molecular taxonomy of some species of genus *Salvia* L. (Lamiaceae) in Kurdistan Region, Iraq. *J Plant Prod* 11:967-974.

Kinene T, Wainaina J, Maina S, Boykin LM. 2016. "Rooting trees, methods for," in Encyclopedia of Evolutionary Biology, ed. Kliman RM (Waltham MA: Academic Press), pp. 489–493.

Klassen GJ, Mooi RD, Locke A. 1991. Consistency indices and random data. *Syst Biol* 40:446–457.

Kluge AG, Farris JS. 1969. Quantitative phyletics and the evolution of anurans. *Syst Zool* 18:1-32.

Kück P, Wägele JW. 2016. Plesiomorphic character states cause systematic errors in molecular phylogenetic analyses: a simulation study. *Cladistics* 32:461-478.

Kumar S, Gadagkar SR 2001. Disparity index: a simple statistic to measure and test the homogeneity of substitution patterns between molecular sequences. Genetics 158:1321-1327.

Kumar S, Stecher G, Li M, Knyaz C, Tamura K. 2018. MEGA X: molecular evolutionary genetics analysis across computing platforms. Mol Biol Evol 35:1547–1549.

Li C-X, Lu SG, Barrington DS. 2008. Phylogeny of Chinese *Polystichum* (Dryopteridaceae) based on chloroplast DNA sequence data (*trnL-F* and *rps4–trnS*). *J Plant Res* 121:19-26.

Madeira F, Pearce M, Tivey ARN, Basutkar P, Lee J, Edbali O, et al. 2022. Search and sequence analysis tools services from EMBL-EBI in 2022. *Nucleic Acids Res* 50 (W1):W276–W279.

Mickevich MF, Farris JS. 1981. The implications of congruence in *Menidia*. *Syst Zool* 30:351-370.

Naim DM, Mahboob S. 2020. Molecular identification of herbal species belonging to genus *Piper* within family Piperaceae from northern Peninsular Malaysia. *J King Saud Univ Sci* 32:1417–1426.

Pryer KM, Schuettpelz E, Wolf PG, Schneider H, Smith AR, Cranfill R. 2004. Phylogeny and evolution of ferns (monilophytes) with a focus on the early leptosporangiate divergences. *Am J Bot* 91:1582-1598.

Sheffield NC, Song H, Cameron SL, Whiting MF. 2009. Nonstationary evolution and compositional heterogeneity in beetle mitochondrial phylogenomics. *Syst Biol* 58:381-394.

Schuettpelz E, Hoot SB. 2006. Inferring the root of *Isoëtes*: exploring alternatives in the absence of an acceptable outgroup. *Syst Bot* 31:258–270.

Speer WD. 2008. Phylogenetic and biogeographic relationships among North American and Hawaiian *Pteridium aquilinum* (L.) Kuhn (Dennstaedtiaceae) based on chloroplast *rps4* and *rps4–trnS* intergenic spacer sequences. *Am Fern J* 98:179–193.

Speer WD. 2024. Examination of the highly variable P8 region (trnL-UAA intron) in the genus *Equisetum*. *J Utah Acad Sci Arts Letts* 100:117-142.

Stavrinides J, Guttman DS. 2004. Mosaic evolution of the severe acute respiratory syndrome coronavirus. *J Virol* 78:76-82.

Swofford DL, Olsen GJ, Waddell PJ, Hillis DM. 1996. Phylogenetic inference. In: Hillis DM, Moritz D, Mable BK (eds.). *Molecular Systematics*. Sinauer Associates; Sunderland, MA, pp. 407–514.

Swofford DL. 2002. PAUP*: phylogenetic analyses using parsimony (*and other methods), version 4.0b10. Sinauer Associates: Sunderland.

Tamura K. 1992. Estimation of the number of nucleotide substitutions when there are strong transition-transversion and G+C-content biases. *Mol Biol Evol* 9:678-687.

Tamura K, Nei M, Kumar S. 2004. Prospects for inferring very large phylogenies by using the neighbor-joining method. *Proc Natl Acad Sci USA* 101:11030-11035.

Tamura K, Stecher G, Kumar S. 2021. MEGA11: molecular evolutionary genetics analysis version 11. *Mol Biol Evol* 38:3022-3027.

Tarrío R, Rodríguez-Trelles F, Ayala FJ. 2000. Tree rooting with outgroups when they differ in their nucleotide composition from the ingroup: the *Drosophila saltans* and *willistoni* groups, a case study. *Mol Phylogenet Evol* 16:344-349.

Thomson JA, Chikuni AC, McMaster CS. 2005. The taxonomic status and relationships of bracken ferns (*Pteridium*: Dennstaedtiaceae) from sub-Saharan Africa. *Bot J Linn Soc* 148:311–321.

Wade T, Rangel LT, Kundu S, Fournier GP, Bansal MS. 2020. Assessing the accuracy of phylogenetic rooting methods on prokaryotic gene families. *PLoS One* 15:e0232950.

Wang J, Raskin L, Samuels DC, Shyr Y, Guo Y. 2015. Genome measures used for quality control are dependent on gene function and ancestry. *Bioinformatics* 31:318-323.

Wang W, Yang Y, Mao X, Zhao R, Dou P, Zhang G. 2015. The phylogenetic affinities of *Pellaea connectens*, a rare endemic Chinese fern. *Phytotaxa* 220:30–42.

Wägele JW. 1996. Identification of apomorphies and the role of groundpatterns in molecular systematics. J Zool Syst Evol Res 34:31-39.

Wägele JW, Mayer C. 2007. Visualizing differences in phylogenetic information content of alignments and distinction of three classes of long-branch effects. *BMC Evol Biol* 7:147.

Wolf YI, Kazlauskas D, Iranzo J, Lucía-Sanz A, Kuhn JH, Krupovic M, Dolja VV, Koonin EV. 2018. Origins and evolution of the global RNA virome. *mBio* 9:e02329-18.

Yang Z, Yoder A. 1999. Estimation of the transition/transversion rate bias and species sampling. J Mol Evol 48:274-283.

Zhong M, Hansen B, Nesnidal M, Golombek A, Halanych KM, Struck TH. 2011. Detecting the symplesiomorphy trap: a multigene phylogenetic analysis of terebelliform annelids. *BMC Evol Biol* 11:369.

Zhong QY, Fu XG, Zhang TT, Zhou T, Yue M, Liu JN, Li ZH. 2021. Phylogeny and evolution of chloroplast tRNAs in Adoxaceae. *Ecol Evol* 11:1294-1309.

Appendix 1: Nucleotide data

Equisetum sequences used in this study are listed by subgenus and then by specimen (and GenBank accession number). Sequences marked with an asterisk (*) were generated by the author. All other sequences were downloaded from GenBank. For further information, please consult the sequence date and description recorded in GenBank.

subg. Equisetum

Eq_arvense01 (MH750112), Eq_arvense02 (MH750108), Eq_arvense03 (JN968380), Eq_arvense04 (AJ583677), Eq_arvense05 (NC_014699), Eq_arvense06 (DQ779227)*, Eq_arvense07 (PP952569)*, Eq_diffusum01 (MH750118), Eq_diffusum02 (AJ583679), Eq_fluviatile01 (MH750119), Eq_fluviatile02 (AJ583680), Eq_fluviatile03 (MH750120), Eq_fluviatile04 (DQ463116), Eq_palustre01 (NC_088053), Eq_palustre02 (MH750129), Eq_palustre03 (MH750128), Eq_pratense01 (NC_088039), Eq_pratense02 (AJ583686), Eq_sylvaticum01 (AJ583689), Eq_sylvaticum02 (PP952571)*, Eq_telmateia01(MH750136), Eq_telmateia02 (AJ583690), Eq_telmateia03 (PP952570)*; *hybrids*: Eq_arvense × Eq_telmateia (MH750114), Eq_×_fontqueri (MH750149), Eq_×_litorale01 (MH750151), Eq_×_litorale02 (MH750150)

subg. *Hippochaete*

Eq_giganteum (AJ583681), Eq_hyemale01 (NC_020146), Eq_hyemale02 (MH750123), Eq_hyemale03 (AJ583682), Eq_hyemale04 (DQ779224)*, Eq_hyemale05 (PP952564)*, Eq_laevigatum01 (AJ583683), Eq_laevigatum02 (MH750125), Eq_laevigatum03 (DQ779225)*, Eq_myriochaetum01 (AJ583684), Eq_myriochaetum02 (MH750127), Eq_myriochaetum03 (PP952572)*, Eq_praealtum (MH750122), Eq_ramosissimum01 (MH750131), Eq_ramosissimum02 (MH750133), Eq_ramosissimum03 (NC_062377), Eq_ramosissimum04 (AJ583687), Eq_ramosissimum05 (MW074919), Eq_scirpoides01 (MH750135), Eq_scirpoides02 (MH750134), Eq_scirpoides03 (MH750124), Eq_scirpoides04 (AJ583688), Eq_variegatum01 (MH750146), Eq_variegatum02 (MH750145), Eq_variegatum03 (MH750144), Eq_variegatum04 (MH750143), Eq_variegatum05 (AJ583691), Eq_variegatum06 (MH750148), Eq_variegatum07 (MH750147), Eq_variegatum08 (MH750142), Eq_variegatum09 (MH750141), Eq_variegatum10 (PP952574)*, Eq_variegatum11 (PP952565)*, Eq_variegatum12 (PP952568)*, Eq_variegatum13 (PP952566)*, Eq_variegatum14 (PP952573)*, Eq_xylochaetum (NC_065985); *hybrids*: Eq_×_ferrissii (PP952567)*, Eq_×_schaffneri (MH750153)

subg. *Paramochaete*

Eq_bogotense01 (MH750117), Eq_bogotense02 (AJ583678), Eq_bogotense03 (MH750115), Eq_bogotense04 (DQ779223)*

Appendix 2: Protein data

Equisetum sequences used in this study are listed by subgenus and then by specimen (and Genbank or UniProtKB/Swiss-Prot accession number). All sequences were downloaded from the GenBank protein database. For further information, please consult the sequence date and description recorded in GenBank.

subg. Equisetum

Eq_arvense1 (ABG77465), Eq_arvense2 (YP_004021783), Eq_diffusum (YP_011094427), Eq_fluviatile (AYO86729), Eq_palustre1 (YP_011095487), Eq_palustre2 (AYO86737), Eq_pratense (YP_011094511), Eq_sylvaticum (Q6H9K4), Eq_telmateia1 (AYO86745), Eq_telmateia2 (AYO86748), Eq_telmateia3 (AYO86749); *hybrid:* Eq_×_fontqueri (AYO86758)

subg. *Hippochaete*

Eq_giganteum (AYO86730), Eq_giganteum1 (CAE47535), Eq_hyemale1 (YP_007374717), Eq_hyemale2 (Q6H9L1), Eq_laevigatum (Q6H9L0), Eq_myriochaetum (CAE47538), Eq_praealtum (AYO86731), Eq_ramosissimum1 (YP_010335566), Eq_ramosissimum2 (CAE47541), Eq_scirpoides (Q6H9K5), Eq_variegatum1 (Q6H9K2), Eq_variegatum2 (AYO86757), Eq_variegatum3 (AYO86756), Eq_xylochaetum (YP_010466398); *hybrids*: Eq_×_schaffneri1 (AYO86763), Eq_×_schaffneri2 (AYO86761)

subg. *Paramochaete*

Eq_bogotense1 (Q6H9L5), Eq_bogotense2 (AYO86724), Eq_bogotense3 (AAL26204)

Is Personal Compulsive Social Media Use Affecting the Happiness of Employees?

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Abstract

The rapid growth of social media and its 5 billion users underscores its significance for businesses. However, individuals may develop compulsive use behaviors when engaging with social media platforms. This study delves into the impact of craving and withdrawal on compulsive social media use and overall happiness. Understanding the interplay between craving, withdrawal, and compulsive social media use is crucial for promoting well-being and happiness in the digital age as employee happiness affects business related outcomes.

Introduction

The social media app market is valued around $49 billion and is expected to grow at a rate of 26% from 2023 to 2030 (Wong, 2023). It is clear that businesses benefit from social media. However, individuals may develop compulsive use behaviors when they engage with social

media (Clements, 2021). Compulsive social media use refers to the excessive and uncontrollable use of online social networking platforms, such as Facebook, Instagram, Twitter, and TikTok. Popular press articles have warned that compulsive social media use can interfere with one's daily life. It can affect a person's sleep, work, personal happiness, and relationships. It also may cause psychological distress, such as mood disorders, anxiety, depression, loneliness, and low self-esteem.

Technology, especially social media and smartphones, triggers the release of dopamine in our brains. Dopamine is associated with pleasure and reward. However, excessive exposure to technology can lead to dependency, where we constantly seek that dopamine hit. This dependency can disrupt our natural mood patterns and affect our overall happiness. Furthermore, spending excessive time online can lead to social isolation. Although technology connects us virtually, it may reduce face-to-face interactions. Loneliness and lack of meaningful connections can negatively impact our happiness. Frequent interruptions from notifications, emails, and social media can hinder our ability to focus. This constant distraction affects our productivity and can lead to feelings of frustration and stress, ultimately impacting our happiness. Social media platforms often present idealized versions of people's lives. Constant exposure to curated content can lead to social comparison and feelings of inadequacy. Envy and self-criticism can erode our happiness.

Research shows that 77% of internet users have a social media profile (Auxier and Anderson, 2021), and nearly 4.9 billion people use social media across the word (Wong, 2023). Users on average spend 145 minutes every day on social media, but estimates show that 20% of adolescents may use social media for at least five hours every day (Zendle and Bowden-Jones, 2019). According to Facebook's own internal research, 39% of social media users report that they are addicted, with 67% of adolescents reporting they feel worse about their own lives as a result of their social media use (Wong, 2023).

Understanding the factors driving compulsive social media use and its associated negative effects have yet to be thoroughly identified. As such, this research seeks to understand the phenomena driving compulsive social media use. In addition, this research looks at the effect of compulsive social media use on relationship satisfaction and general happiness. This is important for business because lower levels of happiness are associated with lower employee productivity (Oswald et al., 2015) and lower overall performance (Bellet et al., 2024), burnout (Santhanam and Srinivas, 2020), and turnover intentions (Thompson and Bruk-Lee, 2021).

Theoretical Development

Figure 1 represents the theoretical and conceptual model used for this study.

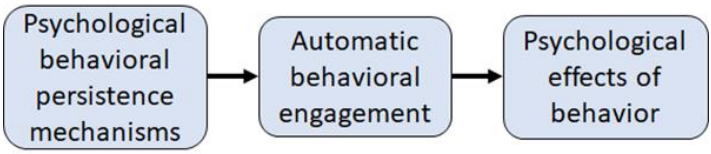

Figure 1: Conceptual model.

According to the work of Simon (1950), once a behavior has started, there are psychological mechanisms internal to an individual that cause a behavior to persist. These persistence mechanisms begin to drive behavior automatically bypassing intention resulting in automatic behavioral engagement. Resulting from this automaticity are the psychological effects from the behavior, which manifest internal to the individual.

The research model for this study is based on this theoretical model examining the psychological effects of automatically engaged behavior. Two different mechanisms of behavioral persistence have been identified for the research model. First are the psychological cravings a person experiences associated with their use of social media. These cravings act as mechanisms of persistence with the behavior. Second are the psychological withdrawals a person experiences when they stop using social media. These withdrawals act internal to the individual and continue until the behavior persists and resumes.

The automatic behavioral engagement of interest in this study is the compulsive use of social media. Compulsive social media use represents a type of behavior that has moved beyond intentionality. It is a behavior that is automatically and compulsively enacted by the person using social media. Driven by the mechanisms of persistence, compulsive social media use happens without intention.

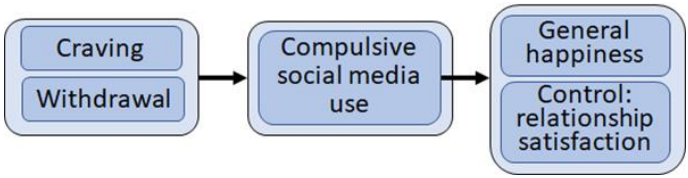

Figure 2: Research model.

The psychological effect of interest in this research model is a person's general happiness. The research model examines how a person's perception of happiness is influenced by their compulsive use of social media (Figure 2). In general, our behaviors affect the way we perceive ourselves and the world around us. The more we engage in certain behaviors, the more we are affected emotionally. Thus, this model primarily examines subjective happiness. A control variable of relationship satisfaction has been identified as an important predictor of general happiness. A full list of constructs and their definitions is included in Table 1.

Table 1: Constructs and definitions

Construct	Definition	Informing Source
General happiness	Subjective enjoyment of an individual's holistic life	Jalloh, 2014
Compulsive social media use	Spontaneous interaction with social media that is unintentional, uncontrollable, effortless and efficient	Clements & Boyle, 2018
Social media craving	An intense desire or urge to obtain an appetitive target (social media)	Clements, 2021
Social media withdrawal	The negative emotions and sensations that arise if a person cannot use a particular technology	Clements, 2021
Relationship satisfaction	The subjective evaluation of one's relationships	Hendrick, 1988

Literature Review

Compulsive Social Media Use

Excessive technology use behavior has been studied as information addiction (Pratt and Palloff, 1999), mobile email addiction (Turel and Serenko, 2010), problematic internet use (Davis et al., 2002), computer addiction (Charlton and Danforth, 2010), internet addiction (Yellowlees & Marks, 2007), and compulsive technology use (Clements and Boyle, 2018). Compulsive social media use is herein defined as "spontaneous interaction with social media that is unintentional, uncontrollable, effortless and efficient" (Clements, 2021).

Compulsive social media use has been associated with a variety of negative outcomes. Hormes et al. (2014) explored the prevalence and severity of social media addiction among college students. They found that 10% of the participants met the criteria for disordered social media

use and that social media addiction was associated with higher levels of depression and anxiety and poorer academic performance. Research has also identified several risk factors for developing compulsive social media behavior, such as personality traits, social influences, and environmental cues (Kuss and Griffiths, 2017).

Research has also shown that compulsive social media use is linked to a fear of missing out and obsessive-compulsive disorder (Fontes-Perryman & Spina, 2022). Individuals experiencing high levels of compulsive social media use seem to have emotion regulation deficits (Hormes et al., 2014). This compulsive behavior has also shown to be linked with low self-esteem and self-awareness (Aladwani and Almarzouq, 2016).

Social Media Craving

An individual's craving is driven by the search for rewards, excitement, and social connection. Research on social media craving has looked at the neural mechanisms involved in the process. Lembke (2021) examined the role of dopamine, a neurotransmitter involved in reward and motivation, in social media craving. This research showed that social media use follows a pattern of reward learning and that abstaining from social media for a period of time can help reduce the craving and restore the balance of dopamine in the brain.

Other research has actively mapped brain activity as technology cravings were induced. Niu et al. (2016) measured the brain activity of internet users while they were exposed to stimulation. They found that certain cues can induce the craving of internet users and that internet addicts' cravings were more intense. They also found that internet addicts had higher levels of excitement and lower levels of inhibition when exposed to a stimulus.

Other research has looked at social isolation and cravings. Tomova et al. (2020) investigated the effects of social isolation on craving. They found that when socially isolated subjects saw photos of people enjoying social interactions, the craving signal in their brain was similar to the signal produced when they saw pictures of food after fasting. This may suggest that social media craving is a response to a hunger for social contact.

A study by Turel et al. (2018) examined the neural correlates of social media craving using functional magnetic resonance imaging (fMRI). They found that social media craving activated brain regions involved in reward processing, emotion regulation, and self-control, and that these activations were influenced by personality traits, such as neuroticism and conscientiousness.

H1: Social media craving will be positively associated with compulsive social media use.

Social Media Withdrawal

Withdrawal refers to myriad adverse symptoms that occur when a person can no longer access an object of addiction. It is the combination of mental and physical effects that manifest when use has stopped. Generally, this is studied with chemical addiction; however, a person may experience withdrawal from technology. Withdrawal from technology refers to the negative emotions and sensations that arise if a person cannot use a particular technology (Clements, 2021).

The core of this type of research comes from the work on problematic online gaming (Kaptsis et al., 2016). This research demonstrated a phenomenon characterized by aversive or unpleasant physical or psychological states that happen when a person stops gaming online. This withdrawal from technology is similar to withdrawal in dependence syndromes as cessation produces mounting psychological and physical tension until the behavior can be completed again. This process is both affected behaviorally and chemically as compulsive behaviors can trigger dopamine release. Excess dopamine exposure in the brain affects the amygdala, which can boost negative emotions such as fear, anxiety and stress when the compulsive behavior ends, leaving addicts seeking the behavior again simply to escape the pain of withdrawal (Zastrow, 2017).

Research in this area has also elicited social media withdrawal effects by taking away the mobile devices of social media users. This work showed that when a person was primarily using a mobile device for social media high levels of withdrawal and distress were seen when the device was taken away (Truzoli et al., 2023).

Part of the distress and anxiety felt when a person stops using social media may stem from a fear of missing out. This can include missing out on popularity, missing out on social group interactions; missing out on information; and missing out on the chance to create or prevent negative comments (Ali et al., 2023). Increased withdrawal symptoms are felt until a person compulsively gives in and uses social media in part to alleviate the symptoms. Thus, social media withdrawal should lead to compulsive social media use.

H2: Social media withdrawal will be positively associated with compulsive social media use.

General Happiness

Happiness generally refers to the state of being happy, feeling contentment, pleasure, satisfaction, and cheerfulness. Subjective happiness, also known as general happiness, has been thoroughly studied in the field of positive psychology (Lyubomirsky and Lepper, 1999). Happiness in this research has been defined either as a notion of how a person feels about their life in general or as an emotional or affective state that a person experiences (Helm, 2000).

Research has identified a variety of factors that contribute to or detract from general happiness. Research has examined school-related factors such as school success and learning engagement that contribute to general happiness (Kaisa et al., 2021). Other factors such as stress, guilt, and social support have also been studied as contributors to happiness (Findler et al., 2016).

Brands using social media to engage customers understand the need to have happy customers. Research done during the global pandemic on luxury brands using social media found that brands can affect an individual's happiness in a positive way (Castillo et al., 2022). Similar research has looked at the effect image-based social media has on loneliness and found that platforms like Instagram and Snapchat can ameliorate loneliness (Pittman and Reich, 2016).

Businesses care whether their employees are happy. Low levels of employee happiness have been linked to poor work productivity. Conversely, it has been found that happiness can lead to a 12% productivity increase (Oswald et al., 2015). Research has identified that happy employees seem to enjoy higher performance at work (Bellet et al., 2024). Further research has identified that employee happiness significantly mediates the link between job demands and organizational outcomes such as intent to leave one's job (Thompson and Bruk-Lee, 2021). Thus, it is best for organizations to pay attention to the factors that may affect employee happiness.

One factor that may negatively affect happiness is social media. It is generally acknowledged that social media use leads to unhappiness. Happiness in U.S. adolescents, which increased between 1991 and 2011, suddenly declined after 2012, just as social media use among the same cohort was rising (Twenge, 2019). The decline has largely been blamed on social media. Similar research—using adults to examine social media use—has shown that social media addiction reduces general happiness and life satisfaction (Çiftci et al., 2023). Thus, it is hypothesized that compulsive social media use will contribute to unhappiness.

H3: Compulsive social media use will be negatively associated with general happiness.

Relationship Satisfaction

Researchers have found that nurturing deep relationships with family, friends, and social circles can significantly impact one's happiness and overall well-being (Sloan, 2017). One of the longest studies on happiness, the Harvard "Study of Adult Development" has established that one of the most important drivers of happiness is deep relationships with other people (Mitchell, 2004).

Research has used machine learning to understand relationship satisfaction in detail and to directly quantify and compare the predictive drivers of satisfaction of romantic couples. This research found that the factors most strongly associated with relationship satisfaction were emotional stability, agreeableness, openness, and conscientiousness (Joel et al., 2020).

People who have close relationships are more satisfied with their lives and are less likely to suffer from depression (Choi et al., 2020) and are more likely to be happy. As relationship satisfaction has repeatedly been shown to contribute to general happiness, a control variable for this construct has been included in the model.

A full list of the hypotheses is included in Table 2.

Table 2: Hypotheses

Number	Hypothesis statement
H1	Social media craving will be positively associated with compulsive social media use
H2	Social media withdrawal will be positively associated with compulsive social media use
H3	Compulsive social media use will be negatively associated with general happiness

Methodology

This study uses survey research design for 3 key reasons. First, a survey design provides a way to tap into the perceptual variables of interest. The constructs are thereby quantified so that comparisons can be made and thereby inferences can be drawn about the relationships between the variables in the study and those in the population. Previous research on psychological constructs has used survey items to assess behaviors that are not easily observable.

Second, a survey design provides the advantage of exploring attributes believed to be found in a large population from a subset of individuals (Fowler, 2002). The main purpose of a survey is to generalize from a sample to a population and thereby inferences can be made about

some behavior (Babbie, 1990). Therefore, this study will be able to sample a subset of the population to learn more about the drivers and outcomes of compulsive use of social media in the greater population.

Third, a survey design allows for standardized measurement. Standard measurement that is consistent across all respondents ensures that comparable information is obtained. Meaningful statistics are desired to examine the extent to which variability in withdrawal and craving account for variability in compulsive use. Likewise, the extent to which variability in compulsive social media use accounts for the variability in general happiness. Without such standardized measurement, meaningful statistics cannot be produced (Fowler, 2002), and any relatedness present between the variables of interest in a given individual would not be comparable with those of another individual.

Previously validated measures were adapted for the survey instrument measuring social media craving (Clements, 2021). Items were scored using a 7-point Likert-type scale ranging from strongly agree (1) to strongly disagree (7). Previously validated measures were used to measure social media withdrawal (Clements, 2021). A total of four items were used in the survey instrument. Items were scored using a 7-point Likert-type scale ranging from strongly agree (1) to strongly disagree (7). Previously validated scales were used to measure compulsive technology use (Clements and Boyle, 2018). Items were scored using a 7-point Likert-type scale ranging from strongly agree (1) to strongly disagree (7). Previously validated scales designed to measure subjective happiness were used in this study (Lyubomirsky, & Lepper, 1999). Each item is completed by choosing on a scale from 1 to 7 different options that finish a given sentence fragment. The options are different for each of the four questions that tap into various aspects of happiness.

Hypothesis Testing

Data collection was done via a web-based survey. Participants were from a United States–based university. Participants were invited through email to take part in the study. A total of 211 college students completed the survey.

A partial least squares–structural equation modeling (PLS–SEM) approach was utilized to test the measurement and structural model. The primary objective in using this approach is maximizing the total explained variance in the dependent variables while evaluating the data quality as determined by the measurement model characteristics.

Before testing the structural model, I assessed the construct dimensionality of the measures and the factorial validity of the latent

constructs. This was done in two phases. The first phase consisted of a principal components analysis (PCA) using SPSS to rigorously analyze construct dimensionality as it cannot be measured directly with PLS but is assumed to be there a priori (Gefen, 2003; Gerbing and Anderson, 1988). The second phase consisted of using Smart PLS to assess two elements of factorial validity—convergent validity and discriminant validity—as suggested by Gefen and Straub (2005). These two elements are critical components of construct validity (Straub et al., 2004).

Next, I tested the measurement model with PLS to assess factorial validity by conducting a confirmatory factor analysis in which the pattern of loadings of the measurement items on the latent constructs were specified in the model. Results of the confirmatory factor analysis showed that all measurement items loaded with significant t-values on the latent constructs as an indication of convergent validity (Gefen and Straub, 2005). To assess the discriminant validity of the measurement model, I examined the correlations of the latent variable scores with the measurement items. This showed that all items loaded highly on their specified factor and not highly on other factors.

To further assess discriminant validity, I conducted an average variance extracted (AVE) analysis. This test determines discriminant validity by examining whether the square root of the AVE for each latent construct is larger than any correlation among any pair of latent constructs (Fornell and Larcker, 1981). Results indicated that the AVEs were well above the 0.50 threshold and that the square roots of the AVEs were consistently larger than any other correlation (Table 3). Results of this type provide further evidence of discriminant validity (Chin, 1998).

Table 3. Construct reliability/validity

Construct	Cronbach's Alpha	Rho_A	Rho_C	AVE
Compulsive	0.90	0.92	0.93	0.77
Craving	0.91	0.92	0.94	0.80
Happiness	0.88	0.95	0.92	0.74
Withdrawal	0.89	0.89	0.93	0.82

After concluding the measurement model was sound, I next assessed the structural model in SmartPLS (Ringle et al., 2005). The first step in assessing the structural model is done by calculating the R2 values of the endogenous latent variables, and then examining path scores to determine the strength of the relationship.

Compulsive use of social media had an R2 value of 0.60. Happiness has an R2 value of 0.10. Next, I examined all the individual path coefficients of the structural model. These values can be interpreted as

standardized beta coefficients of OLS regressions. The path from craving to compulsive use had a score of 0.39. The path from withdrawal to compulsive use had a score of 0.45. The path from compulsive use to happiness had a score of -0.08 (Figure 3).

Figure 3: Results

Discussion

Hypothesis 1 stated that social media craving would be positively associated with compulsive social media use. The results from the analysis are in support of this hypothesis. It appears that people that experience increased cravings for social media are more compulsively using it. Higher levels of craving are indeed associated with higher levels of compulsive use.

Hypothesis 2 stated that social media withdrawal would be positively associated with compulsive social media use. The results from the analysis are in support of this hypothesis. It appears that people experiencing social media withdrawal are more prone to compulsively using it. Higher levels of withdrawal are indeed associated with higher levels of compulsive use.

Hypothesis 3 stated that compulsive social media use would be negatively associated with general happiness. Although the results of the analysis are in support of the hypothesis, the effect—though statistically significant—was rather small. Whether this was an artifact from the survey instrument or whether individuals over/under report is hard to say. However, it seems that higher levels of compulsive social media use are associated with lower levels of subjective happiness.

Understanding the phenomenon of compulsive social media use has significant theoretical implications. From a research perspective, this bridges a gap in the call for studies with a design science orientation (Hevner et al., 2004). Elements of technology design play a pivotal role in driving user behaviors. By delving into the technology features that facilitate highly engaging interactions, we can better study and design voluntary, high-use technologies. Existing information systems (IS) usage models and theories struggle to explain technology use in voluntary contexts. This study highlights an essential assumption often

overlooked in IS literature on continued information technology (IT) use: the technology itself may be a critical trigger for automatic IT behaviors (de Guinea and Markus, 2009). Further study of the precise types of technology that are used outside the workplace that may impact behaviors inside the workplace is warranted.

Another significant contribution lies in the further development of the concept of 'compulsive use' as a novel IS-dependent variable. Although IS research has explored continued use beyond initial adoption, more attention needs to be given to IT use outside organizational mandates. Much post-adoption technology use falls into the realm of personal, voluntary usage. Understanding how individuals engage with technology in this context remains an open question. Moreover, considering craving and withdrawal in this context holds vital implications, because behavior often stems from nonrational and automatic processes.

Future research should delve into how craving impacts system use and its potential negative effects on personal and work-related behaviors. Additionally, exploring technology withdrawal could shed light on its impact on individuals and organizations. Future work should also continue to examine the negative effects technology can have on personal happiness. Further study into the detailed aspects affecting general happiness is also warranted. This is especially true given the relatively weak R2 of the present study.

Businesses want happy employees. Happy employees tend to be more efficient, creative, and engaged in their work. Happy employees are more likely to be satisfied with their jobs. Happy employees are more likely to feel a stronger connection to their organization and be more productive. Future research should more closely study the link between compulsive social media use and happiness as it directly relates to organizational outcomes. It is likely organizations could benefit from limiting and controlling access to social media during work time. A limitation of this study is that other organizational factors that could contribute to happiness were not included. This includes things such as work–life balance, job autonomy and control, fair compensation and benefits, and a supportive environment with opportunities for growth and development.

Social media can have detrimental effects on our well-being and happiness. Although technology offers convenience and connection, it is essential to use it intentionally and mindfully. Balancing our digital interactions with real-world experiences and self-care is crucial for maintaining happiness in the digital age.

REFERENCES

Aladwani, A.M., & Almarzouq, M. (2016). Understanding compulsive social media use: The premise of complementing self-conceptions mismatch with technology. Computers in Human Behavior, 60, 575-581.

Ali, R., McAlaney, J., & Alutaybi, A. (2020, January 29). Redesigning social media platforms to reduce 'FoMO.' The Conversation. https://theconversation.com/redesigning-social-media-platforms-to-reduce-fomo-124228. Accessed September 21, 2023.

Auxier, B., & Anderson, M. (2021) Social Media Use in 2021. Pew Research Center, Washington, DC.

Babbie, E.R. (1990). Survey Research Methods. Wadsworth Publishing Company, Belmont, CA.

Bellet, C.S., De Neve, J.E., & Ward, G. (2024). Does employee happiness have an impact on productivity? Management Science, 70(3), 1656-1679.

Castillo-Abdul, B., Pérez-Escoda, A., & Civila, S. (2022). Social media fostering happiness management: Three luxury brands case study on Instagram. Corporate Governance: The International Journal of Business in Society, 22(3), 491-505.

Çiftci, N., & Yıldız, M. (2023). The relationship between social media addiction, happiness, and life satisfaction in adults: analysis with machine learning approach. International Journal of Mental Health and Addiction, 21, 3500-3516.

Choi, K.W., Stein, M B., Nishimi, K.M., et al. (2020). An exposure-wide and Mendelian randomization approach to identifying modifiable factors for the prevention of depression. American Journal of Psychiatry, 177(10), 944-954.

Clements, J.A. (2021). Technology craving and withdrawal: exploring compulsive mobile app use. In: Salvendy, G., Wei, J. (eds) Design, Operation and Evaluation of Mobile Communications: Second International Conference, MOBILE 2021, Held as Part of the 23rd HCI International Conference, HCII 2021, Virtual Event, July 24–29, 2021, Proceedings. Pp. 195-206. Springer-Verlag, Berlin.

Clements, J.A., & Boyle, R.J. (2018). Compulsive technology use: Compulsive use of mobile applications, Computers in Human Behavior 87, 34-48.

Charlton, J.P., & Danforth, I.D.W. (2010). Validating the distinction between computer addiction and engagement: online game playing and personality. Behaviour & Information Technology 29, 601-613.

Davis, R.A., G.L. Flett, & Besser, A. (2002). Validation of a new scale for measuring problematic internet use: implications for pre-employment screening. Cyberpsychology and Behavior 5, 331-345.

Findler, L., Jacoby, A.K., & Gabis, L. (2016). Subjective happiness among mothers of children with disabilities: The role of stress, attachment, guilt and social support. Research in Developmental Disabilities, 55, 44-54.

Fontes-Perryman, E., & Spina, R. (2022). Fear of missing out and compulsive social media use as mediators between OCD symptoms and social media fatigue. Psychology of Popular Media, 11(2), 173-182.

Fornell, C., & Larcker, D.F. (1981). Evaluating structural equation models with unobservable variables and measurement error. Journal of Marketing Research, 18, 39-50.

Fowler, F.J. (2002). Survey Research Methods, Sage, Thousand Oaks, California.

Helm, D.T. (2000). The measurement of happiness. American Journal on Mental Retardation, 105(5), 326-335.

Gefen, D. (2003). Assessing unidimensionality through LISREL: an explanation and an example. Communications of the Association for Information Systems 12, 2.

Gefen, D., & Straub, D. (2005). A practical guide to factorial validity using PLS-Graph: Tutorial and annotated example. Communications of the Association for Information Systems 16, 109.

Gerbing, D.W., & Anderson, J.C. (1998). An updated paradigm for scale development incorporating unidimensionality and its assessment. Journal of Marketing Research, 25(2), 186-192.

Hendrick, S.S. (1988). A generic measure of relationship satisfaction. Journal of Marriage and the Family, 50, 93-98.

Hirschfeld, R.M, Williams, J.B, Spitzer, R.L, et al. (2000). Development and validation of a screening instrument for bipolar spectrum disorder: the Mood Disorder Questionnaire. American Journal of Psychiatry. 157(11), 1873-1875.

Hormes, J.M., Kearns, B., & Timko, C.A. (2014). Craving Facebook? Behavioral addiction to online social networking and its association with emotion regulation deficits. Addiction, 109(12), 2079-2088.

Jalloh, A. (2014). Measuring happiness: Examining definitions and instruments. Illuminare, 12. https://scholarworks.iu.edu/journals/index.php/illuminare/article/view/3635

Joel, S., Eastwick, P.W., Allison, C.J., et al. (2020). Machine learning uncovers the most robust self-report predictors of relationship quality across 43 longitudinal couples studies. Proceedings of the National Academy of Sciences USA, 117(32), 19061-19071.

Vuorinen, K., Hietajärvi, L., & Uusitalo, L. (2021). Students' usage of strengths and general happiness are connected via school-related factors. Scandinavian Journal of Educational Research, 65(5), 851-863.

Kaptsis, D., King, D.L., Delfabbro, P.H., & Gradisar, M. (2016). Withdrawal symptoms in internet gaming disorder: A systematic review. Clinical Psychology Review, 43, 58-66.

Kuss, D.J., & Griffiths, M.D. (2017). Social networking sites and addiction: Ten lessons learned. International Journal of Environmental Research and Public Health, 14(3), 311.

Lembke, A. (2021). Dopamine Nation: Finding Balance in the Age of Indulgence. Penguin, New York.

Lyubomirsky, S., & Lepper, H.S. (1999). A measure of subjective happiness: Preliminary reliability and construct validation. Social Indicators Research, 46, 137-155.

Mitchell, J.F. (2004). Aging well: surprising guideposts to a happier life from the landmark Harvard study of adult development. American Journal of Psychiatry, 161(1), 178-179.

Niu, G.F., Sun, X.J., Subrahmanyam, K., et al. (2016). Cue-induced craving for Internet among Internet addicts. Addictive Behaviors, 62, 1-5.

Oswald, A.J., Proto, E., & Sgroi, D. (2015). Happiness and productivity. Journal of Labor Economics, 33(4), 789-822.

Pittman, M., & Reich, B. (2016). Social media and loneliness: Why an Instagram picture may be worth more than a thousand Twitter words. Computers in Human Behavior, 62, 155-167.

Pratt, K., & Palloff, R.M. (1999). Building Learning Communities in Cyberspace: Effective Strategies for the Online Classroom. Wiley, New York.

Simon, H.A. (1950). Administrative Behavior, A Study of Decision-Making Processes in Administrative Organization. Macmillan, New York.

Ringle, C.M., Wende, S., & Will, A. (2005). SmartPLS–Version 2.0. Universitat Hamburg, Hamburg.

Santhanam, N., & Srinivas, S. (2020). Modeling the impact of employee engagement and happiness on burnout and turnover intention among blue-collar workers at a manufacturing company. Benchmarking: An International Journal, 27(2), 499-516.

Sloan, M. (2017). The secret to happiness? Here's some advice from the longest-running study on happiness. Harvard Health Blog. Accessed September 22, 2003, at https://www.health.harvard.edu/blog/the-secret-to-happiness-heres-some-advice-from-the-longest-running-study-on-happiness-2017100512543.

Thompson, A., & Bruk-Lee, V. (2021). Employee happiness: why we should care. Applied Research in Quality of Life, 16(4), 1419-1437.

Tomova, L., Wang, K.L., Thompson, T., et al. (2020). Acute social isolation evokes midbrain craving responses similar to hunger. Nature Neuroscience, 23(12), 1597-1605.

Truzoli, R., Magistrati, L., Viganò, C., et al. (2023). Social media users potentially experience different withdrawal symptoms to non-social media users. International Journal of Mental Health Addiction 21, 411-417.

Turel, O., He, Q., Brevers, D., & Bechara, A. (2018). Delay discounting mediates the association between posterior insular cortex volume and social media addiction symptoms. Cognitive, Affective, & Behavioral Neuroscience, 18(4), 694-704.

Turel, O., & Serenko, A. (2010). Is mobile email addiction overlooked? Communications of the ACM, 53, 41-43.

Twenge, J.M. (2019). The sad state of happiness in the United States and the role of digital media. World Happiness Report 2019, Sustainable Development Solutions Network, New York.

Wong, B. (2023, May 18). Top social media statistics and trends of 2023. Forbes. Accessed September 20, 2023, at https://www.forbes.com/advisor/business/social-media-statistics/.

Yellowlees, P.M., & Marks, S. (2007) Problematic Internet use or Internet addiction? Computers in Human Behavior 23, 1447-1453.

Zastrow, M, (2017). News feature: Is video game addiction really an addiction? Proceedings of the National Academy of Sciences USA, 114 (17), 4268-4272.

Zendle, D., & Bowden-Jones, H. (2019) Is excessive use of social media an addiction? BMJ 365, l2171.

Revamping Organizational Hierarchy to Foster Innovation: The Case for RenDanHeYi

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Abstract

This article explores the RenDanHeYi management model as an alternative to traditional hierarchical organizational structures. RenDanHeYi seeks to break down barriers between functions and foster collaboration and innovation through four key elements: encouraging autonomy and decentralization, fostering cross-functional collaboration and communication, emphasizing continuous learning and improvement, and encouraging employee participation and feedback. It argues this model can yield benefits like crossing silos to drive innovation through diverse perspectives, incentivizing calculated risk-taking, promoting innovation through cross-training employees in different roles, and allowing for faster decision-making. Although implementing RenDanHeYi presents challenges, its philosophy of coordination over control and emphasis on flattened yet flexible structures may enable organizations to better innovate, engage employees, and adapt to changing conditions compared with rigid hierarchies. The article

contributes to management theory and practice in proposing this alternative model rooted in Eastern philosophy.

In today's rapidly evolving business landscape, the convergence of technological advancements and the exponential growth of data has fundamentally reshaped the way organizations operate (Aghion et al., 2005). These transformative forces have emerged as critical drivers of innovation, enabling companies to gain a competitive edge and thrive in an increasingly dynamic marketplace (Aghion et al., 2005). However, despite the immense potential that technology and data offer, many organizations find themselves shackled by traditional hierarchical structures that impede their ability to adapt and innovate (Aghion et al., 2005).

This article explores the concept of RenDanHeYi, a relatively new management model that seeks to break down the silos created by traditional hierarchies and foster a culture of innovation and collaboration. It examines four core elements of RenDanHeYi and discusses the benefits and challenges of implementing this model in organizations. Additionally, we will delve into the challenges posed by organizational hierarchies and explore strategies to overcome them, empowering companies to embrace change, foster a culture of innovation, and seize new opportunities in the face of evolving market conditions.

The Downsides of Top-Down Hierarchies

Throughout most of the 20th century, large hierarchical bureaucracies dominated the corporate landscape as businesses sought efficiency, consistency, and control in high-volume manufacturing (Morgan, 2006). However, this traditional top-down, command-and-control structure is poorly suited for today's world where the circumstances are more dynamic and fluid, markets evolve rapidly, and breakthrough innovations are needed on an ongoing basis.

Research has shown that hierarchical structures actually impede the free flow of ideas that is necessary for innovation to happen. When all decisions and problem-solving flow from the top down, it discourages divergent and creative thinking from those on the frontlines (Gong et al., 2012). Employees feel less psychologically safe to experiment with new approaches or share ideas that may contradict their managers' viewpoints. Power and information asymmetries concentrate control with a select few instead of leveraging the full potential of all members of the organization.

The strict demarcation of roles in hierarchies also breeds silos where groups do not collaborate effectively. In fast-paced industries like technology where new opportunities cut across functions, this works against an integrated approach to addressing customer needs (Galbraith, 2014). Bureaucratic rules and lengthy decision pathways of traditional hierarchies slow things down, losing the nimbleness required to act on emergent innovations (Heavey et al., 2014).

Essentially, the command-and-control nature of top-down structures designed many decades ago for stability no longer serve businesses needing constant reinvention. They undermine the formation of new connections and sharing of diverse perspectives that are the lifeblood of innovation. A new paradigm is clearly needed that can both tap existing expertise as well as welcome disruptive ideas from every corner of the organization.

An Overview of RenDanHeYi

To address these challenges, the concept of RenDanHeYi (proposed by Mr. Zhang Ruimin, CEO of Haier Group in 2014) has emerged as a management model that seeks to break down the silos created by traditional hierarchies and foster a culture of innovation and collaboration (Aghion et al., 2005). The terminology "RendanHeyi" provides an illustrative encapsulation of its core concept: where "Ren" stands for employees, and "Dan" symbolizes customer orders. "Heyi" means combining the user value realization with created user value. Hence, the integration of "RendanHeyi" signifies a tight nexus between employees and customer demands. The "win-win" aspect under this paradigm implies that while catering to customer requirements, employees concurrently realize their intrinsic value.

Customer orientation is crucial for understanding the needs of the consumer and enhancing marketplace performance. However, a focus solely on the salient needs of the consumer can have a detrimental effect on innovativeness when latent needs go unrecognized. Similarly, competitor orientation can have a positive effect on performance when it allows firms to generate new products according to their competitive advantages. However, it can also have a detrimental effect on innovativeness when new products result from reactive rather than proactive strategies.

Collaborative innovation networks, which involve collaboration with suppliers, customers, and other partners, have been shown to facilitate knowledge exchange and promote trust, leading to improved innovation performance (Najafi-Tavani et al., 2018). Additionally, supply chain collaboration is essential for implementing cleaner

production and achieving better environmental performance (Touboulic & Walker, 2015).

Implementing the RenDanHeYi model in organizations can be challenging. Traditional hierarchical structures and resistance to relational strategies can hinder the adoption of collaborative and innovative practices. Barriers to collaborative innovation in supply chains include the customer's safety culture, the business model, the parties' understanding of innovation, and the management of collaborative innovation. Overcoming these barriers requires a deep understanding of the forces that hinder relational strategies and the development of effective governance mechanisms (Fawcett et al., 2015; Anderson et al., 2023).

The convergence of technology and data has reshaped the business landscape, and organizations need to adapt and innovate to thrive in this dynamic environment. The RenDanHeYi model offers a solution by breaking down traditional hierarchies and fostering a culture of innovation and collaboration and organizations can overcome the challenges posed by traditional hierarchical structures and seize new opportunities in the face of evolving market conditions.

Not a Dichotomy

Although the RenDanHeYi philosophy proposes a set of organizational elements focused on collaboration, it is important to note that these principles exist on a spectrum that many traditional organizations also exhibit to varying degrees. The hierarchical structure that has dominated organizational design for decades inherently encourages some level of specialization and vertical communication. However, as environments become more complex and fast paced, there is a need to push organizations further along the spectrum towards more cooperative and integrative arrangements. RenDanHeYi provides one philosophical approach aimed at challenging the status quo hierarchical model by taking elements like autonomy, cross-functional interaction, continuous learning, and employee input to greater extents. The next section will explore four core elements of the RenDanHeYi framework, not as a prescriptive formula but as an example of rethinking traditional structure to better leverage collective intelligence across an organization. Adopting these cooperative principles can help transform rigid “silos” into open learning networks that unleash innovation.

Four Elements of RenDanHeYi

The RenDanHeYi philosophy proposes several core organizational elements that can help foster innovation through a collaborative

approach. At the heart of RenDanHeYi is the idea that no single individual or division within an organization has a monopoly on good ideas. Breaking down barriers between functions and levels is necessary to leverage the collective intelligence that exists throughout the organization.

This section will explore four elements of the RenDanHeYi philosophy that can help revamp traditional hierarchical structures into more open and cooperative arrangements: (1) encouraging autonomy and decentralization, (2) fostering collaboration and communication, (3) emphasizing continuous learning and improvement, and (4) encouraging employee participation and feedback. Adopting these elements can transform rigid "silos" into cross-pollinating networks where innovative ideas can flow freely.

Element 1: Encouraging Autonomy and Decentralization

Traditional organizational hierarchies are often characterized by a strict top-down decision-making process, where decisions are made by a select few at the top of the chain of command. However, this approach can stifle innovation and creativity, because it discourages lower-level employees from taking risks and making decisions. RenDanHeYi seeks to turn this model on its head by encouraging autonomy and decentralization.

Companies that have successfully implemented RenDanHeYi have done so by giving employees at all levels of the organization the freedom to make decisions and take risks. For example, the software company Valve is known for its flat organizational structure, where employees are encouraged to work on projects that they are passionate about, regardless of their job title or department. This approach has led to the development of innovative products and services, such as the Steam gaming platform and the HTC Vive virtual reality headset.

Element 2: Fostering Collaboration and Communication

Traditional organizational hierarchies often create silos, where departments work in isolation from one another. This can lead to a lack of communication and collaboration, which can stifle innovation. RenDanHeYi seeks to address this issue by fostering collaboration and communication across departments and levels of the organization.

Companies that have successfully implemented RenDanHeYi have done so by creating cross-functional teams that work together on projects. For example, the automaker Tesla has developed a team-based approach to product development, where engineers, designers, and other employees work together to develop new products and services. This

approach has led to innovative products such as the Model S electric car and the Powerwall home battery.

Element 3: Emphasizing Continuous Learning and Improvement

Traditional organizational hierarchies often place a high value on stability and consistency, which can discourage employees from experimenting and taking risks. RenDanHeYi seeks to address this issue by emphasizing continuous learning and improvement.

Companies that have successfully implemented RenDanHeYi have done so by creating a culture that values experimentation and learning from failure. For example, the online retailer Amazon has a culture that encourages employees to experiment and innovate, with a focus on continuous improvement. This approach has led to innovative products and services such as Amazon Prime and Alexa, the voice-controlled virtual assistant.

Element 4: Encouraging Employee Participation and Feedback

Traditional organizational hierarchies often discourage employees from providing feedback and participating in decision-making processes. RenDanHeYi seeks to address this issue by encouraging employee participation and feedback.

Companies that have successfully implemented RenDanHeYi have done so by creating mechanisms for employees to provide feedback and participate in decision-making processes. For example, the software company Atlassian has developed a system called "FedEx Day," where employees are given 24 hours to work on any project they choose, as long as it is delivered within the allotted time frame. This approach has led to innovative products and services such as Confluence, a collaboration and knowledge management tool.

Four Main Benefits of RenDanHeYi

Beyond its core structural elements, adopting principles from the RenDanHeYi philosophy can also yield significant organizational benefits that directly support increased innovation. When implemented effectively, this collaborative approach aims to break down barriers between functions and roles that traditionally stifle creative exchange. Four key benefits of integrating RenDanHeYi ideals include: (1) crossing silos to drive innovation, (2) incentivizing calculated risk-

taking, (3) promoting cross-training for broader perspectives, and (4) flattening hierarchies for speed.

Benefit 1: Crossing Silos to Drive Innovation

Traditional management hierarchies can lead functional areas like marketing, product development, engineering, and operations to operate independently in silos with limited collaboration. However, true innovation often emerges at the intersection of diverse perspectives and skills. Silos limit an organization's ability to leverage complementary expertise from across the company and spawn new ideas that did not previously occur to individuals working alone in isolated groups. For example, insights from customer service may inspire fresh product features, while manufacturing know-how could refine prototypes in valuable ways. Collaboration across silos exposes organizations to a wider range of innovative possibilities (Girotra, 2010; Tushman & O'Reilly, 1997).

In contrast, flattened, matrix structures aim to break down barriers and encourage closer cooperation between functions. For instance, automaker BMW launched cross-functional "modular families" that pool talent from engineering, manufacturing, purchasing, and other areas to focus specifically on innovation for new vehicle platforms. These integrated teams are better able to develop pioneering yet manufacturable solutions from the outset compared with fragmented silo approaches. Software giant Adobe likewise dissolved vertical business units to induce more collaborative problem-solving across its applications portfolio. Both companies found their new structures stimulated valuable new innovations that siloed groups had missed (Birkinshaw et al., 2008; Rothaermel et al., 2006).

Benefit 2: Incentivizing Calculated Risk-Taking

Beyond organizational reforms, leaders must foster an environment where employees feel motivated to take initiative and prudent risks rather than just minimize mistakes. At many companies, however, the incentives and disincentives embedded in policies, processes, and culture actually serve to discourage risk-taking behavior and maintain the status quo. For instance, bonuses tied predominantly to short-term revenue targets or key performance indicators discourage investments in uncertain long-shot projects that could yield major future benefits. Similarly, public failure or the inability to deliver impossible deadlines can damage careers despite good intentions.

To overcome this, forward-thinking firms implement programs that balance risk and reward. For example, 3M gives scientists autonomy and

funding to pursue "non-core" ideas on 15% of their time through its renowned "fictioneering" initiative. Those blue-sky projects have spawned many of the conglomerate's most profitable innovations, like Post-it Notes. Spotify offers its employees a special "Innovation Days" program providing time, resources, and mentorship to explore bolder concepts outside normal responsibilities. Such schemes help shift mindsets towards viewing failure as a chance to learn rather than a career liability, freeing individuals to energetically pursue innovation (Amabile, 1998; Govindarajan & Trimble, 2010).

Benefit 3: Cross-Training for Broader Perspectives

In traditional hierarchies, deep specialization is often favored over broader cross-training, yet diverse knowledge pools can spark new combinations. Limited perspective prevents breakthroughs that hybridize separate fields. Leaders must therefore provide avenues for employees to gain exposure to different areas of expertise within the organization.

For instance, legal and engineering employee rotations at innovator 3M have led to transformative new products merging materials science and intellectual property strategies. IDEO intentionally staffs projects with generalists rather than only domain experts to facilitate fresh connections. Cross-pollinating perspectives in this way generates novel solutions impossible for narrowly focused workers operating alone within rigid roles. Companies like Google have taken it a step farther by offering "20 percent time" for employees to explore other interests, spawning major programs from Gmail to AdSense. Cross-training orientations shift mindsets away from siloed thinking towards combinatorial innovation (Ancona et al., 2001; West et al., 2001).

Benefit 4: Flattening Hierarchies for Speed

Lengthy decision chains can stifle speedy experimentation so vital to innovation in dynamic markets. Flatter structures empower passionate champions at all levels to advance compelling ideas more swiftly.

Zappos famously dissolved middle management, budget approvals, and most policies to encourage rapid testing of customer-centric hunches. Frontline employees feel trusted to directly try out promising concepts. At Netflix, multi-discipline "squads" and "chapters" rapidly deploy new features or content based on direct consumer insights rather than defined roles or processes slowing change. In contrast, legacy media companies were often trapped innovating via inches due to top-heavy governance.

Although flatter structures forfeit certain controls, the exchange of autonomy for velocity can yield outsized returns. For instance, early agile adopters like Spotify slashed product development cycles from years to mere months by empowering self-organizing cross-functional teams. Their products leapfrogged competition anchored in precedence. In fast markets, the ability to learn from smaller, quicker bets is more valuable than micromanaging larger, lengthy gambles (Burton & Obel, 2004; O'Reilly & Tushman, 2013).

How RenDanHeYi Provides these Benefits Better than Traditional Organizational Structures

The RenDanHeYi philosophy proposes an alternative organizational model intended to foster greater collaboration, cross-fertilization of ideas, and calculated risk-taking—all of which can fuel innovation. Beyond its emphasis on new structural elements and cultural values, the RenDanHeYi approach aims to deliver several key organizational benefits that traditional hierarchical structures tend to inhibit. The RenDanHeYi model leverages its foundational principles of participative coordination, psychological safety, and distributed leadership to overcome obstacles to creativity entrenched in vertical bureaucracy.

- *Crossing Silos to Drive Innovation:* Traditional hierarchies reinforce silos through vertical specialization within rigid departments. This stifles cross-fertilization of ideas. In contrast, RenDanHeYi dissolves these borders by forming cross-functional project teams and cultivating a culture of open communication flows across the organization. When people from procurement collaboratively problem-solve with R&D, it breeds new integrative solutions unseen from within isolated silos. By breaking down barriers, RenDanHeYi unlock synergies to generate more innovative combinations of diverse perspectives.
- *Incentivizing Calculated Risk-Taking:* Hierarchies concentrate power and decision making at the top, discouraging bottom-up idea generation for fear of retribution from risk-averse senior managers. RenDanHeYi distributes leadership and pushes decision rights lower through self-organizing teams. It fosters a psychologically safe environment where intelligent risks generating learning are rewarded rather than punished. Cross-pollinating groups aid each other’s experiments, helping smarter risk-taking that conventional structures inhibit.

- *Cross-Training for Broader Perspectives:* Traditional career ladders reinforce functional silo-thinking, as people remain rooted within specialist departmental scopes. In contrast, RenDanHeYi encourages rotational job sharing and multi-skilling to dissolve such parochial views. Broader marketplace understanding emerges when supply chain experts also learn sales roles. Seeing challenges from new angles, employees synthesize more creative solutions that silo-sticking biases preclude. Over time, societal perspective evolves more conducive to disruptive innovations.
- *Flattening Hierarchies for Speed:* Bureaucracies slow decisions by centralizing approvals up multiple management layers. RenDanHeYi streamlines structures into self-steering teams where authority accompanies responsibilities. Fewer hindrances accelerate prototyping and iterative refinement of novelty. Flatter structures coupled with cross-pollination practices also speed transmission of viable ideas across an organization. Time-to-market compressions fuel competitive advantage in fast-paced industries.

So why does the RenDanHEYi model need to be implemented to obtain these benefits, rather than another organizational model? Although it is not a dichotomy and these principles and benefits exist on a spectrum that many traditional organizations also exhibit and experience to varying degrees, the RenDanHeYi model may be particularly well-suited to obtaining these benefits compared with other organizational models for the following reasons:

- *It is a philosophy of coordination over control*. At its core, RenDanHeYi is based on the philosophy that diverse perspectives should be brought together in a spirit of mutual understanding and coordinated problem-solving, rather than one viewpoint dominating through hierarchy. This collaborative mindset lays the cultural foundation for crossing silos and incentivizing contribution from all parts of the organization.
- *It emphasizes flattened yet flexible structures*. RenDanHeYi advocates structures that dissolve vertical barriers through cross-functional teams and rotational roles, while still allowing for flexible adaptation. This provides the framework for silo-crossing, cross-training opportunities, and streamlined decision-making not afforded by rigid hierarchy.
- *It champions distributed leadership*. Leadership is shared situationally based on expertise rather than centralized control. This

empowers risk-taking and ideation from within self-organizing groups more so than top-down management models.

- *It promotes psychological safety*. A key RenDanHeYi principle is creating an environment where all voices feel safe to contribute without fear of reprisal. This is conducive to calculated risk-taking and idea exchange less likely in authoritarian structures.
- *It encourages holistic problem-solving*. Recognizing that integrating diverse skills yields better solutions, RenDanHeYi is expressly aimed at breaking down barriers to these combinatorial solutions in a way favored by traditional divisions of labor.

Contribution to Management Theory and Practice

The philosophy of RenDanHeYi contributes significantly to both organizational theory and practice. On the theoretical side, it provides an alternative perspective rooted in Eastern thought that moves away from traditional Western hierarchical models. RenDanHeYi enriches cross-cultural understanding of structural design options available to managers. Its focus on flatter, cross-functional team-based structures adds an actionable structural framework to the literature. RenDanHeYi also emphasizes important human and psychological dimensions around mutual understanding, empowerment and psychological safety that are often overlooked in theories centered around structural forms alone.

Additionally, its concepts of combining diverse skills for more holistic problem-solving and distributing leadership situationally introduce more flexible and agile arrangements suited for dynamic environments compared to rigid hierarchies. Empirical evidence corroborates RenDanHeYi's propositions regarding its enabling effects on knowledge-sharing, collaboration, and innovation behavior. For practitioners, the high-level philosophical principles and tangible recommendations provide a blueprint to transition outdated vertical structures toward more synergistic and participative modes of organizing work. Its emphasis on dissolving barriers through fluid participation and leveraging collective intelligence addresses growing pressures on organizations to continuously transform and optimize innovation performance. Overall, RenDanHeYi offers a valuable complementary lens for both advancing organizational theory as well as offering practical guidance to managers in configuring work arrangements amid rising complexity.

Conclusion

RenDanHeYi is a unique and innovative management model that has the potential to revolutionize the way organizations operate. By encouraging autonomy and decentralization, fostering collaboration and communication, emphasizing continuous learning and improvement, and encouraging employee participation and feedback, companies can create an environment that is conducive to innovation and creativity.

Although implementing RenDanHeYi may require significant changes to traditional organizational structures and practices, the benefits of doing so can be substantial. Companies that adopt this model may find that they are better able to attract and retain top talent, improve employee engagement and motivation, and ultimately drive innovation and growth.

Of course, implementing RenDanHeYi is not without its challenges. It requires a willingness to experiment, take risks, and embrace change, and it may not be suitable for all organizations or industries. However, for companies that are willing to invest the time and effort required to make it work, the potential rewards can be significant.

Ultimately, the success of RenDanHeYi will depend on the ability of organizations to balance the need for structure and hierarchy with the need for autonomy and creativity. By finding the right balance between these competing forces, companies can create an environment that is both efficient and innovative and that empowers employees to do their best work. As the business landscape continues to evolve, it will be interesting to see how RenDanHeYi and other similar management models shape the future of work.

References

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and innovation: an inverted-U relationship. The Quarterly Journal of Economics, 120(2), 701-728.

Amabile, T.M. (1998). How to kill creativity. Harvard Business Review, 76(3), 76-87.

Ancona, D.G., Malone, T.W., Orlikowski, W.J., & Senge, P.M. (2001). In praise of the incomplete leader. Harvard Business Review, 79(2), 92-100.

Birkinshaw, J., Hamel, G., & Mol, M.J. (2008). Management innovation. Academy of Management Review, 33(4), 825-845.

Burton, R.M., & Obel, B. (2004). Strategic Organizational Diagnosis and Design: Developing Theory for Application. Springer, New York.

Galbraith, J. R. (2014). Designing Organizations: Strategy, Structure, and Process at the Business Unit and Enterprise Levels. Jossey-Bass, San Francisco, CA.

Girotra, K. (2010). The risk-driven business model: Four questions that will define your company. Harvard Business Review, 88(5), 130-139.

Gong, Y., Cheung, S.Y., Wang, M., & Huang, J.C. (2012). Unfolding the proactive process for creativity: Integration of the employee proactivity, information exchange, and psychological safety perspectives. Journal of Management, 38(5), 1611-1633. https://doi.org/10.1177%2F0149206310380250.

Govindarajan, V., & Trimble, C. (2010). The Other Side of Innovation: Solving the Execution Challenge. Harvard Business Review Press, Boston, MA.

Heavey, C., Ledwith, A., & Murphy, E. (2014). Introducing a new stream of radical innovation to stimulate the pharmaceutical industry. Business Horizons, 57(2), 197-205. https://doi.org/10.1016/j.bushor.2013.11.002.

Morgan, G. (2006). Images of Organization. Sage, Thousand Oaks, CA.

Najafi-Tavani, S., Najafi-Tavani, Z., Naudé, P., Oghazi, P., & Zeynaloo, E. (2018). How collaborative innovation networks affect new product performance: product innovation capability, process innovation capability, and absorptive capacity. Industrial Marketing Management, 73, 193-205.

O'Reilly, C.A., & Tushman, M.L. (2013). Organizational ambidexterity: Past, present, and future. Academy of Management Perspectives, 27(4), 324-338.

Rothaermel, F.T., Agung, S.D., & Jiang, L. (2006). University entrepreneurship: A taxonomy of the literature. Industrial and Corporate Change, 15(4), 691-791.

Touboulic, A., & Walker, H. (2015). Love me, love me not: a nuanced view on collaboration in sustainable supply chains. Journal of Purchasing and Supply Management, 21(3), 178-191.

Tushman, M.L., & O'Reilly, C.A. (1997). Winning Through Innovation: A Practical Guide to Leading Organizational Change and Renewal. Harvard Business Review Press, Boston, MA.

West, M.A., Farr, J.L., & Bunce, D. (2001). Team and organizational creativity. In M.A. West (ed.), Handbook of Work Group Psychology (pp. 311-342). Wiley-Blackwell, Hoboken, NJ.

Investigating the Efficacy of Workbook-style Learning in Enhancing Student Performance in General Chemistry Courses

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Abstract

This study investigates the effectiveness of integrating workbook-style learning (WSL) into university-level chemistry courses. Despite its more common usage in K-12 education, WSL remains underutilized in higher education. Through the development and implementation of chemistry workbooks, this study aims to assess the impact of WSL on student learning outcomes. Data collection involved administering each workbook as a pre-, in-, or post-lecture assignment, along with corresponding quizzes and surveys. Surveys underscored the perceived benefits of WSL, indicating that students would prefer that more of their courses incorporated WSL in the classroom. The findings from this study suggest that although WSL presents a valuable instructional tool, its

optimal implementation requires careful consideration and is topic dependent.

Introduction

General chemistry courses pose significant challenges for students, contributing to high failure rates nationwide. To address this difficulty, we explored the implementation of workbook-style learning (WSL), a technique more commonly associated with K-12 education, within university-level chemistry instruction. In this study, we investigated the potential underutilization or ineffectiveness of WSL in the context of higher education. If WSL is ineffective, it would justify universities not incorporating it as a teaching technique, and there should be a push to remove it from K-12. However, if it is effective, advocating for its integration in higher education becomes imperative. The purpose of this study is to identify whether WSL is beneficial to student learning, and if it is, to identify when it is most beneficial to administer. We created four workbooks, conducted studies, and performed student surveys to assist us in answering these points of inquiry.

Defining the difference between worksheets and workbooks is essential. Unlike worksheets that primarily offer problem sets with minimal guidance, workbooks are designed to systematically break down complex material into manageable topics. They provide background information on each topic, instructional guidance, and progressively challenging exercises to create profound knowledge retention. Workbooks are a type of complex advanced organizer designed to provide a stronger foundation of important principles. When properly used, they aid in fostering a deeper understanding and align with Bloom's taxonomy of learning: remember, understand, apply, analyze evaluate and create (Bloom and Krathwhol 1956). The workbooks help students apply foundational knowledge to their homework and create a longer retention of knowledge.

One of the workbooks we created was entitled the Nomenclature workbook. A portion of this workbook is provided, in Supplemental Figure 1 in the Appendix, to illustrate pedagogical design and instructional effectiveness. As can be seen, workbooks offer a brief description to characterize what an ionic compound is (Supplemental Figure 1A), including its component parts: cations and anions. Next, an organized table is provided to distinguish various types of cations and anions (Supplemental Figure 1B), followed by a flow chart to summarize and simplify the information (Supplemental Figure 1C). Sample problems are provided for the students to demonstrate how to solve

problems (Supplemental Figure 1D). Students are then assisted in solving problems by helping them identify which type of cation and anion are present in the compound, so they can appropriately name that compound (Supplemental Figure 1E). Once students have been provided sufficient opportunities for practice, they are then provided a set of problems, without the guidance, to apply what they have learned (Supplemental Figure 1F). This is done to compartmentalize nomenclature for ionic compounds from the other types of nomenclature (acid nomenclature and molecular compound nomenclature). This helps them gain mastery of this topic, prior to naming a compound without any indication of what type of substance it is. After students have had the opportunity to complete the nomenclature for ionic compounds and the other two types of nomenclature, they are expected to complete a problem set where they are required to identify the type of compound and name it (Supplemental Figure 1G).

Methods

Sampling Protocol

Prior to the commencement of this study, the research design was approved by the Institutional Review Board at Southern Utah University. Participants were recruited via their general chemistry courses—either Chemistry 1110 (Elementary Chemistry) or Chemistry 1210 (Principles of Chemistry 1)—at Southern Utah University. Regardless of participation in the study, all students were presented with the workbook, because each student was expected to complete and turn in the workbook as part of the course. Each student was also required to take a quiz based on the material being taught. Students were incentivized to participate in the study by offering them the opportunity to receive the highest score of the three content quizzes, while nonparticipants would only receive one attempt. Quiz scores were kept confidential to be compliant with the Family Educational Rights and Privacy Act requirements.

Data Collection

Four workbooks (Dimensional Analysis, Nomenclature, Balancing Reactions, and Stoichiometry) were developed for this study. Each workbook was administered as a pre-lecture, in-lecture, or post-lecture assignment to determine the optimal timing for delivery and to assess their efficacy based on content. This required that the study be performed across multiple classes, because each workbook could only be administered once for any given class. The administration of the various

workbooks to a particular class was randomized, in an effort to remove bias (e.g., one class may have had the Nomenclature workbook administered as a pre-lecture assignment and the Dimensional Analysis workbook as a post-lecture assignment whereas another class had a different order). The average class size ranged from 25 to 50 students.

Three quizzes were administered in this study, rather than the traditional two, to acquire a better understanding of the effectiveness of the workbook at different intervals. Quizzes 1 and 3 served as the traditional pre-test and post-test quizzes; quiz 2 was administered immediately after the workbook as a means of monitoring the effectiveness of the workbook. Each quiz adhered to a similar format and had similar, but different questions to maintain the integrity of the analysis.

A schematic representation (Figure 1) illustrates the sequence of administration for the workbook, lecture, homework, and quizzes for pre-, in-, and post-lecture workbooks, respectively. Quiz scores were withheld from students after each attempt to encourage optimal performance on subsequent attempts.

A

$$Quiz\ 1 \rightarrow Workbook \rightarrow Quiz\ 2 \rightarrow Lecture/Homework \rightarrow Quiz\ 3$$

B

$$Quiz\ 1 \rightarrow Workbook/Lecture \rightarrow Quiz\ 2 \rightarrow Homework \rightarrow Quiz\ 3$$

C

$$Quiz\ 1 \rightarrow Lecture \rightarrow Workbook \rightarrow Quiz\ 2 \rightarrow Homework \rightarrow Quiz\ 3$$

Figure 1. Representation of when the (A) pre-lecture, (B) in-lecture, and (C) post-lecture workbooks were distributed.

Following the completion of each workbook, participants were asked to complete an anonymous survey. These surveys sought feedback from students on the perceived utility of the workbooks, the usefulness for examination preparation, and the optimal time to administer the workbook.

Results and Discussion

Table 1 illustrates the average quiz scores for the Nomenclature workbook when administered as either a pre-, in-, or post-lecture assignment. Significant differences were observed in initial understanding among classes, likely influenced by students' prior exposure to chemistry, as represented by the Quiz 1 scores (the traditional pre-assessment). The Quiz 3 scores (the traditional post-

assessment) best indicate when the workbook is most effective because the quizzes, homework, lecture, and workbook had all been completed. For the Nomenclature workbook, we observed that administering this as a pre- and in-lecture workbook was more beneficial than administering it as a post-lecture workbook as evidenced by the higher Quiz 3 scores.

Table 1. Average quiz percentages for the Nomenclature workbook when administered as a pre-, in-, and post-lecture assignment

Workbook	Timing	Quiz 1	Quiz 2	Quiz 3
Nomenclature	Pre-lecture	57%	68%	92%
	In-lecture	47%	80%	89%
	Post-lecture	35%	58%	80%

The statistics that come from Quiz 2 must be considered carefully. Because of the order of assessments (see Figure 1), students had received different levels of instruction when Quiz 2 was administered; consequently, direct comparison of scores is inappropriate. However, this additional quiz provides unique insights into the effectiveness of midterm quizzes that could not be achieved solely by administering the traditional education research pre- and post- assessment quizzes (Quizzes 1 and 3, respectively). For instance, comparison of the Quiz 1 and Quiz 2 pre-lecture scores in Table 1 shows student scores improved from 57% to 68%, solely because of the workbook (because those students were administered Quiz 1 before the workbook and followed by Quiz 2 with no additional instruction; Figure 1A). We can therefore assert that this particular workbook had a positive impact on student learning. Additionally, comparison of Figures 1B and 1C shows that students participating in the in-lecture and post-lecture workbook groups would have received comparable instruction (Quiz 1, workbook, and lecture) prior to the administration of Quiz 2, thereby making it possible to perform a direct comparison into whether in-lecture or post-lecture workbook administration was more effective. As shown in Table 1, Quiz 2 scores for in-lecture and post-lecture administration were 80% and 58%, respectively. This supports our original assertion that this workbook was more effective when administered pre- or in-lecture.

Similar analyses were conducted for the Dimensional Analysis, Balancing Reactions, and Stoichiometry workbooks, with the corresponding averages represented in Table 2. Consistent with the Nomenclature findings, overall mastery for the Dimensional Analysis and Balancing Reactions workbooks occurred with pre- or in-lecture workbook administration, evidenced by Quiz 3 scores. However, we observed that the optimal time to administer the Stoichiometry workbook

was as a post-lecture assignment. These results suggest that the optimal time to administer the workbooks may be subject dependent, and the difficulty of the topic should be considered when deciding when to implement a workbook.

Table 2. Average quiz percentages for the Dimensional Analysis, Balancing Reactions, and Stoichiometry workbooks when administered as a pre-, in- and post-lecture assignment

Workbook	Timing	Quiz 1	Quiz 2	Quiz 3
Dimensional Analysis	Pre-lecture	74%	87%	98%
	In-lecture	69%	89%	99%
	Post-lecture	73%	85%	80%
Balancing Reactions	Pre-lecture	58%	60%	87%
	In-lecture	39%	77%	91%
	Post-lecture	44%	75%	83%
Stoichiometry	Pre-lecture	52%	51%	62%
	In-lecture	44%	77%	85%
	Post-lecture	47%	80%	91%

Pre-lecture Quiz 1 and Quiz 2 comparisons in Table 2 reveal that the Dimensional Analysis workbook was also beneficial to student learning overall. The assessment scores increased from 74% to 87%. However, we observed that the Balancing Reaction and Stoichiometry pre-class Quiz 1 and Quiz 2 scores went from 58% to 60% and 52% to 51%, respectively, showing little to no benefit to student learning from these workbooks. Although one may immediately dismiss these workbooks as being ineffective, it is more likely that students needed to first receive instruction through lecture to attain any semblance of effectiveness for the workbook. This need results from the difficulty of the topic. It also supports the supposition that consideration needs to go into when workbooks should be administered. The results from the student surveys also support this hypothesis, as students perceived this workbook as being beneficial when administered in-lecture and post-lecture, but not pre-lecture.

As part of our study, we also sought to determine whether the optimal time to administer the workbook would coincide with when students perceived it would be most beneficial. Table 3 summarizes the optimal time observed to administer each of the workbooks and compares this with results from student surveys for when participants thought workbooks should be implemented. Student perception of when the optimal time to administer the workbook did not coincide with the

actual optimal time to administer the workbook, emphasizing the importance of empirical assessment in instructional decision-making.

Table 3. Survey results for when students thought the optimal time to administer a workbook was compared with the observed optimal time to administer the workbook

Workbook	Optimal observed timing	Student's preferred timing		
		Pre	In	Post
Nomenclature	Pre-lecture In-lecture	9%	73%	18%
Dimensional analysis	Pre-lecture In-lecture	29%	29%	42%
Balance reactions	In-lecture	6%	41%	53%
Stoichiometry	Post-lecture	11%	67%	22%

Qualitative observations from the professors who incorporated these workbooks in their classroom provide important insights relating to when workbooks should be administered. Their observations underscored the benefits of pre-lecture workbook usage, relating that student preparedness and engagement during lectures increased for certain workbooks (i.e., Dimensional Analysis, Nomenclature, and Balancing Reactions) by noting that students asked more inquisitive questions and had a better understanding of what they did not know. However, they noted that they did not always observe these benefits to the same extent (e.g., with the Stoichiometry workbook), likely because of the difficulty of the material. Professors noted that the Stoichiometry workbook had a poor reception when it was offered as a pre-lecture assignment but that students found it beneficial when it was administered as an in- or post-lecture assignment. It is therefore imperative that professors be cognizant that the optimal time to administer a workbook is topic dependent. Professors also reported concerns when implementing the workbooks as either in-lecture or post-lecture workbooks because, while it ensures that students are being taught the material correctly, there is not always time to complete every problem or be confident that the student completely reads the workbook out of class, causing students to lose out on some benefits of the workbook.

Students were also surveyed to determine whether they thought the workbooks were beneficial. These results indicated that students found the workbooks to be advantageous, with only 1% of students not finding them beneficial. That is not to say that the workbooks could not be improved: 31% reported the workbooks could be improved, while the rest found them strictly beneficial. The suggested improvements

consisted of adding even more difficult problems to the workbooks, as a means of making them even better examination preparation tools. Additionally, feedback showed that students wanted more workbooks for other topics because they found them to be highly beneficial. It is paradoxical for students to ask for more homework, so this type of request speaks to the perceived benefit of WSL from the student's perspective.

Conclusion

In conclusion, this study underscores the underutilization of WSL within university education. Surveys indicate that students would prefer that WSL being integrated into more of their courses. However, considerations must be made of when to administer workbooks, because the optimal time appears to be subject dependent. Both students and professors observed that there were diminished benefits if a workbook for a challenging topic was administered too early. Hence, it is imperative for educators to exercise awareness of these factors when integrating WSL into classroom pedagogy. This necessitates a nuanced approach to curriculum design and delivery to maximize the benefits of WSL for student learning outcomes.

References

Bloom, B.S. and Krathwohl, D.R. (1956). *Taxonomy of Educational Objectives: The Classification of Educational Goals, by a committee of college and university examiners. Handbook I: Cognitive Domain*. New York: Longmans, Green

Appendix

A Naming Ionic Compounds

To name an ionic compound you:

Give the name of the cation first, followed by the name of the anion.

Instruction on how to name the cation and anion are provided in the table below. A flow chart summarizing the table is provided as well.

Important definitions needed to understand the table:

Monoatomic – means that you have just one type of element, even if you have more than one of them. For example, in the compound $BaCl_2$; chlorine is the anion. And will be named as a monoatomic anion because there is only one type of element giving the negative charge (even through there are two chloride ions).

Polyatomic – means that the ion comes as a group of at least two types of elements that are bound molecularly, and occupy a single charge. For example, in the compound Na_2SO_4; SO_4^{2-} is the anion and has the name sulfate. A list of the common polyatomic ions was provided earlier. You should memorize the names of the polyatomic ions and their chemical formulas and charges.

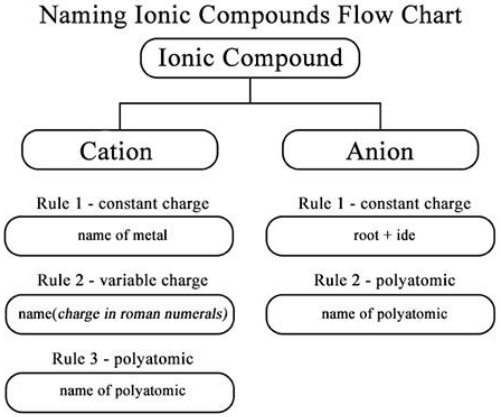
B

Rules for naming the cation	**Rules for naming the anion**
Cation Rule 1 – GROUPS 1, 2, and 13 METALS Several metals only take one type of charge. It is therefore easy to name these ions. Their name corresponds to the name of the element. For example, alkali metals (Li, Na, K, etc.) only take a 1+ charge. Alkaline earth metals (Be, Mg, Ca, etc.) only take a 2+ charge. Al and Ga only take a 3+ charge.	Anion Rule 1 – MONOATOMIC ANIONS Most nonmetals only take one type of charge. It is therefore easy to name these ions. The name corresponds to the name of the element, EXCEPT the ending is replaced with -ide. For example, fluorine becomes fluoride, oxygen becomes oxide, and sulfur becomes sulfide. Halogens (F, Cl, Br, etc.) take a 1- charge. Chalcogens (O, S, Se, etc.) take a 2- charge. N and P take a 3- charge. Note: When H is paired with a metal it takes a 1- charge and is called hydride.
Cation Rule 2 – TRANSITION AND HEAVY METALS Transition metals and some heavier metals, like lead, can take more than one type of charge. It is therefore necessary to specify the charge of the ion. We do this by	

writing the charge of the ion in roman numeral in parenthesis following the name of the element. Note there is another system for naming metals.[1] For example, lead is commonly found as either Pb2+ or Pb4+, and is written as lead(II) or lead(IV), respectively. There are a few exceptions to this rule because these transition metals only take one charge: Ag+ is the silver ion Zn2+ is the zinc ion Cd2+ is the cadmium ion	
Cation Rule 3 – POLYATOMIC CATIONS Polyatomic cations are named by simply writing the name of the polyatomic cation. For example, NH4+ is the ammonium ion and when used in naming is called ammonium.	Anion Rule 2 – POLYATOMIC ANIONS Polyatomic ions are named by simply writing the name of the polyatomic anion. For example, ClO4- is perchlorate and is named as perchlorate

[1]There is an older system for naming metals that can take more than one charge. The Latin root for the element name is used and a suffix of either -ous or -ic is attached for the ion that has the lower and higher charge, respectively. For example, Pb2+ and Pb4+ are plumbous and plumbic, respectively.

C



D

$$Fe_2O_3 = \frac{iron(III)}{cation\ rule\ 2} \quad \frac{oxide}{anion\ rule\ 1}$$

E

$$(NH_4)_2C_2O_4 = \frac{\qquad\qquad}{cation\ rule\ 3} \quad \frac{\qquad\qquad}{anion\ rule\ 1}$$

F

$$Zn(IO_3)_2 = \underline{\qquad\qquad} \quad \underline{\qquad\qquad}$$

G

Indicate whether the compound is binary molecular (M), ionic (I), or an acid (A) and then name the following compounds accordingly.

MgO ____ _____

Supplemental Figure 1: Nomenclature workbook example. Only sample questions are provided, whereas the workbook itself had more practice. (A) A brief description of what an ionic compound is. (B) An organized table that explains the different types of cations and anions. (C) A flowchart that succinctly summarizes the previous explanation. (D) Demonstration problems to show students how to determine a compound name. (E) Sample problems that help students name compounds by informing them which rules they need to follow for the cation and anion. (F) Sample problems that require students to identify the type of cation and anion so they can name the compound. (G) Sample questions that require students to identify and name a compound, without providing the type of compound.

Collaborative Practices Between Utah Teachers and School Social Workers

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Abstract

Collaboration between teachers and school social workers is a crucial aspect of improving schools and addressing the ongoing effects of the COVID-19 pandemic. However, there needs to be more written about what types of collaborative practices should occur between social workers and teachers, including guidance on collaborating within a multi-tiered system of support (MTSS). This research presents preliminary findings from qualitative interviews with four current classroom teachers and four current social workers in Utah K-12 schools. This study examines collaborative practices and the factors that influence collaboration. The types of collaborative activities are categorized as communication-oriented and task-oriented collaborations. Our research underscores the significance of understanding the relationship between teachers and social workers,

particularly in the context of the growing prevalence of embedded and school-based services for students.

Collaboration between teachers and school social workers (SSWs) is crucial for addressing the long-term impact of the COVID-19 pandemic and school improvement. Recent data from the National Center for Education Statistics show that the pandemic has negatively affected the social, economic, physical, and emotional well-being of students and their families. Given this current situation, teachers and social workers need to work together to maximize students' academic success and help alleviate the increased workload on social workers (Bronstein & Abramson, 2003). However, there is limited information available on the specific collaborative practices that should take place between social workers and teachers.

SSWs support the school community, train educators to identify and respond to trauma, accompany educators on home visits to build positive relationships with families, and help identify gaps in school programming for which additional resources may be sought (Finigan-Carr & Shaia, 2018). However, the alarmingly high rates of mental health challenges such as depression and anxiety have left school-based mental health services personnel overburdened with higher caseloads. According to the National Institute of Mental Health (NIMH, 2023), approximately one in every five students may be struggling with their mental health. Despite the high prevalence of mental health disorders among K-12 students, many are not receiving the help they need. The NIMH (2023) estimates that only about half of the children with a mental health disorder received treatment or counseling from a mental health professional in 2020. This coupled with severe workforce shortages and the upcoming end of the Elementary and Secondary Schools Emergency Relief Fund (Lonas, 2024) has left schools unable to expand additional mental health services quickly enough to meet the demand.

This study presents preliminary findings from qualitative interviews with four classroom teachers and four social workers in Utah K-12 schools. Drawing from the evidence-based model of task-centered practice (TCP) (Kelly & Collindres, 2013), we examined the collaborative activities between teachers and social workers, which can be described as communication-oriented and task-oriented collaborations. We use the terms "collaborative activities" and "collaborative practices" interchangeably. Communication-oriented collaboration involves exchanging information and ideas, such as sharing critical student information, accessing data tracking systems, and reaching out for additional support. Teachers and social workers also

engage in task-oriented collaboration, where they delegate responsibilities and take a structured approach to student case management. This includes social workers participating in schoolwide behavioral teams, assisting with individual education plans (IEPs), and supporting students facing high levels of trauma and adversity. The SSW often leads the student support teams and attends professional learning communities (PLCs) to streamline services and increase communication with teachers. Our findings reveal that as embedded and school-based services become more common in schools, it is crucial to understand the relationship between teachers and social workers and, specifically, how they can effectively work together to address the academic and mental health needs of all students.

Review of the Literature

The purpose of collaborative work between teachers and social workers is to ensure the needs of students within and outside the classroom are met. Collaborative practices between teachers and SSWs are imperative because of the rise in school-based and embedded services for children and their families (Viggiani et al., 2002). However, there is limited research about what types of collaborative activities should be occurring between social workers and teachers including guidance on how to collaborate within a MTSS. Although we know the need for teachers and social workers to collaborate, we wanted to examine the collaborative activities current Utah teachers and SSWs engage in to identify and understand what factors constrain or promote collaboration to advance equity, diversity, and inclusion (EDI) for students.

Teacher Education Approach to Collaboration

In teacher education, professional collaboration is defined as collective goal-oriented activities aiming to achieve specific improvements in the teaching and learning processes for a single student, class, or entire school in teacher education (Organization for Economic Cooperation and Development, 2020). It is the idea that when teachers work together, they can address the academic needs of students. Teachers collaborate to design curricula, develop lesson plans, and create instructional materials that align with educational standards and address the needs and interests of their students. They also collaborate to develop and implement assessments that measure student learning, analyze assessment data to inform instructional decisions and adjust teaching strategies to address areas of student need.

This collaboration happens within and across PLCs, which are small groups of educators with shared goals that work together to expand their knowledge and improve their instructional practices and students' academic performance. A typical PLC consists of a facilitator leading a team of teachers that meets regularly to learn new topics, share ideas, and problem-solve. Behavioral issues with students are typically not addressed within a PLC. The focus is on academic progress monitoring and improvement ideas. Collaborative work is done formally, such as having a PLC, and informally, like exchanging information in passing throughout the workday.

Social Work Approach to Collaboration

In the field of social work, collaboration involves professionals working with individuals, families, communities, and other service providers to address complex social issues and enhance well-being. Social workers have a unique perspective on how individuals are affected, and other professionals come together to define common goals, pool resources, and share responsibilities to achieve those goals. They engage in interprofessional collaboration, which involves strategic planning as stakeholders determine how they will rely on one another, seek out one another's expertise, and implement a plan (D'Amour et al., 2005; Interprofessional Education Collaborative, 2011). Social workers often collaborate with professionals from other disciplines, such as psychology, counseling, healthcare, education, and law enforcement, to comprehensively support clients. This interdisciplinary approach ensures that clients receive holistic care that addresses their diverse needs.

In addition, social workers regularly participate in case coordination, where they discuss individual cases with colleagues, supervisors, and professionals from other agencies. These meetings facilitate information sharing, decision-making, and coordinated interventions to support clients effectively. Collaboration is a fundamental aspect of social work practice as professionals leverage their collective expertise, resources, and efforts to improve the lives of their clients.

Intersection of Teacher and Social Work Collaboration

SSW and teacher collaborative practices can help to improve academic performance (e.g., grades and test scores), attendance, and student behaviors (School Social Work Association of America, n.d.). Collaboration combined with case management was more effective in improving student grades and behavior than monetary incentives

(Viggiani et al., 2002). SSWs provide mental health services and have specialized training to meet students' socio-emotional needs and link students and their families with community services essential to promoting student success. Often, a SSW focuses on providing support to vulnerable populations of students at higher risk for truancy and dropping out or being pushed out of school, such as homeless, foster, and migrant children, students transitioning between school and treatment programs or the juvenile justice system, or students experiencing domestic violence (Kelly, 2020). Within a school, the social worker provides coordinated interventions and implements integrated services that support school safety and student learning through the school's MTSS.

MTSS is a framework designed to meet the needs of all students by ensuring that schools optimize data-driven decision-making, progress monitoring, and evidence-based support and strategies with increasing intensity to sustain student growth. The MTSS model includes universal, targeted, and intensive levels of support. The universal level (Tier 1) represents the support provided to each student. Tier 1 practices should be implemented with fidelity before addressing practices for Tiers 2 or 3. The targeted level (Tier 2) represents additional support to intervene or enrich student success. Lastly, the intensive level (Tier 3) represents individually responsive support intended to further intervene or enrich student success and is developed based on individual student needs. Tier 3 support may be provided individually or in a small group and is in addition to, not in place of, Tier 1 instruction and does not necessarily equate to special education services. SSWs are often tasked with leading the response to intervention (RTI) and positive behavior interventions and support (PBIS) methods within the MTSS framework. Overall, both teachers and social workers collaborate within MTSS, which is a system of collaboration and problem-solving to identify difficulties early and with enough specificity to intervene.

Methodology

The purpose of this study was to collect information on the types of collaborative activities current Utah teachers and SSWs engage in together and to understand what factors constrain or promote this sort of collaboration to advance EDI for students. Participants were recruited through purposeful sampling (Palinkas et al., 2015) and snowball sampling procedures. Purposeful sampling helped ensure we had a diverse sample of individuals across various educational settings (e.g., elementary, middle, and secondary level, public, and charter schools). Personal networks were also utilized to recruit participants. The data

collection process consisted of one semi-structured individual interview via Zoom with eight participants (four classroom teachers and four school-based social workers; see Table 1). Most of the participants worked in public schools, except for two participants who worked at a non-public charter school. The average number of years teachers have worked in schools was 14 years. The average number of years social workers have worked in schools was 7 years. However, the average number of years as a clinical social worker was 11.25 years. We did not collect demographic data on race/ethnicity or age. Before beginning our analysis, we cleaned up, listened, and read through the Zoom auto-transcription of each interview recording. Using deductive coding allowed us to explore the meanings, processes, and narratives of interpersonal and intrapersonal phenomena (Fife & Gossner, 2024). We analyzed the interviews to identify collaborative activities between social workers and teachers.

Table 1. Demographics of participants

Participant	Position	Type of Site	Years of Experience	Gender
H. Logan	Teacher	Elementary	28	Female
R. Roy	Teacher	Secondary	13	Male
A. Jamal	Teacher	Elementary	11	Male
M. Annie	Teacher	Secondary	4	Female
A. Callie	Social worker	Charter & secondary	3 in schools + 13 in clinical SW	Female
P. Vicky	Social worker	Charter & elementary	7 in schools + 10 in clinical SW	Female
P. Tricia	Social worker	Elementary & secondary	8 in schools + 8 in clinical SW	Female
H. Evelyn	Social worker	Elementary	10 in schools + 14 in clinical SW	Female

SW, social work.

Findings

The findings in this section reveal how participants engaged in various collaborative activities within their school and describe multiple factors that constrained or promoted their collaboration. They also described how the collaboration helped to address the socio-emotional, behavioral, and academic needs of students. During our data analysis, we found that these activities could be described as either communication-oriented or task-oriented when paired with the field of social work's evidence-based model of TCP (Kelly & Collindres, 2013) and

understanding that teacher collaboration can be diverse and have different depths, ranging from merely superficial to deep-level collaboration (Vangrieken et al., 2015). The TCP is designed to help clients and practitioners collaborate on specific, measurable, and achievable goals (Kelly & Collindres, 2013). It is a short-term, problem-solving approach that focuses on identifying the problem, setting goals, developing tasks, and evaluating progress. Similarly, MTSS is also an evidence-based model, but it uses data-driven problem-solving to integrate academic and behavioral instruction and interventions that propel teacher collaboration. In our study, we found that these activities could be described as communication-oriented collaboration involving exchanging student information, accessing data systems, and seeking additional support, while task-oriented collaboration entailed social workers participating in school teams, assisting with education plans, and supporting students facing adversity.

Communication-Oriented Collaboration

In this study, communication-orientation collaboration is defined as the exchange of ideas and information by teachers and social workers. This type of collaboration may entail sending emails, chats, messaging, "stopping" by their office or classroom, or exchanging documents. The majority of the collaborative activities occurred within the context MTSS model, where the collaboration between social workers and teachers is essential for early identification and intervention, progress monitoring, and data-based assessment of student progress. Some schools have an established team that collaborates with teachers in creating a plan to meet student needs. In contrast, in other schools, teachers are not included in the collaborative efforts to address student needs. "P. Vicky" (social worker) stated: "...collaboration between teachers and us (social workers) is to help support our students. I feel like it would be nice to have more time to just problem-solve together." Nevertheless, teacher "A. Jamal" described his relationship with the school's social worker as transactional—where they were only exchanging information and ideas but not necessarily working together. This description of their collaboration could be described as communication-oriented, where teachers and social workers are sending emails, chats, messaging, "stopping" by their office or classroom, or exchanging documents.

The majority of the teachers described sending and/or receiving critical information from the social worker regarding a particular student experiencing a personal situation, crisis, or behavior impacting their learning. Some of this information was shared using a data dashboard

system, emailing, or simply "stopping by" to discuss a particular situation.

> Our social worker has collaborated with me to help me do some interventions she has suggested, you know, different, like a different type of tracker, check-in, and check-out. She also told me of things that had happened in the previous school year and what worked and what didn't. (H. Logan, teacher)

One teacher described having a process to determine what issues or situations needed to be addressed by a SSW. This referral process was part of the school's student support team (SST) progress monitoring for students in Tier 2 and 3. The teachers described learning from or sending information regarding a student needing to be monitored by the SST team. The assumption was that the social worker was part of this team or that information was shared with them from this team.

All participants described having access to a data tracking system provided by the district. Teachers are trained on how to "pull" data to create and implement interventions in the classroom to support student learning. Some teachers talked about gathering data for the social workers; others described the social workers already having the data and just reviewing it. Moreover, some teachers described reaching out and collaborating with the social worker to receive additional support with students who had challenging behaviors, but not necessarily referring the student to the SST. One teacher described collaborating with her school's social worker because the "social worker had more experience with the kid," and together, they could advocate and support the student.

> I have a student right now who I'm in the process of wanting to get tested for possible resources and evaluation. Our social worker has collaborated with me to help me do some interventions she has suggested…like a different type of tracker, check-in, and check-out. [Social worker] also has been helping me fill out the forms, because there's a lot of it, and helping me upload data, giving me suggestions on things that I could be doing with the student that would help with emotional regulation. (M. Annie, teacher)

In teacher H. Logan's experience, she collaborated with the social worker on implementing an intervention and providing additional contextual information. For teacher R. Roy, the social worker helped to determine that removing a student from class was the appropriate intervention. Some teachers described knowing or using a particular

"tracker" (form) to write down behavior that was recommended by the social worker. It was unclear whether these interventions came from the SST or solely from the social worker working with the student.

Lastly, for two teachers, the collaborative activities with the SSW involved identifying students who needed additional community resources, such as food and housing assistance, holiday family support, and other referrals for basic services. All teachers described the social worker taking the lead or coordinating all efforts related to ensuring students' basic needs are met. Some schools did have a family/community liaison that worked with the administration and SSW to coordinate these efforts.

Although teachers described sharing critical information, referrals to the school's SST, implementing interventions, and connecting families with additional community resources, they also mentioned not knowing the specific roles, responsibilities, and duties of the social worker. For teachers who had a part-time (shared) social worker, they did not know the days the social worker was on-site. Others described not knowing how the day of the social worker was divided up. They knew that social workers were busy and had a lot on their plate but did not know exactly what that entailed. Lastly, one SSW stated, "I would say that that's something that needs to be worked on across the board for sure and how to do that I don't know because I feel like a lot of times we're working in such a crisis mode…". Often the focus of their communication-oriented collaboration focused on a crisis or what they described as "putting out a fire" (P. Tricia, social worker).

Task-Oriented Collaboration

The collaborative activities described by the teachers and social workers in our study could also be identified as task-oriented. Task-oriented collaboration refers to the delegation of tasks and a structural approach to client (student) case management. This type of collaboration is focused on the delegation and completion of tasks to meet goals, deadlines, or outcomes. In our study, the majority of social workers described having multiple roles and responsibilities outside of clinical practice (e.g., intake, individual therapy, groups).

Social workers mentioned being members of schoolwide behavioral teams and assisting with IEPs. Social workers were not just supporting students with IEPs, 504, or other behavioral plans. They were also supporting students facing high levels of trauma and adversities (e.g., gang involvement, racial discrimination and harassment, poverty, homelessness).

In some schools, the social workers led the SST and attended PLCs, which helped to streamline services and support and increase communication. H. Evelyn (social worker) had a delineated tracking system and has trained classroom teachers on how to use it to monitor interventions and behavior. She explains:

> [The team] all sit down and the teacher comes and we talk about interventions and what can be put in place, and then sometimes that will include doing some assessments for the kiddos or putting them like in a social skills group or things like that.

Sometimes, to support particular students, SSWs would enter the classroom to assist teachers with student behavioral issues. Other activities mentioned were student mental health referrals, behavior assessments, and adaptive assessments. One participant stated:

> I have a lot of responsibilities over the social, emotional, and well-being of students. So that looks like group counseling and individual counseling. I also do quite a bit of behavior support. I feel like that depends on the school, but I definitely do a lot of behavior support. So I would say, I do a lot of Tier 1 support for our classrooms, working with our teachers, Tier 2 supports, and Tier 3 supports, and then I also am on our student support team with our administration. We talk about students and how to best support them on that team. (P. Vicky, social worker)

Both social workers and teachers described their collaboration as part of referring students to the school's SST, which is part of the school's MTSS. A. Callie (social worker) stated:

> At our school, we have what's called the MTSS and what the system encompasses is the teacher role. When they can refer to kids what they can do when they see signs. We want them to really be attentive to their student, because a lot of times when we didn't have this system in place, teachers were referring everybody to me, which was kind of out of hand, and then, when they would come to me as the school therapist, it wasn't necessarily a therapeutic matter, and so we've created the system. I think it's like a statewide system that a lot of schools are using. And so there's definitely roles that the teachers play in being able to notice what goes to the counselor. We have forms for them to fill out, to identify, like what behaviors are showing

> how often and how frequent those are showing up in their kid's life.

Another important part of the collaboration was the SSW's task to train teachers on a variety of topics. A teacher participant mentioned: "Even though that kid is dealing with trauma, he's destroying the learning for everybody else. What can I do that is sensitive to the kid's experience but also not sacrificing the experience of other kids?" (R. Roy, teacher). Teachers want to be trained in mitigating crises in their classrooms to provide a safer learning environment. SSWs want to be a resource for their teachers and students. One SSW participant raised imperative questions: "How can my role (SSW) support you in your role? And how can your role (teacher) support me in my role? And how can we work better together?" (H. Evelyn, social worker). H. Evelyn's was proactive in attending faculty meetings early in the year, where she and other SSWs introduced themselves to the teachers and constantly made themselves available and visible to the teachers. Teachers could request different types of training that best met the needs in their classroom. Some participants shared how a social worker would teach social-emotional learning mini-lessons in the classrooms. "H. Logan" (teacher) highlighted that "...it had awesome lessons about inclusion and diversity, and taking care of each other, and treating each other as equals." Other examples of collaborative activities mentioned were schoolwide activities such as Unity Day, Living Traditions, Latinos in Action and People of the Pacific elective course, and other cultural celebrations. Participants also mentioned training topics, including trauma-informed interventions, suicide prevention, behavior techniques in the classroom, and self-care.

SSW participants mentioned the importance of building relationships and how creating connections with the teachers was an essential piece to their collaborations. However, not all social workers had the time to attend all PLCs or faculty meetings. Most of the task-oriented collaboration occurred within referrals to SSTs or for additional mental health and community resources and services.

Challenges to Collaboration

Time was the biggest challenge for collaboration. Even though teachers and social workers engaged in communication-oriented and task-oriented collaboration, the participants described not having enough social workers for the student populations and/or high levels of trauma and behavioral support needed. Several schools had full-time social workers. Others had a full-time social worker, an intern, and a part-time

school psychologist. Others had to share a social worker with several schools. "A. Jamal" (teacher) described having a school counselor and sharing one SSW with several schools, even though they could benefit from having a full-time social worker. In our study, social workers described not having enough time to observe and work with teachers on issues of classroom management because of overwhelming caseloads. This included not having enough time one on one with teachers to follow up on referrals and limited or nonexistent opportunities to facilitate these types of ongoing professional development. Both teachers and social workers felt like they were just putting out fires and not necessarily working in sync to be proactive. In their view, learning more about each other and how to collaborate would ensure that they met the academic and socio-emotional needs of all students, and this would promote educational equity.

Moreover, the participants describe collaborative activities about students' needs and academic success. Our original focus of the study aimed to examine how their collaborative activities advance EDI. However, participants did not explicitly describe advancing EDI as a factor that constrained or promoted their collaboration. Participants did mention their collaboration activities as *potentially* advancing educational equity and cultural competency but did not use the term "EDI." For example, we found that when we asked the participants about this, some of the participants focused on language access (translation, interpreters in home languages) and providing access to basic needs (e.g., food, clothing, housing) for students and their families. The majority of participants broadly described the importance of students from diverse cultural, ethnic/racial, and linguistic backgrounds to be celebrated and validated within schools. This could be due to the current sociopolitical climate in Utah and the passage of House Bill 261 in 2024. At the time of the interviews, this law had passed but not yet been implemented, and some of the participants moved into a "neutral" stance on EDI or substituted it with the term "belonging." For some, although the law prevented various "EDI" practices and language, the work to be culturally responsive needed to occur given their school's high need and demographics of being a Title I school. Although the perception of what impact their collaborative activities had on EDI was unclear, additional research is needed because of the newly implemented HB 261.

Limitations and Future Research

There are several limitations in this study, which include a small sample size and only interviewing teachers and social workers in Utah. Although we managed to interview teachers and social workers from a

diverse range of types of schools (e.g., elementary and secondary level, public and charter schools), because of the sample size we are unable to draw broad conclusions. Future research will include focus groups, school observations, and surveys to get a better understanding of the collaborative process between teachers and SSWs, including the possible impact of the new "Anti-EDI" bill.

Conclusion

Collaboration between social workers and teachers is crucial for addressing students' well-being and academic achievement. Through our analysis, we identified the types of activities and factors for their collaboration that can be classified as communication-oriented and task-oriented collaboration. Although teachers and social workers are currently engaged in multiple collaborative activities, there is a need for proactive training and communication about their roles and responsibilities. More importantly, knowing how and why to collaborate can lead to better identification of teaching strategies or classroom modifications that better support students facing academic and socio-emotional challenges. Teachers want to be trained on how to mitigate behavioral crises in their classrooms to provide a safer learning environment. SSWs want to be a resource for their teachers and students. In these findings, participants prioritized the importance of ongoing communication-oriented collaboration. However, both collaborations are essential to promote equity, diversity, inclusion, and overall student success.

References

Bronstein, L.R., & Abramson, J.S. (2003). Understanding the socialization of teachers and social workers: Groundwork for collaboration in the schools. *Families in Society, 84*(3), 323–330. doi: 10.1606/1044-3894.110

Darling-Hammond, L., & Cook-Harvey, C.M. (2018). *Educating the Whole Child: Improving School Climate to Support Student Success*. Palo Alto, CA: Learning Policy Institute. doi: 10.54300/ 145.655.

D'Amour, D., Ferrada-Videla, M., San Martin-Rodriguez, L., & Beaulieu, M. (2005). The conceptual basis for interprofessional collaboration: Core concepts and theoretical frameworks. *Journal of Interprofessional Care, 19*(Suppl. 1), 116–131.

Fernandez, L. (2019, April 2). Running an effective task group: the 5 C's. SocialWorker.com. https://www.socialworker.com/feature-articles/practice/Running_An_Effective_Task_Group%3A_The_Five_C%27/

Fife, S.T., & Gossner, J.D. (2024). Deductive qualitative analysis: Evaluating, expanding, and refining Theory. *International Journal of Qualitative Methods, 23*. doi: 10.1177/16094069241244856

Finigan-Carr, N.M., & Shaia, W.E. (2018). SSW as partners in the school mission. *Phi Delta Kappan, 99*(7), 26-30. doi: 10.1177/0031721718767856

Fortune, A.E., & Reid, W.J. (2011). Task-centered social work. In F.J. Turner (Ed.), *Social Work Treatment: Interlocking Theoretical Approaches* (5th ed., pp. 513–532). Oxford University Press.

Interprofessional Education Collaborative. (2011). Core Competencies for Interprofessional Collaborative Practice: Report of an Expert Panel. https://www.aamc.org/download/186750/data/core_competencies.pdf

Kelly, M. (2020). School Social Workers' Role in Addressing Students' Mental Health Needs and Increasing Academic Achievement. School Social Work Association of America.

Kelly, M.S., & Colindres, M.E. (2013). Task-centered practice. *Encyclopedia of Social Work*. National Association of Social Workers Press and Oxford University Press. doi: 10.1093/acrefore/9780199975839.013.388

Lonas, L. (2024, June 7). Schools fear job cuts as emergency pandemic funding runs out. *The Hill.* https://thehill.com/homenews/education/4705923-schools-jobs-emergency-coronavirus-pandemic-funding/

Marmo, S., & Berkman, C. (2018) Social workers' perceptions of job satisfaction, Interdisciplinary collaboration, and organizational leadership. *Journal of Social Work in End-of-Life & Palliative Care, 14*(1), 8-27. doi: 10.1080/15524256.2018.1437590.

National Center for Education. (2022, July 6). More than 80 percent of U.S. public schools report pandemic has negatively impacted student behavior and socio-emotional development. https://nces.ed.gov/whatsnew/press_releases/07_06_2022.asp

National Institute of Mental Health. (2023). Mental illness. https://www.nimh.nih.gov/health/statistics/mental-illness

Organization for Economic Cooperation and Development. (2020). *TALIS 2018 results (Volume II): Teachers and School Leaders as Valued Professionals*, TALIS, OECD Publishing. doi: 10.1787/19cf08df-en.

Palinkas, L.A., Horwitz, S.M., Green, C.A., Wisdom, J.P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research, 42*, 533-544.

School Social Work Association of America. (n.d.). *Role of School Social Worker.* https://www.sswaa.org/school-social-work

Utah State Legislature. (2024). *H.B. 261: Equal opportunity initiatives.* https://le.utah.gov/~2024/bills/static/HB0261.html

Vangrieken, K., Dochy, F., Raes, E., & Kyndt, E. (2015). Teacher collaboration: A systematic review. *Educational Research Review*, *15*, 17–40. doi: 10.1016/j.edurev.2015.04.002

Viggiani, P.A., Reid, W.J., & Bailey-Dempsey, C. (2002). Social worker-teacher collaboration in the classroom: Help for elementary students at risk of failure. *Research on Social Work Practice*, *12*(5), 604-620.

Virginia Commonwealth University. (2022, June 29). *The importance of interdisciplinary collaboration in social work.* https://onlinesocialwork.vcu.edu/blog/social-work-interdisciplinary-collaboration.

Exploring Student Outcomes in STEM Education

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Abstract

Technology-focused STEM (science, technology, engineering, math) education is a rapidly changing field of study. Educators need a clear understanding of the forces shaping it and how to respond to those changes. Our aim through this research is to explore student-related outcomes in STEM higher education. We do this by examining data from colleges and universities in 21 different states in the U.S. This research shows that offering more STEM degrees correlates with higher students' starting salaries, which are associated with overall career salaries. However, this research also shows that higher teacher ratings may not correlate with higher student starting salaries. In fact, choosing to attend an expensive university and major in a STEM field may be the key to increasing future career earnings.

1. Introduction

Failing to understand your environment can have dire consequences. Having a thorough understanding of the state of affairs allows for better decisions and strategic planning. To acquire this knowledge, organizations perform annual surveys, reports, and audits to gauge their current states. This knowledge can then be disseminated to key stakeholders to highlight the good and bad in hopes of directing future behavior. We see examples of this in the annual State of the Union address the U.S. President delivers to Congress or in the annual state of affairs reports CEOs deliver to shareholders. Although no such reporting is completely comprehensive, it does bring the governing body relevant and timely insights and awareness. This relevant and timely data of where they have been and where they are now can help with where they want to go.

As educators we face an urgent need to have relevant and timely data regarding our courses, enrollments, tuition costs, teaching quality, job placement statistics, and graduation rates. This is especially true in the post COVID-19 education environment. With the global pandemic, universities were forced to rapidly shift to online education. Enrollment rates and graduation rates saw sharp decreases, and student engagement became more limited. Higher education had to confront challenges posed by the pandemic with little insight into what might be most effective.

There are several factors that technology-focused science, technology, engineering, and math (STEM) programs face. First, these programs are directly affected by rapidly changing technology. Hardware, software, and platforms are constantly changing. In fact, processing power, device connectivity, bandwidth, and storage capacity have traditionally increased exponentially. These rapid changes have caused devices and systems to be fundamentally different every 10 years (Bell, 2008). Educators are directly affected by these changes and must adapt courses, and course content, to account for these differences.

Second, these programs need timely data to better understand how they fit into a broader education paradigm relative to other technical areas of study. Technological advances have caused the overall educational space to be more fluid and less well-defined. For example, the rise of social media has created an entirely new area of study and spawned new courses. Higher education programs need timely data to track the development of these new areas of study.

And third, these programs need timely data to develop more effective pedagogical approaches for technology-intensive courses as these are often the first ones to test new technologies in the classroom. They are also constantly developing new courses and new delivery

methods (e.g., distributed virtual classrooms, penetration testing labs, and courses on machine learning). Take, for example, the development and incorporation of mixed-reality devices. This technology will allow instructors to present three-dimensional (3D) models of their subject matter for all students to interact with. Student interaction will necessarily be different, with students seated around a lecture space centered in the middle of the room. Vastly different from a traditional setting of being seated in rows facing a screen at the front of the room—as is typically done for 2D lectures. To effectively adapt to changes like these, and to improve decision-making, technology-focused STEM programs need timely data.

As educators, we use timely data to engender student success. If we can understand who our students are, their current state of affairs, their challenges, their struggles, and their successes, we can help shape their future in a positive direction. In this same spirit, our aim through this research is to present a view of student outcomes. Our focus is on management information systems (MIS) programs, because they are a good proxy for many technology-focused STEM programs.

2. Literature

Students benefit from a STEM education because it tends to boost academic performance and increase creativity, problem solving, and technological skills (Martin-Paez et al., 2019). The STEM-related discipline of MIS as a field of study has seen continuous evolution since its inception in the 1960s (Hirschheim & Klein, 2012). Also referred to as Information Systems (IS), MIS curricula face frequent changes to remain effective as the global computing field changes so rapidly (Topi et al., 2010). As a field of education, comprehensive MIS curriculum mapping has been proposed many times historically, with our current iteration being 'IS 2010.' To understand the overall effectiveness of MIS curriculum and the attractiveness to potential students, large-scale studies are warranted to review the provision of MIS courses across universities (Stefanidis & Fitzgerald, 2010). Although studies have been done to determine what the MIS common core of knowledge (MIS core) looks like nationwide (e.g., Stefandis et al., 2013; Hwang et al., 2015), there still is an unclear picture of how this fits into the larger narrative. This is especially important given that the recent global pandemic forced a significant change in the styles, systems, and methodologies of education resulting in student disengagement (Izumi et al., 2021).

2.1. Tuition

The potential benefits of higher education are significant, yet rising tuition makes it difficult for today's students to secure those benefits (Mitchell et al., 2019). Schools have been charged with failing to meet the needs of their students and industry for effective education and relevant knowledge (Pfeffer & Fong, 2004). This is particularly egregious when considering the ever rising cost of tuition. Examining the effect of tuition costs is important because it is one instrument that governments can seek to manipulate (Denney, 2014). Past research has suggested that attending a relatively high tuition university has a net positive effect on occupational status and income (Pascarella et al., 1992). However, it is unclear whether this remains the case with such high tuition rates as we see in today's marketplace.

Tuition cost increases of a mere $1000 have been found to reduce enrollment by approximately 2.5% (Hemelt & Marcotte, 2011). Some have argued that tuition should be eliminated in order to have equitable education nationwide. However, even abolishing tuition costs fails to provide the positive outcomes hoped for by implementing this strategy (Denny, 2014) such as higher minority and female enrollments and better graduation rates. Graduation rates themselves have been very difficult to account for (Goenner & Snaith, 2004), but are an important measure of institutional success. It is unclear how tuition affects things such as graduation rates and salary.

2.2. Teacher Quality

As teachers, it is clear that how we do what we do also plays into the equation. How we teach and how effective we are can influence the state of our field. Many colleges and universities have placed greater emphasis on teaching excellence in higher education. Teacher quality is the most important school-related factor affecting student achievement (Looney, 2011); however, teacher credentials are a poor predictor of teaching quality (Goldhaber & Anthony, 2007).

A national survey of instructional strategies of the IS discipline showed that lecture or interactive lecture is the most frequently used teaching method, followed by cooperative learning, problem-based learning, group discussion, and demonstrations (Djajalaksana, 2011). However, knowing what methods we use the most does not quite give full insight into teaching quality.

For a deeper understanding of teaching quality, colleges and universities commonly assess their students' opinions of teachers and employ teaching evaluations to determine the quality and impact of their faculty. Students commonly fill out official university teaching

evaluations at the conclusion of every class for every teacher each semester. Schools use this method because teacher evaluations can contribute to improvements in the quality of teaching and raise student achievement (Looney, 2011).

Studies examining what things might impact a teacher's evaluation have had mixed results, because teaching effectiveness is a very complex subject (Seidel & Shavelson, 2007). For example, the impact of class size on teaching quality has historically mixed findings (Williams et al., 1985; Mateo & Fernandez, 1996). Even the physical classroom environment can impact teacher effectiveness (Hill & Epps, 2010). New pedagogies are being employed in an effort to be more effective and have better teaching quality (Mok, 2014), especially for IS teaching (Tétard, & Patokorpi (2005). Students communicate teacher effectiveness to their peers through third-party evaluation web sites, such as RateMyProfessors.com. These unofficial evaluations should not be dismissed off-hand as they have been shown to highly correlate with official university evaluations (Timmerman, 2008).

2.3. Salary

The impact of the MIS discipline goes beyond the classroom and the IS curriculum as our students graduate and go into the workforce to have successful careers. One metric that has traditionally been used to determine lasting student success is salary. Student-related variables such as cognitive ability and motivation (i.e., grades) have been studied as useful predictors of salary (Roth & Clarke, 1998). Willingness to negotiate has also shown to positively contribute to higher starting salaries for women and men leaving college and entering the workforce (O'Shea & Bush, 2002). Although the correlation is unclear, it is likely that the college or university—and the quality of teachers therein—will also impact salary. Students may elect to go to certain schools because they have a reputation for getting graduates high-paying jobs.

Salary and gender is a topic that warrants our full attention as MIS educators. It is well documented that women continue to earn less than their male colleagues. Research has highlighted that the gender wage gap is a reality (and that it is likely to continue) and that women could benefit from greater education and information pertaining to salary negotiations and expectations (Schweitzer et al., 2014). This is especially true of our field because few women major in MIS (Beyer, 2008) and because women in IS historically tend to be employed at lower levels of companies, make less money, and have greater intentions to leave the company (Baroudi & Igbaria, 1994).

3. Research Insights

Extant literature fails to provide answers for many questions that can grant us insight into the current state of things in STEM education such as: What do enrollments look like? How does tuition vary between schools? What do faculty/student ratios look like? What do faculty/program ratios look like? What do student program rations look like? What do teacher evaluations look like? Where can students go to find these quality teachers? Does a more expensive education grant access to higher quality teachers? Are high-quality teachers in larger universities? What do starting salaries look like? What do 4-year graduation rates look like? The list goes on.

Because research has suggested that attending a relatively high tuition university has a positive effect on income, higher tuition costs should lead to higher starting salaries; we examine this effect in Hypothesis 1. Research has demonstrated a demand for STEM education because STEM graduates enjoy higher employment rates and better salaries (Xue & Larson, 2015). Thus, schools with high percentages of STEM grads should see better overall starting salaries; this effect is examined in Hypothesis 2. Lifetime earnings are certainly influenced by where a person starts. This is one reason why graduates who negotiate for a better starting salary will see higher lifetime earnings (Schweitzer et al., 2014). Better starting salaries should lead to better career salaries, an effect examined in Hypothesis 3.

Teacher quality is an important aspect of education because it can raise student achievement and long-term success. It stands to reason that schools that can spend more on quality teaching should be able to recruit and retain better teachers. Thus, students paying high tuition rates should also benefit from better quality teaching, an effect examined in Hypothesis 4. One important outcome from quality teaching is student success. The aim of quality teaching is achievement and success—not only in the classroom, but in the workplace as well. Thus, better teaching should contribute to better starting salaries; this effect is examined in Hypothesis 5. Quality teaching can be limited by resource constraints. Universities with fewer resource constraints should be able to achieve better quality teaching. Universities with overall more available resources should see higher quality teaching, an effect explored in Hypothesis 6. Smaller class sizes can lead to more personalized education opportunities. Small class size can enable students to engage directly with teachers and peers in more intimate ways. Thus, small classes should be associated with higher quality teaching experiences, effects explored in Hypotheses 7 and 8.

Finally, a student's perception of school support may likely influence teacher evaluations. Students who feel encouraged and supported both in likelihood of successful graduation and through financial aid or other awards are likely to positively evaluate teachers. Family and community support are likely to play into this as well as students attending local universities are likely to have better family and community support. This overall student support may lead to better perceptions of teaching. These considerations are explored in Hypotheses 9-13.

4. Research Methods

Data were collected from 42 colleges and universities in the U.S. (Appalachian State Univ., Arizona State Univ.–Tempe, Auburn Univ., Brigham Young Univ., Clemson Univ., George Mason Univ., Georgia Institute of Technology, Georgia State Univ., Grand Valley State Univ., Indiana Univ.–Bloomington, James Madison Univ., Kennesaw State Univ., Longwood Univ., Michigan State Univ., Mississippi State Univ., Northern Arizona Univ., Purdue Univ., Temple Univ., Univ. of Alabama, Univ. of Alabama–Huntsville, Univ. of Arizona, Univ. of Arkansas, Univ. of Georgia, Univ. of Hawaii–Manoa, Univ. of Idaho, Univ. of Kansas, Univ. of Michigan–Ann Arbor, Univ. of Michigan–Dearborn, Univ. of Montana, Univ. of Memphis, Univ. of Notre Dame, Univ. of Southern California, Univ. of Texas at Dallas, Univ. of Texas at El Paso, Univ. of Utah, Univ. of Washington–Seattle, Utah State Univ., Univ. of Texas at San Antonio, Utah Valley Univ., Wichita State, Weber State Univ., and West Virginia Univ.). Enrollment data collected were time series covering the period from 2001 to 2017 for each course in each semester. Data were collected from publicly listed data at each university's individual web site. In addition, data were collected that examined the specific MIS curriculum being taught for each school from that identified (2001–2017): which classes were being taught (core and electives), enrollments for each class, and which instructor was teaching. Not all universities had data available back to 2001. MIS program core required courses were somewhat different across the universities in this sample.

Data were also collected from U.S. News & World Report's Best Colleges Survey looking at university-level attributes such as total enrollments, undergraduate enrollments, student body demographics, in-state tuition, out-of-state tuition, number of faculty, four-year graduation rate, financial aid awarded, and scholarships awarded. Teacher rating data was also retrieved from ratemyprofessor.com for each university and each instructor currently teaching at that university. Note that

ratemyprofessor.com is not explicitly designed to fully reflect all aspects of teacher effectiveness. Salary data for MIS/IS/computer information science (and the like) graduates were retrieved from current and historical data in PayScale Inc.'s College Salary Reports. PayScale's methodology is found at https://www. payscale.com/college-salary-report/methodology.

4.1. Descriptive Statistics

Table 1 shows university statistics for the schools in this sample. The schools in this sample included a variety of large/small, public/private, and STEM-focused schools from 21 different states.

Table 1. University statistics

Variable	Mean	Median	Low	High
Total enrollment (N)	28,950	28,303	5,073	51,869
Undergrad enrollment (N)	22,655	22,603	4,470	42,477
In-state tuition	$12,294	$10,808	$5,460	$54,259
Out-of-state tuition	$27,793	$26,893	$5,460	$54,259
Student-faculty ratio	18:1	17:1	8:1	23:1
Classes with <20 students	40%	39%	19%	60%
4-year graduation rate	39%	39%	11%	90%
Overall graduation rate	64%	65%	31%	97%
Students rcv. fin. aid	52%	51%	36%	77%
Average award	$9,635	$7,548	$4,112	$37,390
Receiving Pell grants (%)	29%	28%	11%	66%
Average starting salary	$50,167	$49,700	$41,300	$65,000
Early career salary	$50,281	$50,250	$38,900	$68,100
Mid-career salary	$92,274	$94,950	$61,900	$133,800
STEM	22%	21%	7%	78%
Stay in state	60%	60%	5%	90%
Female	44%	47%	23%	64%
Male	55%	54%	36%	77%
Female low	$36,137	$35,624	$30,334	$48,875
Female high	$76,321	$76,071	$59,339	$92,998
Male low	$43,325	$41,711	$36,328	$56,237
Male high	$93,760	$94,049	$70,481	$121,720

Table 2 shows average teacher rating statistics (scale low 1 to 5 high).

Table 2. Teacher rating statistics	
Teaching ratings	**Value**
Professor rating (mean)	3.50
Professor rating (median)	3.60
Professor rating (SD)	0.89
Average number of faculty rated per university	12.56
Observations per university (mean)	19.34
Observations per university (median)	13.87
Observations (SD)	18.81
Total observations	225.80

SD=standard deviation

4.2. Results

Separate multiple linear regressions were used to test the hypotheses related to the dependent variables starting salaries (H1, H2, and H5), career salaries (H3), and teacher ratings (H4, H6–H13).

First, a multiple regression was performed to see whether tuition costs (H1), percentage of STEM degrees (H2), and teacher ratings (H5) were associated with higher starting salaries. Analysis of standardized residuals showed that the data contained no outliers (std. residual min=-1.678; std. residual max=1.964), multicollinearity was not a concern (tolerance >0.1; variance inflation factor [VIF] <10 as shown in Table 3), and errors were independent (Durbin-Watson=1.88).

Histograms of standardized residuals showed that data were approximately normally distributed, and the scatterplot of standardized residuals showed the data met the assumptions of homogeneity of variance and linearity. The results showed that tuition costs, percentage of STEM degrees, and teacher ratings explained a significant amount of variance in higher starting salaries ($F(3,37=26.38$, $p<.001$, $R2 =.68$, $R2$ adjusted $=.66$). Tuition costs ($\boldsymbol{\beta}=.12$, $t(40)=2.60$, $p=.013$) and percentage of STEM degrees ($\boldsymbol{\beta}=27696$, $t(40)=8.41$, $p<.001$) were significantly associated with higher starting salaries, but teacher ratings were not ($\boldsymbol{\beta}=668$, $t(40)=.792$, $p=.443$). Table 4 shows the resulting t-values for the hypothesized relationships.

Next, a linear regression was performed to see whether higher starting salaries were associated with higher career salaries (H3). Analysis of standardized residuals showed the data contained no outliers (std. residual min=-3.455; std. residual max=1.675), multicollinearity was not a concern (Table 3), and errors were independent (Durbin-Watson=1.42). Histograms of standardized residuals showed that data were approximately normally distributed, and the scatterplot of standardized residuals showed the data met the assumptions of

homogeneity of variance and linearity. The results showed that higher starting salaries explain a significant amount of variance in higher career salaries ($F(1,40=27.62$, $p<.001$, $R2 =.41$, R2 adjusted =.39). Starting salaries ($\beta=2.00$, $t(41)=5.26$, $p<.001$) were significantly associated with higher career salaries.

Table 3: Data fitness statistics

Variable	Mean	SD	N	Tol.	VIF
Starting salary	$50,212	$4,678	41	-	-
Tuition	$12,332	$9,349	41	0.998	1.002
STEM degrees	22%	13%	41	0.999	1.001
Teacher ratings	3.5	0.5	41	0.997	1.003
Career salary	$93,817	$15,340	42	1.000	1.000
Tuition costs	$12,332	$9,349	41	0.144	6.943
Total enrollments	30,016	12,337	41	0.584	1.713
Student-to-faculty ratios	17.8	3.4	41	0.603	1.657
Class sizes (percentage <20)	40%	10%	41	0.704	1.421
Four-year graduation rates	38%	18%	41	0.538	1.858
Students rcv. fin. aid	28%	12%	41	0.404	2.477
Average awards	$9,684	$6,393	41	0.133	7.534
Graduation rates	64%	16%	41	0.286	3.497
Students staying in state	61%	18%	41	0.683	1.464
Number of faculty	12.6	7.7	41	0.654	1.528

SD=standard deviation; N=number; Tol.=tolerance; VIF=variance inflation factor

Finally, a multiple regression was performed to see whether tuition costs (H4), number of faculty (H6a), total enrollments (H6b), student-to-faculty ratios (H7), class sizes (H8), four-year graduation rates (H9), students receiving financial aid (H10), average awards (H11), graduation rates (H12), and students staying in state (H13) were associated with higher teacher ratings. Analysis of standardized residuals showed the data contained no outliers (std. residual min=-1.888; std. residual max=1.559), multicollinearity was not a concern (Table 3), and errors were independent (Durbin-Watson=1.48). Histograms of standardized residuals showed that data were approximately normally distributed, and the scatterplot of standardized residuals showed the data met the assumptions of homogeneity of variance and linearity. The results showed that tuition costs, number of faculty, total enrollments, student-to-faculty ratios, class sizes, four-year graduation rates, students receiving financial aid, average awards, graduation rates, and students staying in state did not explain a significant amount of variance in teacher ratings ($F(10,30=.934$, $p=.517$, $R2 =.24$, R2 adjusted =.02).

The results of all of the analyses are summarized in Table 4. Support was not found for any of the hypotheses associated with teacher quality. This interesting finding is discussed further.

Table 4. Hypotheses results

Hypotheses	t	p	Outcome
H1: Higher tuition costs will be associated with higher starting salaries.	2.60	0.013*	Accept
H2: Universities with higher percentages of STEM degrees will have higher starting salaries.	8.40	<.001***	Accept
H3: Higher starting salaries will be associated with higher career salaries.	5.26	<.001***	Accept
H4: Universities with higher tuition costs will be associated with higher teacher ratings.	1.25	0.221	Reject
H5: Universities with higher teacher ratings will be associated with higher starting salaries.	0.79	0.433	Reject
H6a: Universities with more faculty will have higher teacher ratings.	1.36	0.184	Reject
H6b: Universities with larger total enrollments will have higher teacher ratings.	0.07	0.944	Reject
H7: Universities with lower student-to-faculty ratios will have higher teacher ratings.	1.29	0.206	Reject
H8: Universities with smaller class sizes will have higher teacher ratings.	0.75	0.459	Reject
H9: Universities with higher 4-year graduation rates will have higher teacher ratings.	1.97	0.058	Reject
H10: Universities with a higher percentage of students receiving financial aid will have higher teacher ratings.	0.90	0.376	Reject
H11: Universities with higher average awards will have higher teacher ratings.	1.35	0.187	Reject
H12: Universities with higher graduation rates will have higher teacher ratings.	1.28	0.210	Reject
H13: Universities with a higher percentage of students staying in state will have higher teacher ratings.	1.53	0.136	Reject

5. Discussion

STEM education is a rapidly changing field of study. Educators need a clear understanding of the forces shaping it and how to respond to those changes. This research has shown that universities with more STEM degrees (Hypothesis 2) are associated with higher starting salaries, as well as higher overall career salaries (Hypothesis 3). However, this research has also shown that better teaching may not be associated with higher student starting salaries (Hypothesis 5). In fact, choosing to attend an expensive university (Hypothesis 1) and major in a STEM field may be the key to increasing future career earnings. Employers may view students' majors and alma maters as the primary indicators of their potential future value to their organization.

It is important to highlight that self-reported teacher ratings—such as those used in this study—are not a perfect indicator of teacher effectiveness or teacher quality. Teacher quality is an important aspect of education because it can raise student achievement and long-term success. It stands to reason that schools that can spend more on quality teaching should be able to recruit and retain better teachers. Thus, students paying high tuition rates should also benefit from better quality teaching. However; Hypothesis 4 was rejected because universities with higher tuition costs were not associated with higher teacher ratings. Future research might appropriately identify why this might be the case. It is possible that high tuition costs go to support other academic endeavors that do not directly contribute to teacher quality such as research or program development.

The aim of quality teaching is lasting achievement and success—not only in the classroom, but in the workplace as well. Thus, it stands to reason that better teaching should correlate with better starting salaries. However, Hypothesis 5 was not supported in that universities with higher teacher ratings were not associated with higher starting salaries. Thus, quality teaching does not necessarily equate to better paying jobs. Universities and students should pay close attention to other factors that affect salary regardless of teacher ratings.

Quality teaching can be limited by resource constraints, and schools with fewer resource constraints should be able to achieve better quality teaching. It stands to reason that universities with more available resources should enjoy higher quality teaching. However, our results demonstrated that this is not necessarily the case as Hypotheses 6a and 6b were rejected. Larger universities and those with more faculty and larger enrollments did not enjoy higher teacher ratings. It is important to note that using ratemyprofessor.com data is a limiting factor when interpreting the results.

Smaller class sizes can lead to more personalized education opportunities, enabling students to engage directly with teachers and peers in more intimate ways. However, the 7th and 8th hypotheses were rejected, meaning that small classes did not associate with higher quality teaching experiences. It is very likely that individual teachers are more likely to affect the teaching experience than resource availability or class size. Universities wanting to impact teacher quality should focus on the individual teacher rather than attempting structural or organizational changes.

Students who feel encouraged and supported both in likelihood of successful graduation and through financial aid or other awards are likely to positively evaluate teachers. Family and community support are likely to play into this as well as students attending local universities are likely to have better family and community support. However, Hypotheses 9–13 were rejected in that this overall type of student support did not contribute to better perceptions of teaching. The 9th hypothesis was rejected in that universities with higher 4-year graduation rates did not have higher teacher ratings. The 10th hypothesis was rejected in that universities with higher percentages of students receiving financial aid did not have higher teacher ratings. Similarly, the 11th hypothesis was rejected in that universities with higher average awards did not have higher teacher ratings. Likewise, high graduation rates (Hypothesis 12) and staying in state (Hypothesis 13) did not positively impact teacher ratings.

Overall, these findings show that teacher quality is something that is unique to the teacher. Quality teachers can be found in every institution. Universities wanting to impact teacher quality have to focus on the individual teachers. Larger organizational or structural efforts do not necessarily equate to better teachers. Keeping focus on supporting the individual teacher is the best way to ensure quality teaching. Future research can look specifically at those high-performing teachers to see what attributes students value the most and explore how quality teaching can be taught and supported.

5.1. Conclusion, Limitations, and Future Research

Faculty and university administrators need to understand the importance of STEM education, the factors influencing teaching quality, and the need for effective pedagogical approaches for technology-intensive MIS courses. Online education and relatively new types of education like coding bootcamps are becoming more common. Traditional universities are struggling to see a path forward in a dynamic educational environment with increasing emphasis on STEM fields.

This research has made several contributions to the body of knowledge surrounding MIS and STEM-based education. First, it may be likely that majoring in a STEM field at an expensive university will yield greater lifetime earnings. Thus, the prestige of the university may play a bigger role in student earnings than we have identified. Future work may benefit from further study along these lines.

Second, the current study also hints at the notion that our current assumptions about teaching quality may need to be revisited. However, care must be taken when interpreting results around teacher effectiveness because a limitation of this study was using teacher ratings as a proxy for teacher effectiveness. As noted previously, ratemyprofessor.com is a limiting factor when considering the findings of the study because teacher effectiveness is a more complex concept than can be captured with the ratemyprofessor.com data. Further study in this domain is warranted.

Third, this research was unable to come to any significant conclusions about a variety of factors such as smaller universities, smaller class sizes, more faculty, higher graduation rates, and more scholarship funding. Our results indicated that these factors do not necessarily correlate with better teacher ratings and higher salaries. Future research should focus on teasing out whether these factors might contribute to better student outcomes.

6. References

Baroudi, J.J., & Igbaria, M. (1994). An examination of gender effects on career success of information systems employees. *Journal of Management Information Systems*, *11*(3), 181-201.

Bell, G. (2008). Bell's law for the birth and death of computer classes: A theory of the computer's evolution. *IEEE Solid-State Circuits Society Newsletter*, *13*(4), 8-19.

Beyer, S. (2008). Gender differences and intra-gender differences amongst management information systems students. *Journal of Information Systems Education*, *19*(3), 301-310.

Denny, K. (2014). The effect of abolishing university tuition costs: Evidence from Ireland. *Labour Economics*, *26*, 26-33.

Djajalaksana, Y.M. (2011). A national survey of instructional strategies used to teach information systems courses: An exploratory investigation. Ph.D. Dissertation, University of South Florida, Tampa.

Goenner, C.F., & Snaith, S.M. (2004). Accounting for model uncertainty in the prediction of university graduation rates. *Research in Higher Education*, *45*(1), 25-41.

Goldhaber, D., & Anthony, E. (2007). Can teacher quality be effectively assessed? National board certification as a signal of effective teaching. *The Review of Economics and Statistics*, *89*(1), 134-150.

Hill, M.C., & Epps, K.K. (2010). The impact of physical classroom environment on student satisfaction and student evaluation of teaching in the university environment. *Academy of Educational Leadership Journal*, *14*(4), 65.

Hirschheim, R., & Klein, H.K. (2012). A glorious and not-so-short history of the information systems field. *Journal of the Association for Information Systems*, *13*(4), 188.

Hemelt, S.W., & Marcotte, D.E. (2011). The impact of tuition increases on enrollment at public colleges and universities. *Educational Evaluation and Policy Analysis*, *33*(4), 435-457.

Hwang, D., Ma, Z., & Wang, M. (2015). The information systems core: a study from the perspective of IS core curricula in the US. *Information Systems Education Journal*, *13*(6), 27.

Izumi, T., Sukhwani, V., Surjan, A., & Shaw, R. (2021). Managing and responding to pandemics in higher educational institutions: initial learning from COVID-19. *International Journal of Disaster Resilience in the Built Environment*, 12(1), 51-66.

Looney, J. (2011). Developing high-quality teachers: teacher evaluation for improvement. *European Journal of Education*, *46*(4), 440-455.

Martín-Páez, T., Aguilera, D., Perales-Palacios, F.J., Vílchez-González, J.M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education,* 103, 799–822.

Mateo, M.A., & Fernandez, J. (1996). Incidence of class size on the evaluation of university teaching quality. *Educational and Psychological Measurement*, *56*(5), 771-778.

Mitchell, M., Leachman, M., & Saenz, M. (2019). State higher education funding cuts have pushed costs to students, worsened inequality. *Center on Budget and Policy Priorities*, 24, 9-15.

Mok, H.N. (2014). Teaching tip: The flipped classroom. *Journal of Information Systems Education*, *25*(1), 7.

O'Shea, P.G., & Bush, D.F. (2002). Negotiation for starting salary: Antecedents and outcomes among recent college graduates. *Journal of Business and Psychology*, *16*(3), 365-382.

Pascarella, E.T., Smart, J.C., & Smylie, M.A. (1992). College tuition costs and early career socioeconomic achievement: do you get what you pay for? *Higher Education*, *24*(3), 275-290.

Pfeffer, J., & Fong, C.T. (2004). The business school 'business': Some lessons from the US experience. *Journal of Management Studies*, *41*(8), 1501-1520.

Roth, P.L., & Clarke, R.L. (1998). Meta-analyzing the relation between grades and salary. *Journal of Vocational Behavior*, *53*(3), 386-400.

Schweitzer, L., Lyons, S., Kuron, L.K.J., & Ng, E.S.W. (2014). The gender gap in pre-career salary expectations: a test of five explanations. *Career Development International*, *19*(4), 404-425.

Seidel, T., & Shavelson, R.J. (2007). Teaching effectiveness research in the past decade: The role of theory and research design in disentangling meta-analysis results. *Review of Educational Research*, *77*(4), 454-499.

Stefanidis, A., & Fitzgerald, G. (2010). Mapping the Information Systems curricula in UK universities. *Journal of Information Systems Education*, *21*(4), 391-410.

Stefanidis, A., Fitzgerald, G., & Counsell, S. (2013). IS curriculum career tracks: a UK study. *Education+ Training*, *55*(3), 220-233.

Tétard, F., & Patokorpi, E. (2005). A constructivist approach to information systems teaching: A case study on a design course for advanced-level university students. *Journal of Information Systems Education*, *16*(2), 167-176.

Timmerman, T. (2008). On the validity of RateMyProfessors.com. *Journal of Education for Business*, *84*(1), 55-61.

Topi, H., Valacich, J.S., Wright, R.T., Kaiser, K., Nunamaker Jr, J.F., Sipior, J.C., & de Vreede, G.J. (2010). IS 2010: Curriculum guidelines for undergraduate degree programs in information systems. *Communications of the Association for Information Systems*, *26*(1), 18.

Williams, D.D., Cook, P.F., Quinn, B., & Jensen, R.P. (1985). University class size: Is smaller better? *Research in Higher Education*, *23*(3), 307-318.

Xue, Y., & Larson, R.C. (May 2015). STEM crisis or STEM surplus? Yes and yes. *Monthly Labor Review*, U.S. Bureau of Labor Statistics, Washington, DC.

Scale Analysis of Natural Convection Over a Heated Vertical Plate

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Abstract

Scale analysis is used to estimate the order of magnitude of desired quantities when analytical or numerical solution is difficult to achieve. This paper presents a derivation of the governing equations of convection heat transfer, specifically natural convection, along with two methods of scale analysis, one derived by Bejan and the other by Capobianchi and Aziz. Both methods of scale analysis were used to verify, support, and compare the results of a previous experiment conducted at Southern Utah University. This previous experiment investigated the thickness of the laminar thermal boundary layer caused by natural convection over a heated vertical plate with constant heat flux. Scale analysis was used to estimate the thickness of the thermal boundary layer under these same conditions. Both methods of scale analysis predicted the same order of magnitude for the thickness of the thermal boundary layer as was evaluated in the previous experiment.

Introduction

Convection heat transfer is governed by the continuity, momentum, and energy equations (conservations laws). These laws, in differential form, are represented by highly nonlinear and coupled equations that are challenging to solve numerically. Because of the complexity of these equations and the difficulty of a numerical solution, scale analysis may be performed to estimate the order of magnitude of desired quantities. In scale analysis, the magnitude of each differential term in the conservation laws is estimated and then rearranged and simplified to give an order-of-magnitude estimate of the desired quantities.

Scale analysis is useful for many different types of convection with various boundary conditions. Bejan [1] modeled scale analysis of natural convection for fluids with both high and low Prandtl numbers on a flat vertical. Capobianchi and Aziz [2] conducted scale analysis on natural convection over a vertical surface for three boundary conditions: constant surface temperature, constant surface heat flux, and a plate heated from the backside. Ashraf and Wahid [3] overcame the challenge of finding numerical solutions using specialized software. They solved the conservation equations for natural convection over a vertical plate with constant heat flux. Similarly, Jha et al. [4] faced the difficulty of numerical solutions using the shooting method and other complex mathematics for natural convection over a vertical surface with nonuniform heating.

This report applies the scale analysis performed by Bejan as well as by Capobianchi and Aziz to natural convection over a vertical plate with constant heat flux. In this case, scale analysis will be used to estimate the order of magnitude of the thickness of the thermal boundary layer. This analysis was performed to verify and support the results of a previous experiment conducted at Southern Utah University (SUU) where the thermal boundary layer thickness was measured experimentally with a thermocouple apparatus and visually using Schlieren imaging [5]. The two methods of scale analysis will be compared to the results of the previous experiment for validation.

Theory

Governing Equations

The governing equations of convection heat transfer over a flat surface are the continuity, momentum, and energy equations. For simplicity, the flow is assumed to be two-dimensional (2D), steady-state,

with constant properties. The continuity equation arises from the conservation of mass. That is

$$\dot{m}_{in} = \dot{m}_{out} \tag{1}$$

where $\dot{m}_{in}$ is the mass flow rate (kg/s) entering the control volume and $\dot{m}_{out}$ is the mass flow rate (kg/s) leaving the control volume. Figure 1 shows the velocities of flow through a differential control volume, with the z-direction assumed to be of unit length. In this figure, u and v represent the velocities of flow (m/s) in the x and y directions, respectively.

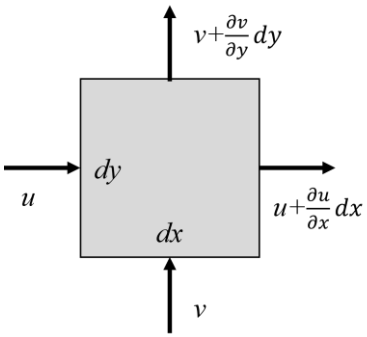

Figure 1. Differential control volume for conservation of mass.

Using Eq. (1) and substituting in the definitions of mass flow rate using the velocities in Fig. 1, the continuity equation for 2D, steady flow becomes [6, p. 395]

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2}$$

The momentum equations are derived from Newton's 2nd Law of Motion as [6, p. 395]

$$ma = F_{net} \tag{3}$$

where m is the mass of the fluid (kg), a is the acceleration (m/s^2), and F_{net} is the sum of body forces (N) and surface forces (N) acting on the fluid. Figure 2 shows the surface forces acting on a differential control volume in the x-direction. In this figure, τ and P represent shear and pressure forces, respectively.

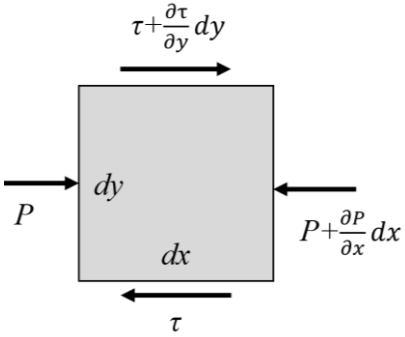

Figure 2. Differential control volume for conservation of momentum in the x-direction.

The acceleration in the x-direction can be obtained by taking the total derivative of the x-velocity, u as [6, p. 396]

$$a_x = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} \tag{4}$$

The mass of the control volume can be expressed as the product of density and volume. Equation (4) can be substituted into Eq. (3) along with the surface forces (Fig. 2). Ignoring body forces and noting that $\tau = \mu(\partial u/\partial y)$, the x-momentum equation becomes [6, p. 396]

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = \mu\frac{\partial^2 u}{\partial y^2} - \frac{\partial P}{\partial x} \tag{5}$$

where ρ is the density (kg/m^3) of the fluid and μ is the dynamic viscosity (Pa·s). A similar derivation can be performed to obtain the y-momentum equation.

The energy equation results from the conservation of energy using the 1st Law of Thermodynamics. This states that the rate of energy change for a steady-state system is zero. The net rate of energy change is due to heat and mass, assuming no work is done. The rate of energy change (W) due to mass within a differential control volume in the x-direction can be expressed as [6, p. 398]

$$\Delta\dot{E}_{m_x} = -\rho c_p\left(u\frac{\partial T}{\partial x} + T\frac{\partial u}{\partial x}\right)dxdy \tag{6}$$

where c_p is the specific heat capacity (J/kg·K) of the fluid and T is the temperature (K). The rate of energy change in the y-direction can be expressed similarly to Eq. (6). Combining the x and y directions results in the total rate of energy change due to mass being [6, p. 398]

$$\Delta \dot{E}_m = -\rho c_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) dxdy \tag{7}$$

The total rate of energy change due to heat (W) can be expressed using Fourier's Law of Conduction in the x and y directions. For a two-dimensional (2D) conduction heat transfer, Fourier's law yields [6, p. 398]

$$\Delta \dot{Q} = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) dxdy \tag{8}$$

where k is the thermal conductivity (W/m·K) of the fluid. The complete energy equation is obtained by combining Eqs. (7) and (8) as [6, p. 398]

$$\rho c_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \tag{9}$$

where $\frac{k}{\rho c_p}$ can be replaced by α, the thermal diffusivity (m^2/s). Together, Eqs. (2), (5), and (9) govern the steady-state convection heat transfer for a two-dimensional surface .

In the case of natural convection, gravitational forces cannot be ignored as a body force. A gravitational term must be added to the x-momentum equation, which turns Eq. (5) to

$$\rho \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = \mu \frac{\partial^2 u}{\partial y^2} - \frac{\partial P}{\partial x} - \rho g \tag{10}$$

where g is the gravitational constant (m/s^2). Outside the boundary layer where $u = v = 0$, the variation in pressure is equal to the gravitational term according to Eq. (10). Assuming the variation in pressure within the boundary layer is negligibly different from the variation in pressure outside the boundary layer, then the pressure term in Eq. (10) can be replaced with $-\rho_\infty g$, where ρ_∞ is the density of the fluid outside the boundary layer. The volumetric expansion coefficient (1/K), represented by β, when assuming constant pressure, can be expressed as [6, p. 536]

$$\beta = -\frac{1}{\rho} \frac{\rho_\infty - \rho}{T_\infty - T} \tag{11}$$

where T_∞ is the ambient temperature (K). It should be noted that for an ideal gas $\beta = 1/T$ [5, p. 536]. Equation (11) can be rearranged and substituted into Eq. (10) to give [6, p. 538]

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \nu \frac{\partial^2 u}{\partial y^2} + g\beta (T - T_\infty) \tag{12}$$

where v is the kinematic viscosity (m^2/s) of the fluid. Note that the y-momentum equation can be obtained by a similar analysis.

Scale Analysis

Bejan Scale Analysis

Bejan scale analysis starts with estimating the scale of x and y for a vertical surface as $x \sim \delta_T$ and $y \sim H$ respectively. In this expression, δ_T is the thickness of the thermal boundary layer (m) and H is the height of the plate (m). Applying these scales to the continuity equation, Eq. (2) becomes

$$\frac{u}{\delta_T} \sim \frac{v}{H} \tag{13}$$

Applying scale analysis to the energy equation, the terms in Eq. (9) can be represented as

$$u\frac{\Delta T}{\delta_T};\ v\frac{\Delta T}{H};\ \alpha\frac{\Delta T}{{\delta_T}^2};\ \alpha\frac{\Delta T}{H^2} \tag{14}$$

Noting that $\delta T << H$, the last term in Eq. (14) can be considered negligible and, from Eq. (13), the first and second terms in Eq. (14) are of the same scale and only one needs to be considered. In the case of a vertical surface, the y-direction is of interest, therefore the second term is only considered in this analysis . Then, from Eq. (14), it can be shown that the scale of v is

$$v \sim \frac{\alpha H}{{\delta_T}^2} \tag{15}$$

Applying scale analysis to the y-momentum equation yields

$$\frac{uv}{\delta_T};\ \frac{v^2}{H};\ v\frac{v}{{\delta_T}^2};\ g\beta\Delta T \tag{16}$$

where once again the first and second terms in Eq. (16) are of the same scale according to Eq. (13) and only one needs to be considered . Each term in Eq. (16) can be divided by $g\beta\Delta T$ yielding

$$\frac{v^2}{Hg\beta\Delta T};\ \frac{vv}{{\delta_T}^2 g\beta\Delta T};\ 1 \tag{17}$$

where the first term represents inertia, the second term friction, and the third term buoyancy. Rayleigh's Number for a vertical plate of height H and Prandtl's Number are defined as [6, p. 390, 541]

$$Ra_H = \frac{g\beta\Delta T H^3}{\alpha\nu} \tag{18}$$

$$Pr = \frac{\nu}{\alpha} \tag{19}$$

where the Prandtl Number is defined as the ratio of the molecular diffusivity of momentum to the molecular diffusivity of heat. For gases, the Prandtl Number is approximately one. Using these definitions and the scale of v in Eq. (15), the terms in Eq. (17) can be rewritten as

$$\left(\frac{H}{\delta_T}\right)^4 {Ra_H}^{-1} Pr^{-1};\ \left(\frac{H}{\delta_T}\right)^4 {Ra_H}^{-1};\ 1 \tag{20}$$

Both the inertial term and the frictional term in Eq. (20) must be of scale 1 to match the buoyancy term of 1. The inertial and frictional terms are very similar except for Prandtl's Number. For air Pr ≈ 1, therefore these terms can be considered to be the same scale and either one can be used for scale analysis. The scale of ΔT can be obtained by rearranging Fourier's Law of Conduction as

$$\Delta T \sim \frac{q"\delta_T}{k} \tag{21}$$

where q" is the heat flux (W/m^2) through the surface. Using the scale of ΔT in the definition of RaH yields Rayleigh's number as a function of heat flux as

$$Ra_H = \frac{g\beta H^3 q"\delta_T}{k\alpha\nu} \tag{22}$$

Substituting Eq. (22) into either the inertial or frictional term in Eq. (20) yields

$$\frac{Hk\alpha\nu}{{\delta_T}^5 g\beta q"} \sim 1 \tag{23}$$

This scale can be rearranged to obtain

$${\delta_T}^5 \sim \frac{Hk\alpha\nu}{g\beta q"} \tag{24}$$

To simplify this relationship, Raq" can be defined as

$$Ra_{q"} = \frac{g\beta H^4 q"}{k\alpha\nu} \tag{25}$$

Finally, substituting the quantity in Eq. (25) into Eq. (24) yields a simple representation of the scale of the thermal boundary layer thickness as

$$\delta_T \sim H(Ra_{q"})^{-\frac{1}{5}} \tag{26}$$

This relationship is the result of Bejan scale analysis and can be used to estimate the scale of δT in natural convection over a vertical surface with constant heat flux.

Capobianchi and Aziz Scale Analysis

Capobianchi and Aziz scale analysis follows a similar process with x~δT and y~H. The relationship in Eq. (13) is used in this method of scale analysis. However, the scale of *v* in Eq. (15) is written in a different form as

$$v \sim \frac{\alpha/H}{(\delta_T/H)^2} \tag{27}$$

Similarly, from the energy equation, the scale of u can be represented as

$$u \sim \frac{\alpha/H}{\delta_T/H} \tag{28}$$

Applying these relationships to the y-momentum equations yields

$$\left(\frac{\alpha/H}{\delta_T/H}\right)\left(\frac{\alpha/H}{\delta_T(\delta_T/H)^2}\right) + \left(\frac{\alpha/H}{(\delta_T/H)^2}\right)\left(\frac{\alpha/H}{H(\delta_T/H)^2}\right) \sim \frac{\nu(\alpha/H)}{{\delta_T}^2(\delta_T/H)^2} + g\beta\Delta T \tag{29}$$

where the terms on the lefthand side are of the same scale according to the continuity equation, and either one can be ignored. In this case, the second term will be considered in this analysis. Dividing both sides of Eq. (29) by $g\beta\Delta T$ and rearranging greatly simplifies the relationship as

$$\frac{1}{(\delta_T/H)^4}\left(\frac{\alpha^2}{H^3 g\beta\Delta T} + \frac{\nu\alpha}{H^3 g\beta\Delta T}\right) \sim 1 \tag{30}$$

Substituting Eq. (21) into Eq. (30) yields

$$\frac{1}{(\delta_T/H)^5}\left(\frac{k\alpha^2}{H^4 g\beta q"} + \frac{k\nu\alpha}{H^4 g\beta q"}\right) \sim 1 \tag{31}$$

It should be noted that the terms inside the parentheses match the definitions of the modified Rayleigh's Number as it was expressed in Eq. (25) and the Boussinesq Number, which is defined as the product of

Rayleigh's Number and Prandtl's Number [2]. Using Eq. (25) a modified Boussinesq Number for constant heat flux can be represented as

$$Bo_{q"} = Ra_{q"} \cdot Pr = \frac{H^4 g\beta q"}{k\alpha^2} \tag{32}$$

Substituting Eqs. (25) and (32) into Eq. (31) yields

$$\frac{1}{(\delta_T/H)^5}\left(\frac{1}{Bo_{q"}} + \frac{1}{Ra_{q"}}\right) \sim 1 \tag{33}$$

Using the relationship in Eq. (32) and solving Eq. (33) for δ_T yields

$$\delta_T \sim H\left(\frac{1+Pr}{Bo_{q"}}\right)^{\frac{1}{5}} \tag{34}$$

This relationship is the result of Capobianchi and Aziz scale analysis and can also be used to estimate δ_T for natural convection over a vertical plate receiving constant heat flux.

Results and Discussion

According to the data from the SUU experiment [5] (presented in Appendix A), the average air temperature within the thermal boundary layer was approximately 32°C. The properties of air at this temperature were used for scale analysis. Equations (26) and (34) were used to estimate the order of magnitude of the thickness of the thermal boundary layer in the SUU experiment. Using Eq. (26), Bejan scale analysis predicted a value of 0.094 in for the boundary layer thickness. Using Eq. (34), Capobianchi and Aziz scale analysis estimated a thickness of 0.112 in. These values along with the thickness measured in the SUU experiment are summarized in Table 1.

Table 1. Experimental value and scale analysis estimates

Variable	Previous experiment	Scale analysis	
		Bejan	Capobianchi and Aziz
Thickness, δ_T (in)	0.75	0.094	0.112

The thickness of the thermal boundary layer in the SUU experiment was measured to be approximately 0.75 in. It is important to note that the purpose of scale analysis is not to accurately predict the experimental value itself but to predict the proper order of magnitude. Both methods of scale analysis predicted the correct order of magnitude for the thermal boundary layer thickness. This result supports and adds validity to the

experimental data found in the experiment conducted at SUU and helps verify its accuracy.

Although both methods of scale analysis provide the scale predictions, Capobianchi and Aziz's method gave a slightly better estimatation. This is likely because of the role of Prandtl's number in their method as opposed to Bejan's method. Bejan scale analysis assumes that Prandtl Number for air is approximately 1. This was one of the key simplifying assumptions made to arrive at Eq. (26). However, Capobianchi and Aziz scale analysis does not make this assumption, and the Prandtl Number appears in Eq. (34). This allowed the Prandtl Number to be calculated using the properties of air at the average temperature within the thermal boundary layer. Using Eq. (19), the calculated Prandtl Number was approximately 0.728. This value is over 25% different from the assumption made in Bejan scale analysis. However, despite the difference between the Prandtl Numbers used in each method, both methods predicted approximately the same order of magnitude for the thermal boundary layer thickness. This fact supports the idea that both methods of scale analysis give meaningful and accurate results.

Conclusions and Recommendations

Two methods of scale analysis were derived and used to verify and validate the results of a previous experiment conducted at SUU. Both Bejan's and Capobianchi and Aziz's methods predicted the order of magnitude of the thermal boundary layer thickness found in the SUU experiment for natural convection over a vertical plate with constant heat flux. These scale analysis estimates achieved the goal of supporting and validating the results of the SUU experiment. The results presented also help illustrate how scale analysis is useful when analytical or numerical solutions are significantly more difficult to achieve.

Moving forward, it may be useful to investigate the feasibility of applying the shooting method of solving partial differential equations to this problem. Jha et al. [4] used this method, which reduces boundary value problems to initial values problems that can be solved assuming different conditions until the solution satisfies the correct boundary values. A proper numerical solution could further validate and support experimental results and be used to compare the accuracy of scale analysis. In addition, the usefulness of scale analysis within natural convection problems can be further investigated by applying the method to problems with varying conditions such as the magnitude of the heat flux, plate size, using a cold plate rather than a hot plate, and different plate geometries. Scale analysis presents a promising method to make

useful predictions in complex problems when numerical solutions and softwares are not available.

References

[1] Bejan, A., *Convection Heat Transfer*, John Wiley & Sons, 2013.

[2] Capobianchi, M., and Aziz, A., (2012) "*A scale analysis for natural convective flows over vertical surfaces*," Int. J. Thermal Sci. 54, 82-88.

[3] Ashraf, N. and Wahid, M.N., (2023) "*Natural convection over a vertical flat plate: A numerical and experimental investigation*," AIP Conference Proceedings 2749, pp. 040004-1-040004-11.

[4] Jha, A.K., Shukla, P., and Ghosh, P., (2022) "*Free convection boundary layer correlations for a vertical plate with nonuniform heating*," Numer. Heat Transf. B: Fundamentals, 82 (6), 243-255.

[5] Hatch, D., Peterson, J., Brown, B., Katnick, J., and Siahpush, A.S., (2023) "*Natural convection over a heated vertical plate*," Journal of the Utah Academy of Sciences, Arts, and Letters, 100, 217-234.

[6] Cengel, Y.A., and Ghajar, A.J., (2015) *Heat and Mass Transfer: Fundamentals & Applications*, Fifth Edition. McGraw-Hill, New York.

Appendix A

This appendix presents the data from the experiment performed at Southern Utah University and the properties of air used for scale analysis.

Table A1. Thermocouple measurements (°C) of the thermal boundary layer

Height	1/8in	1/4in	1/2in	3/4in	1in	5/4in
8in	45.77	38.16	26.36	25.24	23.69	23.60
7in	45.38	35.38	26.07	25.15	23.66	23.62
6in	42.17	34.27	25.83	24.60	23.55	23.55
5in	43.42	33.83	25.66	24.44	23.70	23.51
4in	42.82	31.64	25.07	24.28	23.55	23.52
3in	40.77	30.84	25.08	24.05	23.47	23.51
2in	40.07	28.50	24.50	23.62	23.40	23.31
1in	38.12	27.61	23.96	23.40	23.30	23.22
0in	32.07	23.62	23.16	23.06	23.04	23.07

Reproduced with permission from Hatch et al. [5]

The properties of air at 30°C used for scal analysis computations were thermal conductivity, k = 0.02588 W/m·K, thermal diffusivity, α = 2.208 × 10^{-5} m^2/s, and kineatmic viscosity, v = 1.608 × 10^{-5} m^2/s.

Analysis of Air Subjected to a Constant Heat Flux Within a Tube Under Forced Convection

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ABSTRACT

This analysis aimed to verify known theoretical prediction for the convection heat transfer coefficient (h) by subjecting air to a constant heat flux while undergoing forced convection in a thin-walled copper tube. The linear relationship between the surface temperature of the tube and the temperature of airflow along the tube was also investigated. A pitot probe was used with a manometer to determine the velocity of air flowing through the tube. A constant heat flux was applied to the outer surface of the copper tube using heating tape. The temperatures of air at the inlet and outlet of the copper tube were recorded and compared with the temperatures of the outer surface of the tube. The testing was performed first with the tube at room temperature and second with the tube preheated to achieve steady state in a shorter time. The temperature and velocity measurements were used to experimentally determine the convection heat transfer coefficient. This value was then compared with

a theoretical value. The percent difference for these values was under 2% for both methods.

INTRODUCTION

The motivation for this experiment was a study performed previously to calculate the convection heat transfer coefficient of air using forced convection in a tube [1]. The rate at which heat exchanges between air and a surface depends on the convection heat transfer coefficient for the air. Several parameters are required for the computation of the convection heat transfer coefficient, which can lead to complex equations that are only fitted for certain conditions. For every condition, a verification of the equation can be made via an experimental set-up. One such method of experimentation can be performed by flowing air through a thin-walled cylinder while constant heat flux is applied to the surface of the tube [1]. This flow of air is known as forced convection [2], and the boundary conditions of a thin-walled tube are analyzed in [3].

The outer surface of the tube also transfers heat to the ambient air. This heat transfer is presented in [4]. To reduce the wasted energy and maximize the heat transfer to the air inside the tube, the tube may be insulated. This relationship with axial distance is shown through the calculation of convective heat transfer coefficients of surfaces under natural convection [5].

The benefits of a small-diameter tube can be seen by studying the flow diagrams for cylinders. These analyses show that in smaller tubes, the temperature is more homogenous throughout the cross-section of the tube because of better mixing. These diagrams can be examined with an analysis of the heat transfer for ducts [6]. This temperature increases throughout the length of the tube, al though this increase is dependent on the speed of the airflow. As the airflow speed increases, the convection heat transfer coefficient increases. This is shown in an analysis of the convection heat transfer in circular tubes [7].

These factors all contribute to the computation of the convection heat transfer coefficient. Once the convection heat transfer coefficient has been determined for a specific case, it can be used in the testing and design of materials by evaluating their thermal capabilities. This method is exemplified by examining the convection heat transfer coefficient influence on thermal building design [8].

In this experiment performed at Southern Utah University (SUU), air will be subjected to a constant heat flux under forced convection through a 57-in thin copper tube to evaluate the convection heat transfer

coefficient and compare the relationship between the surface temperature of the tube and the temperature of the air at the inlet and outlet of the tube.

THEORY

This experiment utilized surface constant heat flux to heat air as it passed through a copper tube. To predict the heat transfer coefficient, we used the ideal gas law to determine the density of the air as [9]

$$\rho = \frac{P_s}{RT_e} \tag{1}$$

where ρ is the density of the air (kg/m^3), P_s is the absolute static pressure of the atmosphere (Pa) evaluated from the Cedar City Airport pressure data [10], R is the specific gas constant (287 J/kg·K) [11], and T_e is the tube exit absolute temperature (K).

A pitot probe was placed at the outlet of the tube to measure both static and stagnation pressure to determine the change in pressure using Bernoulli's equation as [9]

$$\frac{P_t}{\rho g} + \frac{V_{stag}^2}{2g} + z_1 = \frac{P_s}{\rho g} + \frac{V_{e,avg}^2}{2g} + z_2 \tag{2}$$

where P_t is the total or stagnation gauge pressure (Pa), g is the gravitational acceleration (m/s^2), V_{stag} is the velocity of the flow of air at the stagnation point (m/s), z_1 is the height of the stagnation point (m), $V_{e,avg}$ is the average velocity of the flow of air at the exit of the tube (m/s), and z_2 is the height of the exit point (m).

The air is stagnated, so V_{stag} is equal to zero [9], and Z_1=Z_2. Considering these assumptions, Eq. (2) simplifies to

$$\frac{P_t}{\rho} = \frac{P_s}{\rho} + \frac{V_{e,avg}^2}{2} \tag{3}$$

Equation (3) can then be used to solve for the difference in pressures (ΔP) as

$$(\Delta P) = P_t - P_s = \frac{V_{e,avg}^2 \rho}{2} \tag{4}$$

A manometer was used in conjunction with the pitot probe to determine ΔP. The concept of the pitot probe at the outlet of the tube is shown in Figure 1.

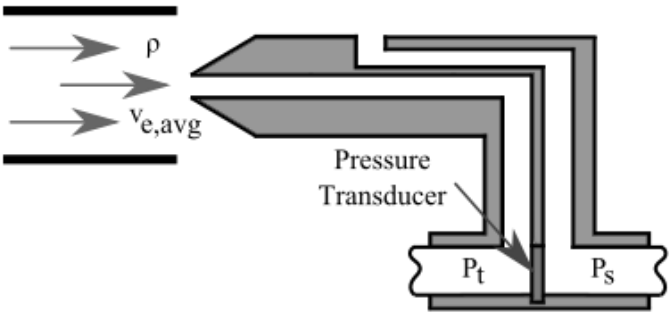


Figure 1. The pitot probe at the outlet of the tube.

The manometer connects to both the P_t and P_s outlets of the pitot probe, and the height difference of the water in the manometer is then read. The difference in pressure can then be calculated using [9]

$$\Delta P = \rho_w g \Delta h \tag{5}$$

where ΔP is the change in pressure of the system (Pa), ρ_w is the density of the water (kg/m^3), and Δh is the change in height of the water in the manometer. The ΔP is then used to solve for the average velocity at the outlet of the tube [9] by rearranging Eq. (4) into

$$V_{e,avg} = \sqrt{\frac{2\Delta P}{\rho}} \tag{6}$$

This velocity is then used to determine the Reynolds number of the flow. The Reynolds number (Re) is defined as [11]

$$Re = \frac{V_{e,avg} D}{\nu} \tag{7}$$

where D is the inside diameter of the circular tube (m) and ν is the kinematic viscosity of the fluid (m^2/s). The Reynolds number is then used to determine whether the flow is turbulent or laminar. For internal flow, if $Re > 10{,}000$ then the flow is considered turbulent [9]. For a turbulent flow, the entrance regions are defined as [11]

$$L_{h,turbulent} \approx L_{t,turbulent} \approx 10D \tag{8}$$

where $L_{\mathrm{h,turbulent}}$ is the hydrodynamic entrance region (m) and $L_{\mathrm{t,turbulent}}$ is the hydrodynamically fully developed region (m). These regions are presented in Figure 2.

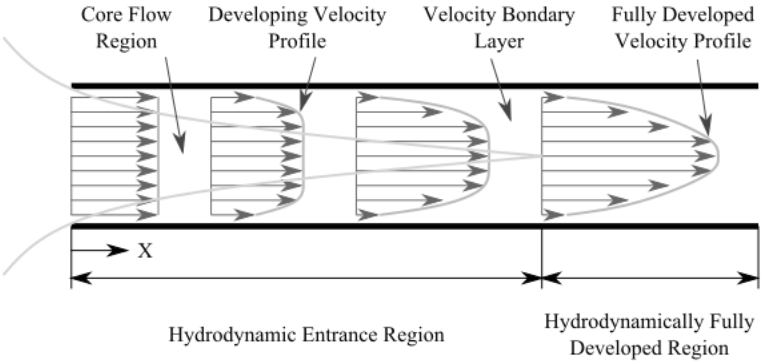


Figure 2. The development of the velocity boundary layer in a tube.

In the region after the entrance region, the hydrodynamically fully developed region, the fluid is thoroughly mixed [11]. A constant heat flux can then be applied to the fluid and the temperature difference between two points can be calculated. The heat flux configuration is presented in Figure 3.

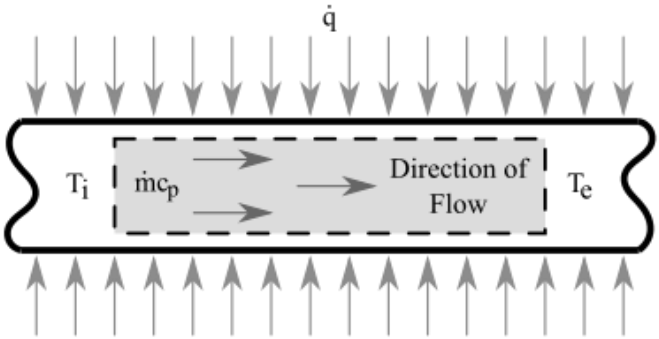


Figure 3. Heat transfer to a fluid through a thin-walled tube.

In this figure, $\dot{q}$ is the constant heat flux applied at the surface (W/m^2), T_{i} is the inlet temperature of air (℃), $\dot{m}$ is the mass flow rate (kg/s), c_{p} is the specific heat (J/kg·K), and T_{e} is the exit temperature of

air (°C). The total rate of heat transfer can be evaluated from the heat flux on the tube as [11]

$$\dot{Q} = \dot{q} A_{\mathrm{s}} \tag{9}$$

where $\dot{Q}$ is the rate of heat transfer rate (W) and A_{s} is the outside surface area of the tube (m^2). The $\dot{Q}$ can also be expressed as [11]

$$\dot{Q} = \dot{m} c_{\mathrm{p}} (T_{\mathrm{e}} - T_{\mathrm{i}}) \tag{10}$$

The mass flow rate can be evaluated as [11]

$$\dot{m} = \rho V_{\mathrm{e,avg}} A_{\mathrm{cs}} \tag{11}$$

where $\mathrm{A_{Cs}}$ is the inside cross-sectional area of the tube (m^2). Substituting Eq. (11) into Eq. (10) yields

$$\dot{Q} = \rho V_{\mathrm{e,avg}} A_{\mathrm{cs}} c_{\mathrm{p}} \Delta T \tag{12}$$

where $T_{\mathrm{e}} - T_{\mathrm{i}}$ is defined as ΔT. This equation uses the experimentally measured temperature values to evaluate $\dot{Q}$. Comparing this value with the measured $\dot{Q}$ will determine the amount of heat transfer lost to the environment. Equation (12) can then be solved for ΔT as

$$\Delta T = \frac{\dot{Q}}{\rho V_{\mathrm{e,avg}} A_{\mathrm{cs}} c_{\mathrm{p}}} \tag{13}$$

The $\dot{Q}$ used in this equation is the measured rate of heat transfer from the constant heat flux supplied by a heating element. The ΔT evaluated from Eq. (13) is then compared with the experimentally measured ΔT to determine the percent error for the temperature change. The convection heat transfer coefficient can be evaluated as [11]

$$h = \frac{\dot{Q}}{A_{\mathrm{s}} \Delta T} \tag{14}$$

where h is the convection heat transfer coefficient ($\mathrm{W/m^2 \cdot K}$). The $\dot{Q}$ used in this equation is the calculated value found in Eq. (12). The h value from Eq. (14) provides an experimental value for h, which can then be compared with the empirical value expressed as [11]

$$h = 0.023 \left(\frac{k}{D}\right) Re^{0.8} Pr^{0.4} \tag{15}$$

where k is the thermal conductivity of the fluid (W/m·K) and Pr is the Prandtl number of the fluid (unitless), which is raised to the power of 0.4 for heating the fluid. Eq. (15) is valid when $0.7 \leq Pr \leq 160$ and $Re > 10{,}000$ [11].

MATERIALS

The following materials and equipment were used in the experiment (see Appendix for sources).

- 30-ft automatic electric heat cable
- 12 thermocouples
- Husky mini regulator with ¼-in gauge
- SURAIELEC watt meter
- Manometer
- Insulation
- ¾-in × 5-ft copper type L hard temper straight tube
- Air hose with ¼-in connector
- ¼-in × ¾-in quick connect brass garden hose irrigation blow fitting
- ¾-in MHT brass coupling fitting
- ¾-in copper pressure cup × FIP female adapter fitting
- Two ¼-in × ¼-in NPT Female Industrial Coupler
- ¼-in MNPT × ¼-I/M industrial steel plug
- Pitot probe

PROCEDURE

Set-Up

- Wrap the length of the copper tube with the 30-ft automatic electric heat cable.
- Attach the thermocouples to the tube.
- Install the insulation.
- Connect the air hose to the tube using thread sealant tape in the following connection order:

1. Air hose
2. ¼-in × ¼-in NPT female industrial coupler
3. ¼-in MNPT × ¼ I/M industrial steel plug
4. Air pressure regulator
5. ¼-in × ¼-in NPT female industrial coupler

6. ¼-in × ¾-in quick connect brass garden hose irrigation blow fitting
7. ¾-in MHT brass coupling fitting
8. ¾-in copper pressure cup × FIP female adapter fitting
9. ¾-in copper type L hard temper straight tube

- Use the manometer to measure pressure.

This configuration can be seen in Figure 4. The setup of the experiment is shown in Figure 5, and the manometer and pitot probe are shown in Figure 6.

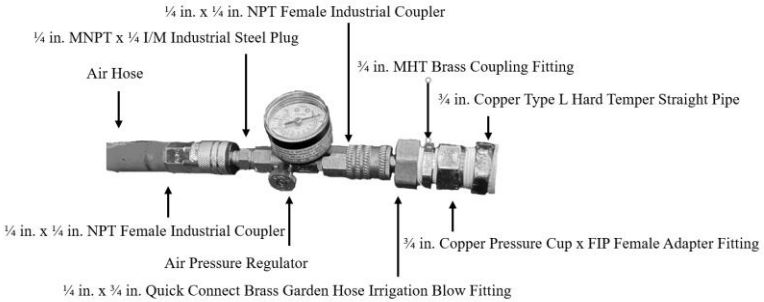


Figure 4. Air hose to tube attachment and fittings.

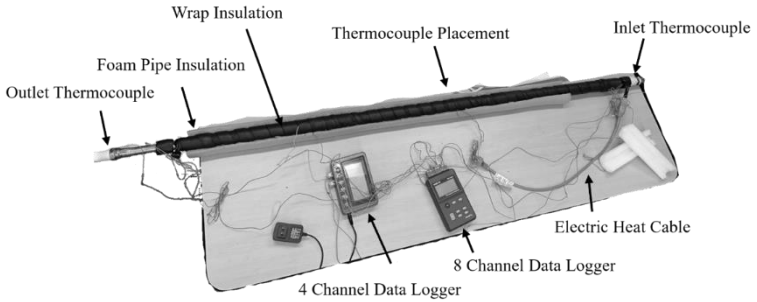


Figure 5. Overhead view of the testing apparatus.

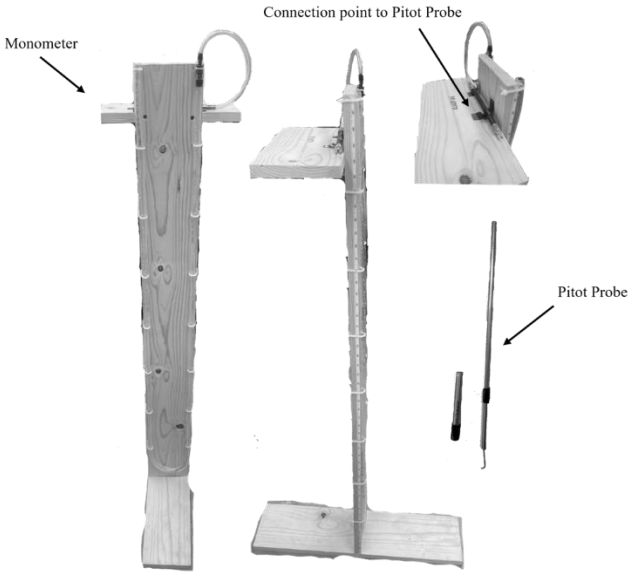


Figure 6. Depiction of the manometer and pitot probe.

The following steps are for Test Method 1, which has the tube starting at room temperature:

- Plug in the electric heat cable to the electric usage monitor.
- Apply ice to the thermostat on the electric heat cable (the cable will not activate until it reads a temperature below 40°F).
- Once a wattage is displayed on the electric usage monitor, start recording.
- Turn on the air compressor and open the pressure regulator.
- Allow the system to reach steady state.
- Record the wattage displayed on the electric usage monitor and the pressure of the pressure regulator, and measure the pressure difference using the manometer and the pitot probe. Ensure the pitot probe is measuring close to the thermocouple at the exit of the tube in the middle of the exit flow.

The following steps are for Test Method 2, which has the tube preheated:

- Plug in the electric heat cable to the electric usage monitor.

- Apply ice to the thermostat on the electric heat cable (the cable will not activate until it reads a temperature below 40°F).
- Allow the tube to reach 80°C.
- Start recording.
- Turn on the air compressor and open the pressure regulator.
- Allow the system to reach steady state.
- Record the wattage displayed on the electric usage monitor and the pressure of the pressure regulator, and measure the pressure difference using the manometer and the pitot probe. Ensure the pitot probe is measuring close to the thermocouple at the exit of the tube in the middle of the exit flow.

EXPERIMENTAL RESULTS

The tube parameters are presented in Table 1. The Prandtl number (Pr) and conduction heat transfer coefficient (k) were evaluated from the published values for air at the average temperature of the flow entering and exiting the tube (bulk temperature) [12]. The result of the evaluation is presented in Table 2.

Table 1. Copper tube dimensions

Variable	Value
Interior diameter (m)	0.0199
Surface area (m^2)	0.0907
Cross-sectional area (m^2)	0.0003

Table 2. Evaluated parameters for both experiments

Parameters	Test 1	Test 2
ΔP (Pa)	450.7	567.3
Ve,avg (m/s)	28.2	31.5
Tin (°C)	19.9	19.7
Tout (°C)	37.7	36.4
$\dot{Q}$ (W)	180.3	177.3
Re	33,736	37,762
ρair (kg/m3)	1.137	1.142
ν (m^2/s)	1.66 (10^{-5})	1.66 (10^{-5})
ΔTtheory (°C)	17.9	15.7
ΔTactual (°C)	17.8	16.7
Pr	0.7127	0.7127
k (W/m·K)	0.0268	0.0268
hactual (W/m2·K)	111.0	124.8
htheory	113.2	123.9

The speed of sound in dry air at 20°C is 343 m/s [9]. From velocities presented in Table 2, the Mach number is very low, and the assumption of air considered to be incompressible fluid is valid. The temperature of the airflow along with the temperatures taken on the surface of the tube are presented in Figures 7 and 8 for Tests 1 and 2, respectively. The data from 2 thermocouples that were placed in the same locations along the tube were averaged. Also, in these figures, the locations L_2 and L_1 denote where the thermocouples were placed relative to the outlet where L_2 = 0.48 m and L_1 = 0.97 m from the outlet (L_2 was closest to the outlet and $L_1$was closest to the inlet).

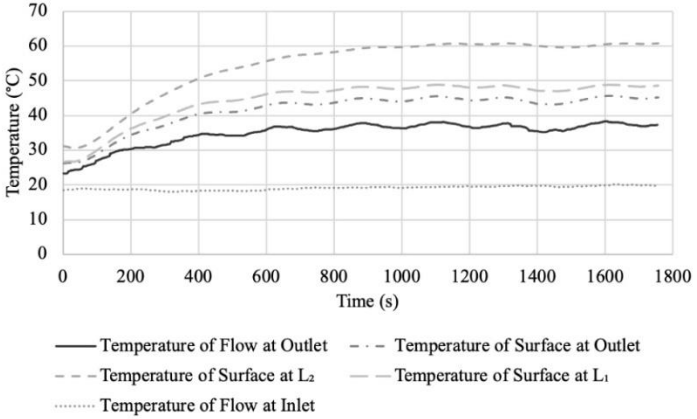


Figure 7. Temperature vs time of the flow and surfaces of the tube for Test 1.

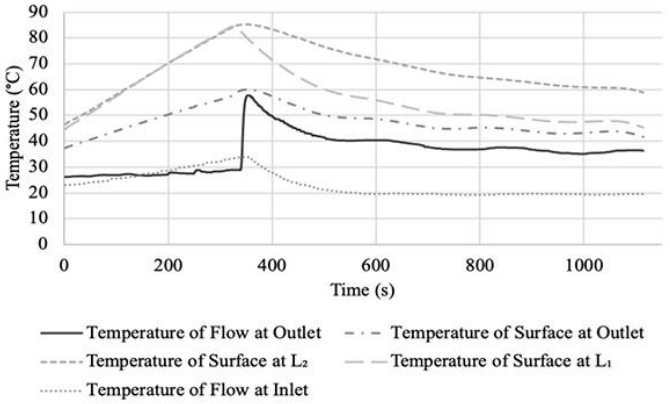


Figure 8. Temperature vs time of the flow and surfaces of the tube for Test 2.

DISCUSSION AND ANALYSIS

In Table 2, the experimental change in temperature for Test 1 was approximately $\Delta T_{\text{actual}} = 17.8°\text{C}$ and the theoretical value was approximately $\Delta T_{\text{theory}} = 17.9°\text{C}$. These two values have a percent difference of 0.63%. Using the evaluated velocity, the time for air to travel the full length of the tube is approximately 0.05 seconds (a very short time). This suggests that the convective heat transfer coefficient was high. From Table 2, the experimental and theoretical convective heat transfer coefficients were evaluated to be $h_{\text{actual}} = 111.0 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$ and $h_{\text{theory}} = 113.2 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$, respectively. This shows that the convective heat transfer coefficient of air can be approximated with minimal error using the process of this experiment. This evaluation also verifies the accuracy of the theoretical calculation of Eq. (15).

Figure 7 shows the temperatures of the surface of the tube while showing the temperature of the flow at the inlet and outlet of the tube. As expected, all of the temperatures are parallel to each other, when they reached steady state temperatures.

In Table 2, the experimental change in temperature for Test 2 was $\Delta T_{\text{actual}} = 16.7°\text{C}$ and the theoretical value was $\Delta T_{\text{theory}} = 15.7°\text{C}$. This difference, while not as accurate as the first test, still displays a very minimal error between the values. There was a different average velocity of the flow from the first test and, because of these varying conditions, the values changed slightly every time the experiment was conducted. With the increase in velocity, the time for air to travel the full length of the tube was 0.046 seconds. This is faster than the first test, which can also explain why there are lower values for the change in temperatures in this test. The air was still heated significantly in such a short period of time, again suggesting that the convective heat transfer coefficient was high. The experimental and theoretical coefficients were approximately $h_{\text{actual}} = 124.8 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$ and $h_{\text{theory}} = 123.9 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$, respectively. These values have an extremely low percent difference of approximately 0.71%.

Whereas in Test 1, the constant heat flux was applied at the same time as the flow of air, Test 2 had a different initial condition. In an attempt for the system to reach a steady-state value faster than in Test 1, the constant flux was applied first, and the middle of the tube was first heated to approximately 80°C before the airflow started. The temperatures collected from the middle of the tube at locations L_1 and L_2 were relatively similar while increasing in temperature. The other temperatures seen on the graph also increased as well. This temperature increase was due to the thermocouples experiencing conduction from the

tube while they were attached to the surface. This is not the case with the thermocouple measuring the outlet temperature of the flow because it was not attached to the surface of the tube. After the middle of the tube reached approximately 80°C, the airflow was started. This can be seen in Figure 8 at approximately 350 seconds, which shows the surface temperature values having a sharp decrease.

CONCLUSIONS

This experiment verified the theoretical prediction to measure the convection heat transfer coefficient of air with minimal error. The main source of error was the air flow, which was connected to an industrial air compressor. The compressor constantly recompresses air to fill the tank, which can cause fluctuations in the air pressure. Although this was minimized with the pressure regulator attached to the tube, it was not a perfect solution. Another source of error was the ambient temperature around the experimental set-up. The experiment was conducted in a heavily trafficked shop. Also, although the insulation around the tube was considered to be a perfect insulator, in reality, this would not be the case, and we experienced some wasted heat to the environment. Another source of error can be attributed to the accuracy of the measurement devices, specifically, the pitot probe, manometer, and the thermocouples.

Even with the sources of error described above, Test 1 and Test 2 resulted in a percent difference value of 1.98% and 0.71%, respectively, for the theoretical and experimentally calculated convective heat transfer coefficient of air. Although the initial conditions of the experiment can cause a change in the transient response of the system, only the steady-state response was used in the analysis of the convective heat transfer coefficient. This experiment also confirmed the relationship between the velocity of airflow and the convective heat transfer coefficient [7]. That is, as the velocity of the airflow is increased, the convective heat transfer coefficient also increases. As previously stated, the convective heat transfer coefficient can vary drastically. This is because of the numerous variables required for the computation of the coefficient. This experiment gives a valuable way to calculate such coefficient to accurately predict and analyze the heat transfer induced by air.

RECOMMENDATIONS

After analyzing the experimental data, several recommendations could be made to further explore the convective heat transfer coefficient of air flowing through a tube. These recommendations are to: (1) have a pitot probe at different locations continuously measuring the velocity of the airflow; (2) have thermocouples inside of the tube measuring the

exact temperature of the airflow rather than the surface temperature of the tube; (3) select a different tube material to gain knowledge of the system performance; and (4) vary the type of fluid that is flown through the tube because this could also significantly influence the convective heat transfer characteristics of the system. This exploration could provide further development of guidelines for selecting the most suitable heat transfer fluids in specific industrial and environmental settings.

ACKNOWLEDGMENTS

This project would not have been possible without the help and support of the Department of Engineering and Technology at Southern Utah University. Their contributions included providing the equipment and assistance from faculty.

BIBLIOGRAPHY

[1] W.R. Kaminski, "A series of heat transfer experiments for the mechanical engineering technology student," in *1998 Annual Conference*, Seattle, 1998.

[2] C.H. Transfer, "Engineering ToolBox," [Online]. Accessed November 2, 2023, at https://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html.

[3] S. Seghir-Ouali, D. Saury, S. Harmand, O. Phillipart, and D. Laloy, "Convective heat transfer inside a rotating cylinder with an axial air flow," *International Journal of Thermal Sciences,* vol. 45, pp. 1166-1178, 2006.

[4] J. Fernández-Seara, F.J. Uhía, and J.A. Dopazo, "Experimental transient natural convection heat transfer from a vertical cylindrical tank," *Applied Thermal Engineering,* vol. 31, pp. 1915-1922, 2011.

[5] H.B. Awbi, "Calculation of convective heat transfer coefficients of room surfaces for natural convection," *Energy and Buildings,* vol. 28, pp. 219-227, 1998.

[6] J. Kurnia, A.P. Sasmito, and A. Mujumdar, "Laminar convective heat transfer for in-plane spiral coils of non-circular cross sections ducts: A computational fluid dynamics study," *Thermal Science,* vol. 16, pp. 107-116, 2012.

[7] D. Yu, D. Zhang, L. Wu, X. Kong, and Q. Yue, "Analysis of the influence of convection heat transfer in circular tubes on ships in a polar environment," *Atmosphere*, vol. 13, pp. 149, 2022.

[8] J. Chávez-Galán, R. Almanza, and N. Rodríguez Cuevas, "Convective heat transfer coefficients: experimental estimation and its impact on thermal building design for walls made of different Mexican building materials," *Concreto y Cemento. Investigación y Desarrollo*, vol. 5, pp. 26–38, 2014.

[9] Y.A. Çengel and J.M. Cimbala, *Fluid Mechanics: Fundamentals and Applications*, McGraw-Hill Education, 2018.

[10] "Cedar City, Utah Aviation Weather Report and Forecast," [Online]. Accessed October 25, 2023, at https://www.usairnet.com/cgi-bin/launch/code.cgi?sta=KCDC&state=UT.

[11] Y.A. Çengal and A. Ghajar, *Heat and Mass Transfer: Fundamentals and Applications*, edition 5, New York, New York: McGraw-Hill education, 2015.

[12] P. Evans, "Properties of air at atmospheric pressure," [Online]. Accessed March 29, 2015, at https://theengineeringmindset.com/properties-of-air-at-atmospheric-pressure.

Appendix

Item	Website for purchase	Date of purchase
30-ft electric heat cable	https://www.homedepot.com/p/Frost-King-30-ft-Automatic-Electric-Heat-Cable-Kit-Accessory-HC30A/100196471	Nov. 9, 2023
Thermocouples	https://www.amazon.com/HUATO-S220-T8-Thermocouple-Traceable-Certificate/dp/B07SJRG6Y8	Nov. 9, 2023
Husky mini regulator with ¼-in gauge	https://www.homedepot.com/pep/Husky-1-4-in-In-Line-Air-Adjustment-Valve-With-Gauge-HDA70200AV/100072735	Nov. 9, 2023
SURAIELEC watt meter	https://www.amazon.com/Suraielec-Calculator-Protection-Electricity-Electrical/dp/B08GSPLZBN	Nov. 9, 2023
¾-in × 5-ft copper type L hard temper straight tube	https://www.homedepot.com/p/Cerro-3-4-in-x-10-ft-Copper-Type-L-Hard-Temper-Straight-Pipe-3-4-L-10/100354233	Nov. 9, 2023
¼-in × ¾-in brass garden hose irrigation blow fitting	https://www.homedepot.com/p/Everbilt-1-4-in-x-3-4-in-Quick-Connect-Brass-Garden-Hose-Irrigation-Blow-Out-Fitting-2-Pack-860520/317716403	Nov. 9, 2023
¾-in MHT brass coupling fitting	https://www.homedepot.com/p/Everbilt-3-4-in-MHT-Brass-Coupling-Fitting-801679/300095972	Nov. 9, 2023
¾-in copper pressure cup × FIP female adapterfitting	https://www.homedepot.com/p/Everbilt-3-4-in-Copper-Pressure-Cup-x-FIP-Female-Adapter-Fitting-C603HD34/100347144	Nov. 9, 2023
¼-in × ¼-in NPT female industrial coupler	https://www.homedepot.com/p/Husky-1-4-in-x-1-4-in-NPT-Female-Industrial-Coupler-HDB20100AV/100056376	Nov. 9, 2023
¼-in MNPT × ¼ I/M industrial steel plug	https://www.homedepot.com/p/Husky-1-4-in-MNPT-x-1-4-in-I-M-Steel-Plug-12224HOM/205330366	Nov. 9, 2023
Pitot probe	https://www.unitedsensorcorp.com/boundary.html	Nov. 12, 2023

Two-Dimensional Heat Conduction Through a Short Cylinder

Daniel Hofeling, Logan Nicholass, Evan Percival, and Ali S. Siahpush
Southern Utah University

ABSTRACT

The transient temperature empirical and analytical solutions for one-dimensional (1D) conduction heat transfer for plane walls and long cylinders may be used to determine the temperature distribution and heat transfer in two-dimensional (2D) heat conduction systems. Using a superposition approach (also known as the product solution), the 1D solutions may be used to obtain the 2D solution. This concept was tested using a short cylinder (steel 1018), where the solution is assumed to be valid when all surfaces of the cylinder are subjected to convection heat transfer with the same convective heat transfer coefficient and no internal heat generation. To study this concept, a short steel cylinder was both cooled and heated to -1°C and 45°C, respectively. Thermocouples were placed at both ends, the center of gravity, and the outer central surface of the cylinder. As the set temperature was reached, the cylinder was suspended such that the only mode of heat transfer was natural convection at the ambient temperature. The cylinder then was allowed to return to the ambient temperature as temperature data was recorded. The analytical results, as expected, showed exponential tendencies in

both heating and cooling, and they followed the experimental results closely. Sensitivity analysis was performed on various parameters including the convective heat transfer coefficient, which proved to have a significant impact on the analytical solution. The data from this experiment strongly supported the theoretical equations for 2D heat transfer in a short cylinder.

INTRODUCTION

Thermal conduction is the movement of heat energy through solid objects due to a temperature difference. The study and modeling of heat conduction are crucial in the design of many common systems, such as water piping, wall insulation, and electronic devices. There are numerous reasons why it is important to understand the flow of heat in a system, such as preventing overheating an engine component or properly insulating a room to prevent heat loss.

One-dimensional (1D) heat transfer is the movement of heat along a single geometric axis of an object. The equations describing the transient 2D flow of heat in an object are the product of the 1D solutions [1]. The majority of heat transfer textbooks [1, 2] cover multi-dimensional heat transfer because it is crucial for understanding the real-world thermal design of a system.

To study these theories, an experiment was performed at Southern Utah University's (SUU) mechanical engineering heat transfer laboratory using a short, steel-1018 cylinder. A short cylinder is defined by the length-to-diameter ratio less than 1.85 [3].

This paper describes the theoretical background of 2D heat transfer, how to perform the experiment, the theoretical and experimental temperature results, and how the experiment may be improved.

THEORY

Two-Dimensional Heat Transfer

The Biot number is used in the analysis of transient conduction heat transfer. The Biot number (Bi) describes the ratio of the conduction resistance to the convective resistance at the surface. The Biot number is defined as [1, p. 240]

$$Bi = \frac{hL_c}{k} \tag{16}$$

where h is the convective heat transfer coefficient $(\mathrm{W/m^2K})$, L_c is the characteristic length (m), defined as the ratio of the volume to the surface area, and k is the thermal conductivity $(\mathrm{W/mK})$.

The Fourier number is also important in heat transfer analysis, specifically in transient heat conduction. The Fourier number (τ) is dimensionless and is the ratio of the rate of heat conduction in an object to the rate at which heat is stored in the object. The Fourier number is expressed as [1, p. 246]

$$\tau = \frac{\alpha t}{L^2} \tag{17}$$

where α is the thermal diffusivity $(\mathrm{m^2/s})$, t is the time (s), and L is the length of the object (m).

Some common geometries analyzed in 1D include a plane wall with a thickness $2L$, and a long cylinder with a radius of r_0 as shown in Fig. 1.

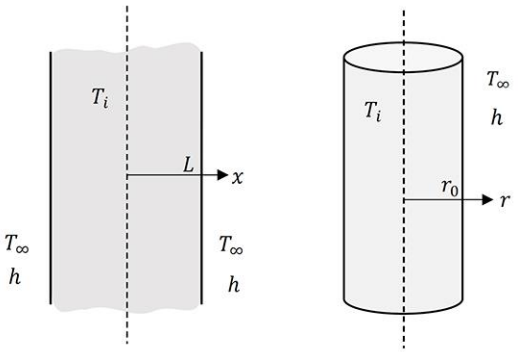


Figure 1. Convective heat transfer of plane wall and long cylinder.

Assuming a uniform initial temperature in the object, heat transfer takes place between these objects and their ambient surroundings with a constant and uniform convective coefficient. The internal temperature profiles for a plane wall are assumed to show symmetry about the center plane as shown in Fig. 2.

For a 1D object, the transient heat transfer solution is obtained by solving the heat partial differential equations. The solution involves an infinite series, and the first-term approximation solution for a plane wall is expressed as [1, p. 250]

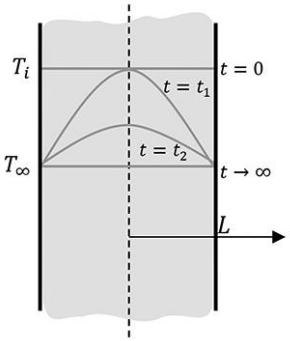


Figure 2. Symmetrical thermal profile in plane wall over time.

$$\theta_{\text{wall}} = \frac{T(x,t) - T_\infty}{T_i - T_\infty} = A_1 e^{-\lambda_1^2 \tau} \cos\left(\frac{\lambda_1 x}{L}\right) \tag{18}$$

where $T(x,t)$ is the temperature at the given position x (m) at time t (s), T_i is the initial temperature (°C), and T_∞ is the ambient temperature (°C). The constants A_1 and λ_1 are functions of the Biot number, and L is one-half of the thickness of the wall (m). For a long cylinder, the dimensionless temperature is defined as [1, p. 250]

$$\theta_{\text{long cyl}} = \frac{T(r,t) - T_\infty}{T_i - T_\infty} = A_1 e^{-\lambda_1^2 \tau} J_0\left(\frac{\lambda_1 r}{r_0}\right) \tag{19}$$

where $T(r,t)$ is the temperature at the given time and radius (m), J_0 is the zeroth order Bessel function of the first kind, r is the position along the radius (m), and r_0 is the radius of the solid cylinder (m). It should also be noted that the values of λ_1 and A_1 are unique to both the plane wall and the long cylinder.

The product of the dimensionless temperatures for both the plane wall and the long cylinder provides the solution for the dimensionless temperature for a short cylinder, expressed as [1, p. 269]

$$\theta_{\text{short cyl}} = \theta_{\text{wall}} \theta_{\text{long cyl}} \tag{20}$$

(18) and (19) can be substituted into (20) and further expanded to form an expression for the temperature at any given location in the cylinder over time. The final equation may be presented as

$$T(r,x,t) = \left[A_1 e^{-\tau\lambda_1}\cos\left(\frac{(\lambda_1 x)}{L}\right)\right]\left[A_1 e^{-\tau\lambda_1} J_0\left(\frac{\lambda_1 r}{r_0}\right)\right](T_i - T_\infty) + T_\infty \quad (21)$$

Convective Heat Transfer Coefficient

The value of h depends on several variables, including the geometry and orientation of the object, the thermophysical properties of the ambient fluid, and the variation of temperature on the surface of the object. These complexities introduce various challenges for the analytical evaluation of the h value, but many studies have provided relatively simple equations for common geometries, including a short cylinder [1].

In convection heat transfer evaluation, it is common to nondimensionalize the convective heat transfer coefficient with the Nusselt number (Nu). The Nusselt number is defined as [1, p. 382]

$$\mathrm{Nu} = \frac{hL_c}{k} \quad (22)$$

Eq. (7) may be rearranged to provide the convective heat transfer coefficient as

$$h = \frac{\mathrm{Nu}k}{L_c} \quad (23)$$

Determining the Nusselt number or Number. ????? over the surface of a horizontal cylinder is defined as [1, p. 542]

$$\mathrm{Nu} = \left(0.6 + \frac{0.387\mathrm{Ra}_D^{\frac{1}{6}}}{\left[1 + (0.559/\mathrm{Pr})^{\frac{9}{16}}\right]^{\frac{8}{27}}}\right)^2 \quad (24)$$

where Ra_D is the Rayleigh number, and Pr is the Prandtl number. The Rayleigh number is defined as [1, p. 541]

$$\mathrm{Ra}_D = \frac{g\beta(T_s - T_\infty)L_c^3}{\nu^2}\mathrm{Pr} \quad (25)$$

where g is the acceleration due to gravity ($\mathrm{m/s^2}$), β is the coefficient of volume expansion at the film temperature ($1/\mathrm{K}$), T_s is the initial surface temperature of the cylinder (℃), and ν is the kinematic viscosity of the ambient fluid ($\mathrm{m^2}/s$).

MATERIALS AND PROCEDURE

The following equipment and materials were utilized in this experiment (see Appendix for details).

- Four K type mini-connector thermocouple
- Four-channel thermocouple SD data logger
- Three-inch diameter by 5-inch long 1018 steel cylinder
- Suspension apparatus
- Freezer
- Heating pad

The experimental apparatus and materials are presented in Fig. 3.

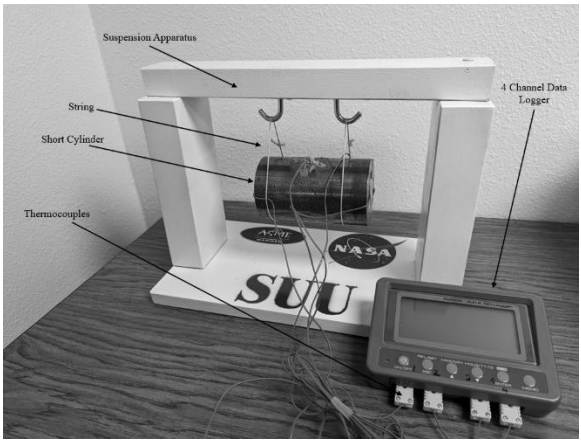


Figure 3. Experiment with suspension apparatus.

Next, the experimental procedures are described.

Set-up

1. A small hole was drilled in the middle of the cylinder and directly to the center of the 1018-steel cylinder.
2. Thermocouples were attached to the surface of both ends, inside of the small hole drilled previously, and the surface of the cylinder opposite of the small hole.

Heating to Room Temperature

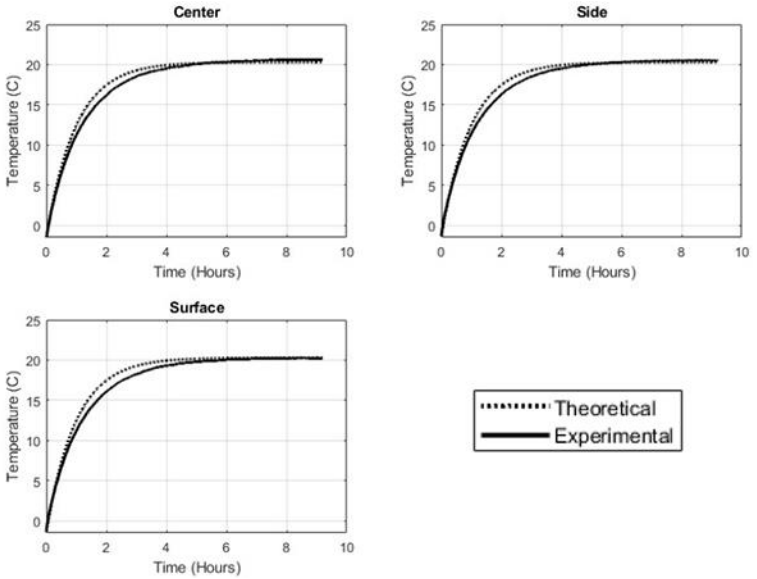
1. The cylinder and attached thermocouples were placed inside a freezer and allowed to cool down until all thermocouples reached the steady state temperature (-1°C).
2. The cylinder was then removed and suspended by the strings in the suspension apparatus.
3. The temperatures were recorded by the data logger.
4. Once steady state was reached, data collection was terminated.

Cooling to Room Temperature

1. The cylinder was wrapped in a heating pad and allowed to heat to the steady state temperature of 45°C.
2. Upon reaching 45°C, the cylinder was suspended by the strings in the suspension apparatus.
3. The temperatures were recorded by the data logger.
4. Once steady state was reached, data collection was terminated.

RESULTS AND DISCUSSION

The results for the cooling cylinder are shown in Fig. 4, and the results for the warming cylinder are shown in Fig. 5.



Fiure 4. Experimental and theoretical temperatures for heating.

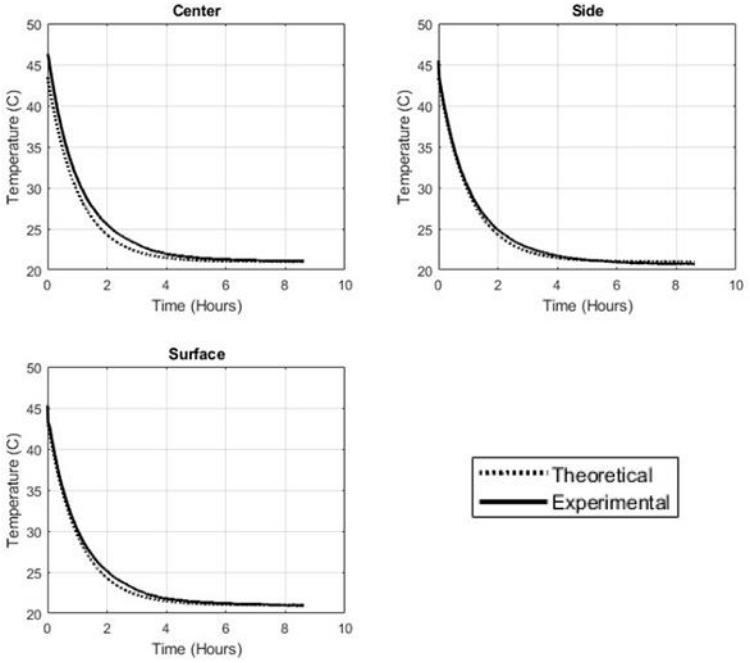


Figure 5. Experimental and theoretical temperatures for cooling.

Ignoring thermal radiation heat transfer, using (24), the h value due to the natural convection heat transfer was evaluated to be approximately $5\ \mathrm{W/m^2K}$. However, the heat transfer laboratory contains an HVAC system that may turn on as temperature drops occur, introducing temporary forced convection and increasing the h value. For this reason, the h value was considered to be slightly higher at approximately $8\ \mathrm{W/m^2K}$, which is closer to the standard value for surfaces inside of a building [1]. Sensitivity analysis also proved that the h value greatly impacted the behavior of the theoretical temperature, and most closely matched the data at a value of $8\ \mathrm{W/m^2K}$.

The theoretical and experimental results for the heating (Fig. 4) showed the most discrepancy in the range of about 1 to 4 hours. The experimental results showed that the cylinder warmed slower than predicted; however, the discrepancy between the two does not exceed more than 1°C. The side and surface of the cylinder reached the steady-state temperature of 20.3°C in approximately 6 hours, while the center reached the steady-state temperature in approximately 6.5 hours.

Similarly, the curves for the cooling experiment showed discrepancies in a range of about 1 to 4 hours, but the errors are less significant than they were for the heating experiment. The actual curves for the side and surface show a quick drop in temperature near the start of the experiment, likely as it was being transferred from the heating pad to the suspension apparatus. The plot for the center did not show a similar temperature drop at the start because it was less sensitive than the outside surfaces of the cylinder.

The theoretical calculations closely predicted the temperature over time for both the cooling and warming of the cylinder. Over approximately 4.5 hours, before the temperatures had reached steady state, the prediction was within 1°C for all locations, suggesting the overall solution for 2D heat conduction has high accuracy. Material properties and the experimental conditions are presented in Table.

Table 1. Material properties and experimental conditions

Variable	Description	Value	Units
h	Convective heat transfer coefficient	8.00	W/m^2K
k	Thermal conductivity [4]	51.9	W/mK
c_p	Specific heat capacity of 1018 steel [4]	490	J/kgK
ρ	Density of 1018 steel ref [4]	7870	kg/m^3
ν	Kinematic viscosity of ambient air [1]	1.75×10^{-5}	m^2/s
α	Thermal diffusivity of 1018 steel [4]	1.36×10^{-5}	m^2/s
$T_{\infty,h}$	Ambient temperature during heating	20.3	°C
$T_{\infty,c}$	Ambient temperature during cooling	21.4	°C

SOURCES OF ERROR

Various errors throughout the experiment led to a difference between the theoretical and experimental results. The first error that may have impacted the experiment is the transfer of the cylinder from the heating and cooling stations to the suspension apparatus. During the transfer, some heat was lost to the ambient air; although this error is assumed to be negligible, it had some effect on the initial temperature.

Another error that potentially affected the data is the error from the temperature sensors. Although the K-type thermocouples and the digital 4-channel thermocouple data logger were used within their temperature ratings, they still have some level of inaccuracy. As shown in Table 2, the error from the thermocouples and data logger is expected to be minimal (±0.002°C and ±0.1°C, respectively). These may have had an impact on the experimental results, but it was likely a minor error.

Table 3. Equipment accuracy		
Equipment	**Accuracy (°C)**	**Accuracy (%)**
TWTADE 2M K type mini-connector thermocouple	± 0.002	± 0.5
Digital 4-channel thermocouple data logger	± 0.1	± 0.3

The primary source of error was due to the value of h. As stated earlier, h had the greatest impact on the heat transfer from the cylinder. Although it was assumed that h was at a constant value of 8 $\mathrm{W/m^2K}$, it is more likely that the value of h fluctuated over time such that the rate of heat transfer also fluctuated. This led to some of the disparities between the theoretical and experimental curves.

CONCLUSION AND RECOMMENDATIONS

This experiment successfully showed the relationship between the experimental and theoretical curves produced by the short cylinder and the corresponding equations of 2D heat conduction. These curves were based on the unique material properties of this specific cylinder. The theoretical equations were found to be accurate (within 1°C) at all times for both heating and cooling.

Future replications of this experiment to further explore the concepts discussed can make adjustments to eliminate some of the errors presented. One of these adjustments is to enlarge the diameter of the cylinder. Enlarging the diameter of the cylinder would enhance the analysis of the difference in temperature between the center of gravity and the surface of the cylinder. This would allow the observer to better understand how the heat is transferred radially and axially. Another adjustment that could be made is to use cylinders made of different materials. This would change properties such as thermal conductivity, specific heat capacity, and density. By changing the materials, how the transient temperature curves change can be observed, providing insight as to how each unique material reacts with the ambient conditions. Using a more controlled environment would also improve the results of the experiment. Controlling factors such as the convective heat transfer coefficient can increase the accuracy of this experiment as this was found to have the greatest impact on the results. The theoretical equations assume constant properties; therefore, regulating the ambient environment would further validate this assumption.

ACKNOWLEDGMENTS

This project was made possible by Southern Utah University's Department of Engineering and Technology and faculty, as well as their assistance from the NASA Utah Space Grant Consortia.

BIBLIOGRAPHY

[1] Y.A. Cengel and A. Ghajar, (2015) *Heat and Mass Transfer Fundamentals & Applications*, 5th Edition. McGraw-Hill.

[2] T.L. Bergman, A.S. Lavine, F.P. Incropera, and D.P. DeWitt, (2020) *Fundamentals of Heat and Mass Transfer*, 8th Edition, Wiley.

[3] J. Ndisya, A. Gitau, F. Roman, and D.O. Mbuge, (2022) Simulation of transient heat transfer during forced convection cooling of cocoyam (*Colocasia esculenta* (L.) Schott) tubers, *Heliyon* 8, e12360.

[4] MatWeb, [Online]. AISI 1018 Steel, cold drawn, high temperature, stress relieved, 50-76 mm round. Accessed March 16, 2024 at https://www.matweb.com/search/datasheet_print.aspx?matguid=aca5faa6647a414b8a062c67174fa4ab.

APPENDIX

Item	Website for purchase	Date of purchase
Four K type mini-connector thermocouple	https://www.amazon.com/Mini-Connector-Thermocouple-Temperature-Measure-50-250%C2%B0C/dp/B07MMLY3PZ	Feb. 14, 2024
Four-channel thermocouple SD data logger	https://www.amazon.com/Instruments-Thermometer-Thermocouple-Temperature-K-Thermocouple/dp/B00M9Z3JJ8	Feb. 14, 2024
Heating pad	https://www.walmart.com/ip/Sunbeam-Heating-Pad-with-Controller-and-3-Heat-Settings-12-x-15-Blue-Frost/ 2897379181	Mar. 7, 2024

Performance Analysis of a Spray-Type Passive Downdraft Evaporative Cooler

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ABSTRACT

This paper analyzes the cooling performance of a spray-type passive downdraft evaporative cooler (PDEC). This research aims to determine the optimal number of fine-mist spray nozzles for a small, low-cost PDEC system to evaluate the cooling performance of each number of nozzles in a dry climate. The evaporative cooler considered in this undergraduate research used a fan and heater at the inlet to simulate various ambient wind speeds and temperatures. Relative humidity and dry-bulb temperature at the inlet were used to predict the outlet temperature using psychrometric equations and charts. The effectiveness ratio of the system was calculated by comparing performance to the ambient wet-bulb depression and was used to predict the outlet air temperature and cooling capacity for different outdoor air temperatures and relative humidities. Water usage efficiency was analyzed using air- and water-flow rate and relative humidity measurements. A greater

number of nozzles provided better cooling performance but introduced excess water in the exiting airstream.

INTRODUCTION

The year 2023 was the warmest year on record [1]. The use of air conditioners (AC) and fans for cooling accounts for almost 20% of electricity use of buildings worldwide and 10% of all global energy consumption, and these percentages are climbing steadily. Despite the enormous strain already placed on electricity systems around the world, most households in hot climate countries do not have AC [2]. There is therefore a growing need for more energy-efficient and cost-effective air conditioning alternatives. Evaporative cooling has been in use for millennia, and "swamp cooler" units have been widespread use in the southwest U.S. since the 1930s [3]. Today, in the dry climate regions of the U.S., only approximately 4% of households use evaporative cooling as their primary cooling method, and 16% use it only as a secondary cooling system [4]. Evaporative cooling is an effective, low-cost, and energy-efficient cooling method in dry climates.

Human Comfort

The thermal comfort zone for humans varies depending on three environmental factors: temperature, relative humidity, and air motion. Each region of the world has its unique climate, humidity, and wind patterns, yet extensive research has been performed to identify the ideal conditions where the human feels most comfortable [5]. In the U.S., the thermal comfort zone when resting or during light amounts of activity generally is considered to be between 20°C and 25°C, allowing the body to comfortably dissipate waste heat without the need to exert extra effort in maintaining its core temperature 0. Another important factor is relative humidity. The comfortable range for indoor relative humidity in the U.S. is typically between 30% and 70%, with 50% being the ideal relative humidity [5, 6]. At 100% relative humidity, the air cannot hold any more moisture, and during rain, the air moisture is 100% [7]. During high relative humidity, humans are no longer comfortable because this causes a "sticky" feeling, and humans are more prone to overheating because sweat can no longer cool down the body. On the other hand, low relative humidity causes cracked skin and excessive dryness. Neither extreme is comfortable. For different regions, engineers work to balance these factors by adding or removing heat and moisture to create the ideal environment for humans [5].

Cooling Systems

There are many different types of cooling systems available in the market. Some systems are better for more humid areas such as AC units. Some AC units work by removing moisture from the air using coils or fans depending on the type of the system, cooling down the air and making it drier. In humid areas, cooling the air using evaporation is no longer viable [5]. This type of cooling system is also much more costly and complicated while operating compared with other methods with water as the cooling system.

The focus of this paper is on evaporative cooling used for drier climates. Evaporative cooling is ideally an adiabatic process [5]. Heat from the air is absorbed by liquid water, which is converted to water vapor, thereby cooling and humidifying the air. Water has a large latent heat of vaporization; therefore, a significant amount of heat is absorbed by it during evaporation without raising its temperature [7].

There are many types of cooling systems that use evaporative cooling techniques, including swamp coolers, the most common system. A lesser-known system is called passive downdraft evaporative cooling (PDEC), which is the focus of this research. There is a lack of research describing how these systems work and are analyzed without the use of expensive equipment or software.

Passive Downdraft Evaporative Coolers (Windcatcher)

Most modern evaporative coolers use blowers to drive hot air through the cooling medium and provide airflow to the cooled space. Since antiquity, cities in hot desert climates such as those in the Middle East (especially Iran) have taken advantage of the wind by implementing windcatchers *(*Persian: بادگیر, bâdgir) to direct air down through towers and over water to provide cooling [8]. PDECs are a type of evaporative cooler that creates airflow without relying on a mechanical blower (although a blower or a windcatcher can contribute significantly to the total airflow) [9]. PDECs create airflow by inducing a downdraft through a tower. At the top of the tower, air is evaporatively cooled by either water-soaked pads like those in a swamp cooler or by spraying water downward directly into the air. The downward wind velocity (kinetic energy) and higher density of the cooled air causes it to sink to the bottom of the tower, thereby inducing a downdraft that pulls fresh air in at the top.

Windcatchers are often installed at the top of the tower to direct and provide more airflow through the tower. By adding momentum to the air with the water spray, spray-type PDECs can generate more airflow than a wetted pad PDEC and can respond faster to fluctuating outdoor

conditions [9]. Although a windcatcher can be used, the ability of a spray-type PDEC to create its airflow is important when consistent wind is not available. Figure 1 shows the basic design of a spray-type PDEC.

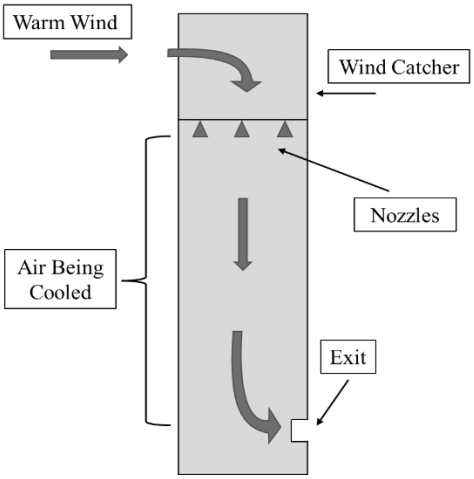

Figure 1. Spray-type PDEC tower diagram.

No sufficient analytical model currently exists to fully predict the performance of a spray-type PDEC, although some articles have been published attempting to model systems with specific geometries using computational fluid dynamics software. Givoni [10] presented a simple regression-based model based on the inlet temperature, outlet temperature, and wet-bulb temperature measurements using an effectiveness ratio. He also presented an empirical model (based on his regression model), but it is entirely based on his test setup and does not generalize to other designs**Error! Reference source not found.**. P erformance parameters may include droplet size, water flow rate, ambient air flow rate, tower height, tower aerodynamics, tower thermal conductivity, ambient temperature, and of course wet-bulb temperature of the ambient air [11]. Because of the substantial number of parameters, this system is too complex to fully model without the use of computational fluid dynamics software.

Our research analyzes a small-scale PDEC and aims to provide insight into using fine misting nozzles in a PDEC and how different numbers of nozzles influence a PDEC's cooling ability. A simple PDEC set-up as described in this paper may be used to start further research on the topic.

THEORY

Wet bulb temperature is a measure used in meteorology and thermodynamics to describe the lowest temperature that can be reached by evaporating water into the air at constant pressure [7]. In the case of evaporative cooling, wet-bulb temperature is used to represent the ideal minimum air temperature that can be achieved through evaporative cooling for given air conditions. Wet-bulb depression is defined as the difference between the dry-bulb temperature and the wet-bulb temperature and is useful for estimating the potential temperature decrease using evaporative cooling [11].

An equation has been developed to calculate wet-bulb temperature from relative humidity and dry-bulb temperature as [12]

$$\begin{aligned} T_{wb} = T_{db} \cdot \tan^{-1}[0.151977(\phi + 8.313659)^{0.5}] \\ + \tan^{-1}(T_{db} + \phi) \\ - \tan^{-1}(\phi - 1.676331) \\ + 0.00391838\phi^{1.5} \tan^{-1}(0.023101\phi) \\ - 4.686035 \end{aligned} \quad (1)$$

where T_{wb} is the wet-bulb temperature (°C) and T_{db} is the dry-bulb temperature (°C).

In an ideal evaporative cooler, no heat is added to the air and the exiting air is saturated. Because this process is essentially the same as an adiabatic saturation process, the wet-bulb temperature is assumed to be constant [5]. This assumption also relies on the water temperature to be the same as the exit temperature of the air. A temperature difference would allow for some non-evaporative heat transfer between the air and water. In the ideal case, the dry-bulb temperature of the outlet air is the same as the wet-bulb temperature, and the outlet air is at 100% relative humidity.

In practice, several factors can influence the effectiveness of an evaporative cooler. Heat can be added to the system through motors or from the housing of the cooler exposed to ambient air and thermal radiation. The exit air may not be fully saturated, or there may be a temperature difference between the water and inlet air. To account for these factors, an effectiveness ratio (ε) is evaluated as [11]

$$\epsilon = \frac{\Delta T_{\text{actual}}}{\Delta T_{\text{ideal}}} = \frac{T_{\text{db,in}} - T_{\text{db,out}}}{T_{\text{db,in}} - T_{\text{wb}}} \quad (2)$$

where $T_{db,in}$ and $T_{db,out}$ are dry-bulb temperatures at the inlet and outlet of the tower, respectively.

The effectiveness ratio of an evaporative cooling tower system can be determined by measuring the wet-bulb temperature and the dry-bulb temperatures at the top and bottom of the cooling tower for several

different inlet air temperatures. Presenting the actual temperature change vs. the ideal temperature change, the effectiveness ratio is the slope of the best-fit line through the data. Once the effectiveness ratio is determined, the outlet temperature can be evaluated by rearranging Eq. (2) for outlet temperature as

$$T_{db,out} = T_{db,in} - \epsilon\,(T_{db,in} - T_{wb}) \tag{3}$$

In addition to the "effectiveness method" of predicting outlet temperature, a psychrometric chart can also be used. Because the wet-bulb temperature is assumed to be constant, the wet-bulb temperature and the relative humidity of the exit air can be used to predict the exit dry-bulb temperature using a psychrometric chart. A simplified psychrometric chart to demonstrate how dry-bulb temperature can be evaluated is shown in the Appendix. Psychrometric equations may also be used to predict outlet temperature [7].

The total enthalpy of atmospheric air is the sum of the enthalpies of dry air and the water vapor, evaluated as [7]

$$h = h_{dry} + HR \cdot h_g \tag{4}$$

where h is the total enthalpy of moist air (kJ/kg), h_{dry}, and h_g are the enthalpies of dry air and water vapor, respectively, and HR is the humidity ratio. The humidity ratio is expressed as [7]

$$HR = \frac{\omega}{\rho_{dry}} \tag{5}$$

where ω is the absolute humidity (kg vapor/m^3 dry air) and ρ_{dry} is the density of the dry air (kg/m^3). The enthalpy of dry air can be evaluated as [7]

$$h_{dry} = c_p T \tag{6}$$

where c_p is the specific heat of dry air (1.006 kJ/kg·K) and T is the temperature (K). By combining Eqs. (4-6), the total enthalpy of air becomes

$$h = c_p T + \frac{\omega h_g}{\rho_{dry}} \tag{7}$$

The evaporative cooling process is assumed to be isenthalpic ($h_{in} \cong h_{out}$) [7]. Therefore, the total enthalpy at the inlet and outlet of the cooling tower may be expressed as

$$h_{in} \cong h_{out} = c_p T_{out} + \frac{\omega_{out} h_{g,out}}{\rho_{dry}} \tag{8}$$

By solving Eq. (8) for T_{out}, the outlet temperature can be evaluated as

$$T_{out} \cong \frac{h_{in} - \frac{\omega}{\rho_{dry}} h_{g,out}}{c_p} \tag{9}$$

Note that all of the methods described above for calculating outlet temperature rely on humidity measurements at the outlet of the tower. In other words, the performance of a PDEC cannot be accurately modeled without experimental results for that particular set-up unless computational fluid dynamics software is used.

Cooling Capacity

It is necessary to determine the cooling rate of a system to ensure it is adequate to cool a given space. The cooling rate ($\dot{Q}$) is a function of the air mass flow rate and the temperature drop (ΔT) from the entrance to the exit of the tower as [5]

$$\dot{Q} = \dot{m} c_{\mathrm{p}} \Delta T \tag{10}$$

$$\dot{m} = \rho v A_c \tag{11}$$

where $\dot{m}$ is the mass flow rate of the atmospheric air-vapor mixture (kg/s), ρ is the density of the air-vapor mixture (kg/m^3), T is the air temperature (K), v is the air velocity (m/s), and A_c is the cross-sectional area of the exit (m^2).

The water vapor in air can be treated as an ideal gas at atmospheric pressure [7]. The density of an ideal gas can be calculated by solving the ideal gas law equation as

$$\rho = \frac{m}{V} = \frac{P}{RT} \tag{12}$$

where m is mass (kg), V is volume (m^3), P is pressure (Pa), R is the specific gas constant (J/kg·K), and T is the absolute temperature (K) of the gas.

The total density of the air-vapor mixture is then the sum of the partial densities of the dry air and water vapor as [7]

$$\rho = \left(\frac{P_{\mathrm{dry}}}{R_{\mathrm{dry}} T_{out}}\right) + \left(\frac{P_{\mathrm{v}}}{R_{\mathrm{v}} T_{out}}\right) \tag{13}$$

where P_{dry} and P_v are the partial pressures of the dry air and water vapor (Pa), respectively, T_{out} is the outlet air temperature (K), R_{dry} is the specific

gas constant of dry air (287.058 J/kg·K), and R_v is the specific gas constant of the water vapor (461.495 J/kg·K) [5].

The partial pressures at the outlet can be evaluated as [7]

$$P_v = \phi P_{sat} \tag{14}$$

$$P_{dry} = P_{atm} - P_v \tag{15}$$

where P_{sat} is the saturation pressure of water at the outlet temperature and P_{atm} is the total atmospheric pressure. By combining Eqs. (10-15), the cooling rate is evaluated as

$$\dot{Q} = \left(\frac{P_{atm} - \phi P_{sat}}{R_{dry} T_{out}} + \frac{\phi P_{sat}}{R_v T_{out}}\right) v A_c c_P \Delta T \tag{16}$$

Similarly, the cooling rate can be predicted for various ambient air temperatures and humidities once the effectiveness ratio of the system is known. Equation (2) may be rearranged for ΔT ($T_{db,in}$-$T_{db,out}$) as

$$(T_{db,in} - T_{db,out}) = \epsilon(T_{db,in} - T_{wb}) \tag{17}$$

Equation (17) can be used in place of ΔT in Eq. (16) to predict the cooling performance of the system as

$$\dot{Q} = \left(\frac{P_{atm} - \phi P_{sat}}{R_{dry} T_{out}} + \frac{\phi P_{sat}}{R_v T_{out}}\right) v A_c c_p \epsilon(T_{db,in} - T_{wb}) \tag{18}$$

Note that the air density will change slightly with different temperatures and humidities, so the cooling rate calculation may be slightly affected.

Water Usage Efficiency

The efficiency (η) of the system can be described by the percentage of water evaporated. Not all of the water will evaporate—some will remain liquid and collect on the walls or base of the tower or be ejected out as liquid water at the outlet with the exiting air. The efficiency of an evaporative cooler is therefore the ratio of water vapor added to the air compared with the amount of water sprayed through the nozzles as

$$\eta = \frac{\dot{m}_{v,added}}{\dot{m}_w} = \frac{\dot{m}_{v,out} - \dot{m}_{v,in}}{\dot{m}_w} \tag{19}$$

where $\dot{m}_v$ is the mass flow rate of water vapor (kg/m^3) and $\dot{m}_w$ is the mass flow rate of water supplied by the nozzles (kg/m^3).

The amount of water vapor added to the air can be calculated by determining the absolute humidity (ω) of both the ambient and exiting air as [13]

$$\omega = \frac{\mathrm{m_v}}{V_{air}} = \frac{\dot{m}_v}{\dot{V}_{air}} \tag{20}$$

where $\dot{m}_v$ is the mass flow rate of water vapor (kg/s) and $\dot{V}_{air}$ is the volumetric flow rate of the dry air (m^3/s). The mass flow rate of water vapor can be calculated by rearranging the absolute humidity equation as

$$\dot{m}_v = \omega \dot{V}_{air} \tag{21}$$

The volumetric flow rate of air can be calculated using the velocity (v) of air and cross-sectional area (A_c) of the section of the system (entrance or exit) as [5]

$$\dot{V} = vA_c \tag{22}$$

Note that the volumetric flow rate should be calculated separately for the entrance and exit, because the air density changes as water is added and the temperature drops. Next relative humidity can be expressed as the ratio of the vapor pressure of water in the air to the saturation pressure at a given temperature [7].

$$\phi = \frac{P_v}{P_{sat}} \tag{23}$$

Equation (23) may be rearranged to evaluate P_v as

$$P_v = \phi P_{sat} \tag{24}$$

The ideal gas law relationship for the vapor pressure of water in the air is [7]

$$P_v V = m_v R_v T \tag{25}$$

Equation (25) may be rearranged to present the absolute humidity as

$$\omega = \frac{m_v}{V} = \frac{P_v}{R_v T} \tag{26}$$

By combining Eqs. (24) and (26), the absolute humidity can be evaluated in terms of relative humidity as

$$\omega = \frac{\phi P_{sat}}{R_v T} \tag{27}$$

where Rv is the specific gas constant of water vapor (461.5 J/kg·K) and T is temperature (K). When air velocities, relative humidities, temperatures, and saturation pressures are measured or predicted, Eq. (27) may be used to evaluate the absolute humidities. Finally,

substituting Eq. (21) into Eq. (19), the efficiency can then be expressed as

$$\eta = \frac{\omega_{out}\dot{V}_{air,out} - \omega_{in}\dot{V}_{air,in}}{\dot{m}_w} \quad (28)$$

LIST OF MATERIALS/EQUIPMENT

- Arduino Uno
- DHT22 (3-pin) humidity and temperature sensor
- Kestrel 1000 anemometer
- Protmex PT6508 humidity and temperature sensor

PROCEDURE

1. Calculate the flow rate of the nozzles by collecting the mist produced for 2 minutes in a container and measuring the volume using a graduated cylinder.
2. Nozzle selection
3. Determine the type of nozzles needed based on desired mist coverage. For this experiment, 0.3-mm orifice nozzles are used (Figure 2).

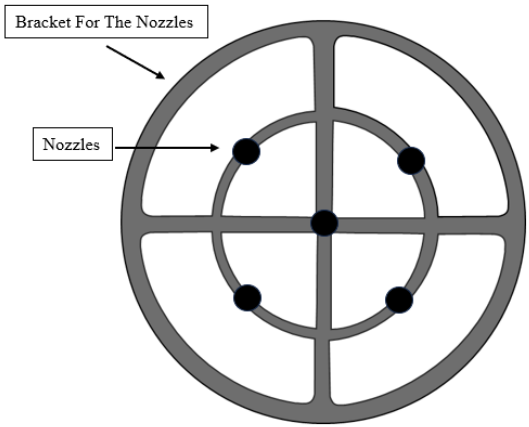

Figure 2. Drawing shows the 5-nozzle arrangement on the acrylic bracket.. This bracket is placed inside the tubing used for the tower.

4. Ensure the DHT22 sensor is positioned away from the heat sources to ensure accurate readings, as shown in Figure 3.

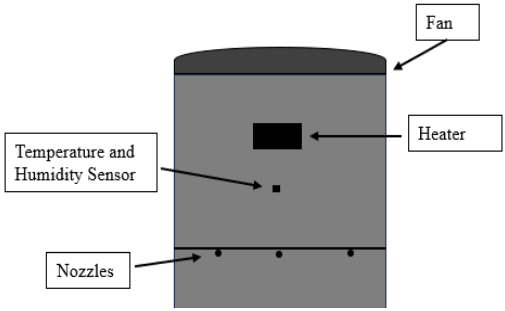

Figure 3. Sensor placement. Drawing shows the sensor placement relative to the other items inside the drainpipe used for the tower.

5. Complete heater placement and activation with sensor calibration as shown in Figure 4.
6. The larger heater will operate at full power, whereas the other is equipped with adjustable controls that are mounted on the shorter pipe, enabling varied heat levels for experimental simulations.

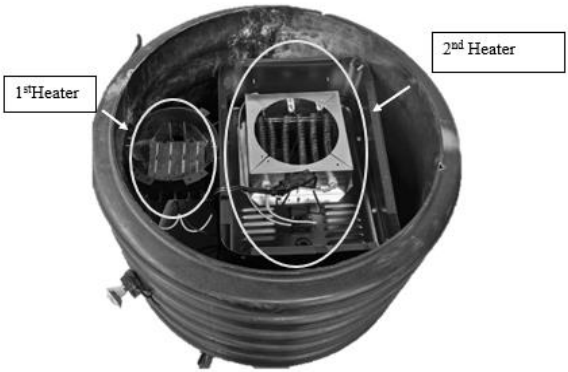

Figure 4. Heater placement. Photograph shows the setup used for both heaters inside a smaller drainpipe that connects to the main drainpipe creating the tower.

7. Connect the Arduino to the DHT 22 sensor.
8. Activate the fan and heaters, allowing the system to reach steady state at the desired outlet temperature.
9. Once both inlet and outlet temperatures are the same (reached steady state), activate the water supply.

10. Complete fan installation and power management as shown in Figure 5. Ensure each heater is plugged into a separate outlet to ensure constant power.

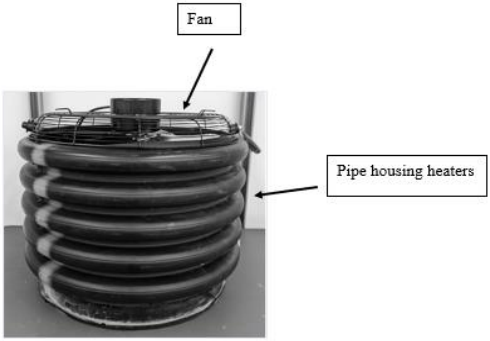

Figure 5. Fan placement. Photograph shows how the fan sits on top of the smaller drainpipe.

The complete layout of the PDEC is shown in Figure 6. Figure 7 shows the placement of the Protmex to measure outlet temperature and humidity.

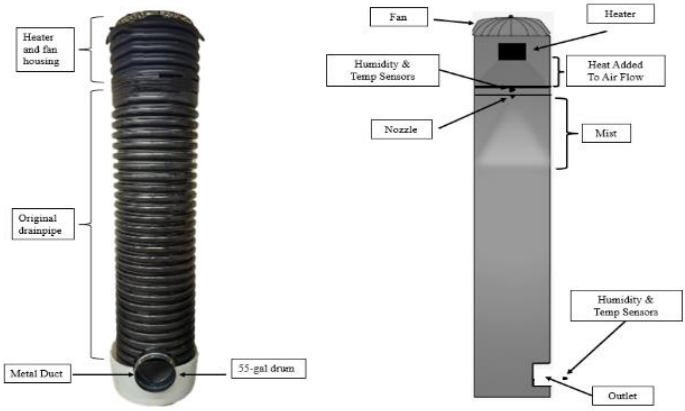

Figure 6. (Left) Tower setup; (right) schematic diagram of tower setup.

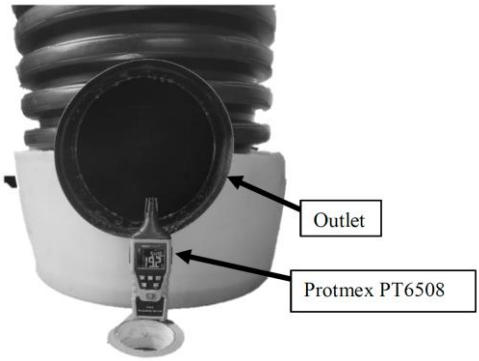

Figure 7. Measuring outlet humidity and temperature.

RESULTS AND DISCUSSION

The airflow rate at the exit was calculated using the measured airspeed using an anemometer. The inlet air speed was 1.6 m/s before the spray was turned on for all tests. The water and airflow rates for each nozzle configuration are presented in Table 1.

Table 1. Water and air flow rates

Variables	Number of Nozzles			
	2	3	4	5
Water flow rate (L/hr)	4.26	8.01	11.4	13.9
Exit air flow rate (m^3/hr)	602	602	584	693

The cooling capacity of the five-nozzle configuration is significantly more than the other nozzle configurations. This may be in part due to a higher outlet airflow rate.

The temperature difference between the inlet and outlet is plotted against the wet-bulb depression (T_{in}-T_{wb}) for each nozzle configuration in Figure 8. The slope of the best-fit line through each dataset is the effectiveness ratio (ε) of that nozzle configuration. Because the effectiveness ratio does not directly account for different airflow rates at the inlet of the tower, these effectiveness ratios are only valid for the inlet airflow rate used during testing. The R^2 value for each best-fit line is over 0.99, which indicates a good fit to the data.

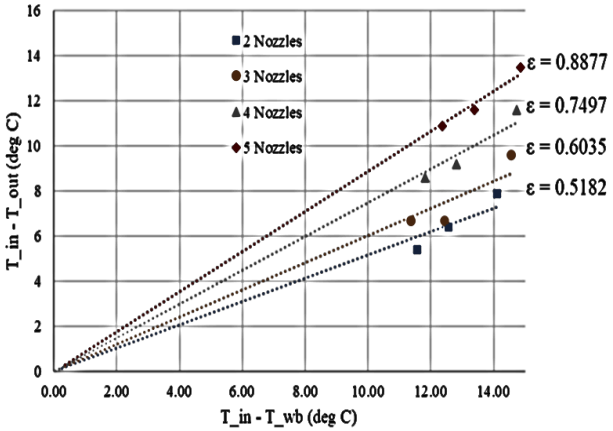

Figure 8. Wet-bulb depression and effectiveness ratios (slopes).

For each nozzle setup, the inlet wet-bulb temperature was calculated at the inlet for each heat setting using Eq. (1). The effectiveness ratios for each nozzle configuration were used to calculate outlet temperatures. The wet-bulb temperature and outlet relative humidity were used to determine the expected outlet temperature using a psychrometric chart. Inlet temperature and inlet and outlet humidities were used to calculate outlet temperatures using Eq. (9). These temperatures predicted using different methods are presented in Table 2.

Table 2. Comparison of measured vs. predicted T_{db} outlet temperatures

Inlet temp.	Method	Outlet temperature (°C)			
Number of nozzles		2	3	4	5
Low ~26.6°C	Measured	21.4	20.8	17.9	14.6
	Effectiveness	20.8	20.6	17.6	14.5
	Psychrometric chart	22.8	22.2	19.1	16.1
	Psychrometric eqs.	23.4	20.8	17.3	15.6
Medium ~29.1°C	Measured	23.1	23.8	19.0	16.6
	Effectiveness	23.0	23.0	18.6	16.3
	Psychrometric chart	23.9	26.1	21.7	20.7
	Psychrometric eqs.	21.7	26.1	21.8	20.3
High ~33.6°C	Measured	26.0	26.3	21.0	18.5
	Effectiveness	26.6	27.1	21.6	19.0
	Psychrometric chart	29.7	30.3	25.8	23.2
	Psychrometric eqs.	26.3	32.6	28.8	27.1

At low and medium inlet heat, all nozzle configurations cooled the outlet air to within the human comfort range. At high inlet heat, only the four- and five-nozzle configurations cooled the outlet air to comfortable temperatures. The temperature predictions of both the psychrometric chart and psychrometric equations were quite different than the measured temperatures. This is likely in part due to the water temperature being lower than the air temperature. If the water is at a lower temperature than the air, heat will transfer from the air to the water. The psychrometric evaluations do not account for this non-evaporative cooling. The accuracy of the humidity readings also plays a major role in the psychrometric predictions.

The cooling capacity of each nozzle configuration and inlet heat setting were calculated using Eq. (10) and are presented in Figure 9. The average high temperature for July in Cedar City is 32.8°C, with a relative humidity of 31%, which corresponds to the wet-bulb temperature of 20.7°C and a wet-bulb depression of 12.1°C [14]. The predicted cooling capacities were evaluated by Eq. (3) using the average air flow rate measured during testing. The predicted cooling capacities for the average high temperatures of July in Cedar City are displayed in Figure 10.

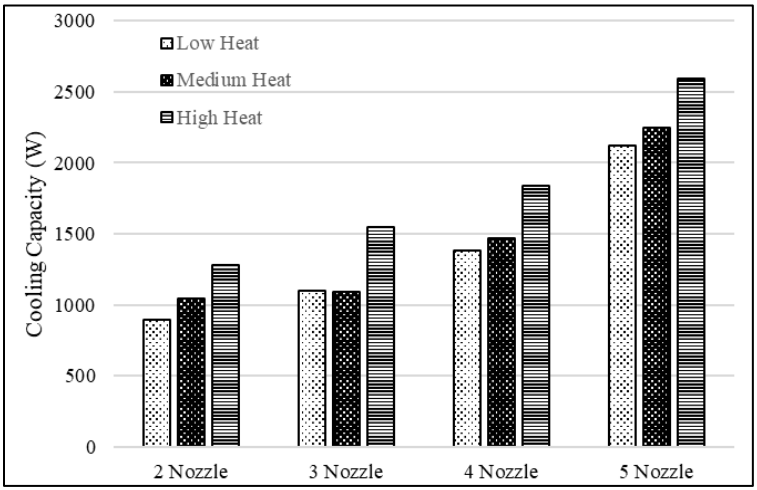

Figure 9. Cooling capacity of each nozzle configuration.

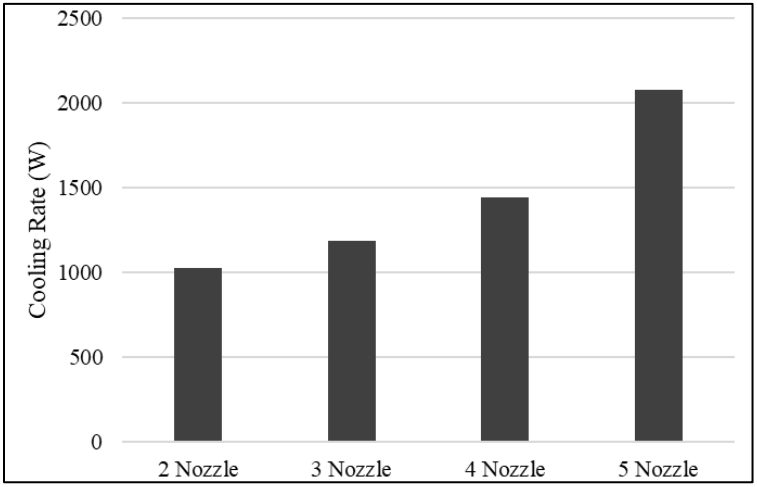

Figure 10. Predicted cooling capacity of each nozzle arrangement for average July temperature highs in Cedar City, Utah.

The predicted cooling capacities are based on the average measured air flow rate of each nozzle configuration. The effectiveness ratio does not account for different air flow rates; therefore, the incoming wind speeds that are different than those tested would produce different cooling rates. A higher windspeed would lead to a greater cooling capacity. Additionally, a greater wet-bulb depression will generally result in a larger cooling capacity because the change in temperature from the inlet to the outlet is larger.

Under the Cedar City, Utah, conditions, the four-nozzle configuration provides approximately the same cooling capacity as a small window-mounted AC. Small window-mounted ACs are typically rated for 1,465 W of cooling, which is advertised to cool a 14-m^2 room [15]. This room size estimate does not account for variations in local climate, room height, shading, window size, or other thermal considerations, but it serves as a convenient baseline.

Water Usage Efficiency

In the ideal case, all of the water sprayed in the PDEC will evaporate before exiting the tower. Unevaporated water means wasted energy and wasted water. Eq. (28) was used to calculate the water usage efficiency for each nozzle configuration and heat setting. The efficiency values are presented in Figure 11.

The calculated efficiencies of the two-nozzle configuration at medium and high heat are significantly greater than the other efficiency values. This may be due to measurement error because the efficiency calculations are highly sensitive to the humidity measurements. The large apparent error in these results prevents any conclusions from being made about changes in efficiency for different numbers of nozzles. However, the results indicate that most of the water supplied by the nozzles did not evaporate. The efficiency might be improved by increasing the tower's height and diameter. Increasing the height would allow more time for the water to evaporate before reaching the exit. Increasing the diameter would help prevent some of the water from spraying directly onto the inside surface of the tower, and the added space would allow for more airflow and contact between air and water.

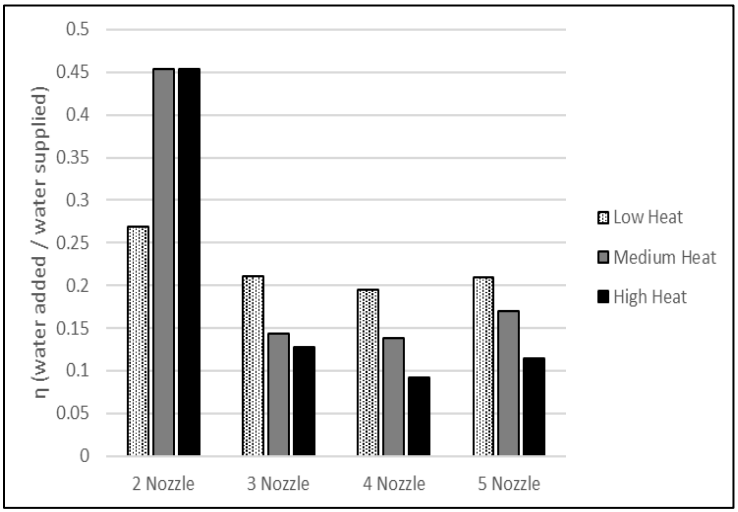

Figure 11. Water usage efficiency (η) for each nozzle configuration and heat setting.

Limitations of the System

Regardless of the cooling capacity of the system, the output temperature is still extremely important. When calculating the cooling capacity required for a conventional AC system, it is assumed that the output temperature is at or below the desired room temperature, but this may not always be the case with an evaporative cooler. For example, the five-nozzle configuration in the July conditions in Cedar City has a predicted output temperature of 22°C, which is a comfortable room

temperature. However, at higher ambient temperatures, the outlet temperature from the cooler could easily exceed the human comfort range. This is not adequate for cooling a living space during very hot outdoor conditions. Under very hot conditions, the cooling capacity of the system may only be useful as a supplemental cooling system.

Water consumption is also a concern with evaporative coolers. The greater the cooling rate, the more water is evaporated and lost to the air. Because evaporative cooling is only viable in dry climates, water consumption can be a major concern if the usage of evaporative cooling becomes more widespread.

As stated before, the purity of the water used for spray-type systems is important, and the type of nozzle determines the water purity required. In this case, the nozzles have small orifices and so are prone to clogging by impurities and hard water deposits. If this does happen, an inline filter can help remove impurities before they reach the nozzles. Larger nozzles with larger orifices will not have as many problems with clogging. Microbial contamination and growth must also be considered, both in the water introduced to the air and on the wet surfaces of the system.

In our experiment, moisture in the exiting air became a problem with both the four- and five-nozzle configurations. The mist exiting the tower with the five-nozzle configuration can be seen in Figure 12.

Figure 12. Liquid water exiting the tower when using five nozzles.

Increasing the tower height will help to eliminate this problem by increasing the distance in which the water can evaporate. A wider or

larger-diameter tower will also allow for a greater evaporation rate because more air will travel through the tower. Unless the excess water can be removed from the air at the outlet, the mist problem may limit the number of nozzles that can be used. In Givoni's test setup, the tower was a straight tube whose exit was just the bottom of the tube. This allowed the excess water to land directly into a reservoir and be pumped back to the top of the tower [10]. However, the droplet size used in his tests was likely *much* larger than the one used in this research and the moisture would not be directed out into the room as much as with fine mist nozzles.

SOURCES OF ERROR

The potential error sources are from the equipment used in taking measurements. Errors reported by the manufacturers are shown in Table 3 for the DHT22 sensor, Table 4 for the Kestrel 1000 anemometer, and Table 5 for the Protmex PT6508.

Table 3. Reported errors from the manufacturer of the DHT22 sensor [15]

Variable	Range	Accuracy	Resolution sensitivity	Repeatability	Hysteresis
Temperature (°C)	-40 to 125	±0.2	0.1	±0.2	--
Relative humidity (%)	0.0 to 100	±5.0	0.1	±1.0	±0.3

Table 4. Reported errors from the manufacturer of the Kestrel 1000 anemometer [16]

Variable	Value
Measuring range (m/s)	0.6 to 40
Range accuracy (% reading)	± 3
Resolution (m/s)	0.1

Table 5. Reported errors from the manufacturer of the Protmex PT6508 [17]

Variable	Range	Accuracy
Temperature (°C)	-20 to 60	--
Relative humidity (%)	0 to 100	±3

Liquid water was observed at the exit of the tower, especially for the four- and five-nozzle configurations. The humidity sensor at the exit was therefore subjected to fairly wet conditions and may have given a

higher humidity reading than it should have. The wet conditions may have also caused the exit temperature readings to be lower than the actual air temperature because the water temperature was lower than the exit temperatures. This may help explain why the measured outlet temperatures were consistently lower than the predicted temperatures, especially for the tests with four and five nozzles.

The DHT22 humidity and temperature sensor was positioned close to the heaters because of size constraints. The placement of the sensor, left or right, within the tower had a large effect on its temperature and humidity readings. To account for this, an initial dry test was conducted without water spray. The system was allowed to reach the steady state with the fan and heater(s) on for each heat setting. Once the steady state was reached, the inlet and exit temperatures were compared, and the DHT22 sensor was moved until the inlet and exit temperatures were the same. Because there were two heaters, the appropriate position of the sensor was different for the different heat settings. The sensor position for each heat setting was noted so the sensor could be placed in the appropriate position for each heat setting during actual testing. Despite this, the sensor position may have caused the temperature and humidity readings to not reflect the actual average conditions of the air.

The water usage efficiency as well as the psychrometric equations method of calculating outlet temperature are highly sensitive to the humidity measurements. As such, errors in humidity measurements have a large effect on these results.

The effectiveness ratios were calculated from only three data points each. However, the R^2 value for each trendline was over 0.99, so the trendlines align closely with the data. More data points would be preferable to ensure accurate effectiveness values.

CONCLUSION

The investigation into the spray-type PDEC tower has provided valuable insights into its cooling performance and operational characteristics. Through the construction and testing of a small-scale PDEC prototype with varying numbers of spray nozzles, we observed that the cooling effectiveness of the system correlated positively with the number of nozzles employed. The results validate the effectiveness of using fine misting nozzles in a PDEC, whereas previous research has focused on higher water flow rates and larger droplets. This finding underscores the potential of PDEC technology as an efficient and sustainable cooling solution, particularly in arid and semi-arid regions where evaporative cooling can be most beneficial.

However, the increase in cooling performance with additional spray nozzles is accompanied by a notable challenge—the escalation of liquid water sprayed out of the tower's exit. This phenomenon raises concerns regarding water usage efficiency and environmental impact, because excess water loss may compromise the sustainability of the system and lead to undesirable consequences such as water wastage and water damage to the space being cooled. In its current state, the cooling performance of this PDEC is adequate with four or five nozzles, but the water spraying out of the exit limits this system to three or fewer nozzles.

Moving forward, further research and development efforts are warranted to address this issue and optimize the balance between cooling effectiveness and water consumption in PDEC towers. Potential strategies may include refining nozzle design, adjusting operating parameters such as tower height and diameter, or integrating supplementary technologies to minimize water loss without sacrificing cooling performance. To achieve more accurate results in future research, steps should be taken to improve the accuracy of humidity and temperature measurements. By overcoming these challenges, PDEC technology can fulfill its promise as a cost-effective, energy-efficient, and environmentally friendly cooling solution, offering relief in regions susceptible to high temperatures and water scarcity. Ultimately, the findings presented in this study contribute to the ongoing advancement and adoption of PDEC technology, paving the way for its widespread application in diverse climatic contexts.

ACKNOWLEDGMENTS

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REFERENCES

[1] Nullis, C., (2024), "Climate change indicators reached record levels in 2023: WMO." World Meterological Organization. Retrieved March 19, 2024, from https://wmo.int/news/media-centre/climate-change-indicators-reached-record-levels-2023-wmo.

[2] IEA, (2018), “The future of cooling.” *IEA*, Paris, France, p. 22. Retrieved March 19, 2024, from https://www.iea.org/reports/the-future-of-cooling.

[3] AZEVAP, (2024), “History of Evaporative Cooling Technology.*”* AZEVAP. Retrieved March 19, 2024, fom https://www.azevap.com/history-technology.php.

[4] Hronis C, Beall R, (2022) “Housing characteristics overview from the 2020 Residential Energy Consumption Survey (RECS).” U.S. Energy Information Administration Webinar. Retrieved March 19, 2024, from https://www.eia.gov/consumption/residential/status/pdf/RECS%202020%20Webinar.pdf.

[5] Çengel, Y.A., Ghajar A.J., (2015) *Heat and Mass Transfer, Fundamental and Applications*, 5th ed. McGraw Hill.

[6] Occupational Safety and Health Administration, “Office Temperature/Humidity”, Retrieved March 11, 2024 from https://www.osha.gov/laws-regs/standardinterpretations/2003-02-24.

[7] Çengel, Y.A., Boles, M.A., and Kanoğlu, M., (2015) *Thermodynamics: An Engineering Approach*, 8th ed. McGraw Hill.

[8] Shokoohi, K., “The ancient Persian way to keep cool”, BBC, August 10, 2021. Retrieved March 31, 2024, from https://www.bbc.com/future/article/20210810-the-ancient-persian-way-to-keep-cool.

[9] Paanchal, J.B., Mehta, N., (2017) “A review on design of passive down draft evaporative cooling in commerical building,” *IJARIIE* 3 (2), 4054

[10] Givoni B, (1994) *Passive and Low-Energy Cooling of Buildings.* Wiley.

[11] Kang D., Strand, R., “Significance of parameters affecting the performance of a passive down-draft evaporative cooling (PDEC) tower with a spray system,*”* Applied Energy 178, 269-280.

[12] Stull, R., (2011) “Wet-bulb temperature from relative humidity and air temperature,” *Journal of Applied Meteorology and Climatology*, 50(11), 2267-2269.

[13] Raffety, J., "Absolute Humidity," Britannica, March 8, 2024, Retrieved March 31, 2024, from https://www.britannica.com/science/absolute-humidity.

[14] "Annual weather averages in Cedar City," timeanddate.com. Retrieved March 18, 2024 from https://www.timeanddate.com/weather/@5536630/climate.

[15] Farrell, M.H., "How to properly size a window air conditioner," Consumer Reports," 17 June 2023. Retrieved March 19, 2024, from https://www.consumerreports.org/appliances/air-conditioners/how-to-size-a-window-air-conditioner-a5802959073.

APPENDIX

This appendix presents a simplified psychrometric chart to illustrate its use in evaluating dry-bulb temperature from wet-bulb temperature and relative humidity. The dashed lines in Figure A1 represent the given wet-bulb temperature and relative humidity values for evaluating the expected dry-bulb temperature.

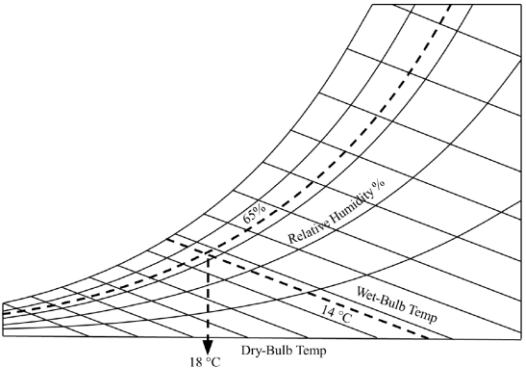

Figure A1. Simplified psychrometric chart used for evaluating dry-bulb temperature.

Experimental Results of Water and Air Solar Heating System

Savanah L. Higley, Capri L. Franzen, Gage W. Van Dyke, Larry T. Webster, and Ali S. Siahpush
Southern Utah University

ABSTRACT

Solar water and air heating systems are a renewable and sustainable method to collect solar energy, especially in developing countries where water and air heating techniques using electricity are possibly expensive, inefficient, or scarce. Solar heaters utilize thermal radiation to heat water or air in a relatively short time. The purpose of this paper is to design a cost-effective, multifunctional solar heater, which can be used for heating both air and water. Testing with water was performed by pumping water at a continuous rate through an insulated water reservoir. The water tests were performed in Cedar City, Utah, under ambient weather conditions in October 2023. Tests were performed using clear plastic bottles to minimize the natural convection heat transfer and also without the bottles to validate the effectiveness of plastic bottles. During the tests using the bottles and water, the average temperature change of the water in the reservoir was 27.5°C, while the average temperature change in the reservoir without the plastic bottles was 16.4°C. The air experiments were performed in February 2024 with a similar set-up as the water experiments but without the reservoir. The

air experiment was designed to heat a typical small room. During this test, the air temperature in the room increased from the ambient air temperature to 32.8°C.

INTRODUCTION

Engineers have experimented with energy sources ranging from wind power and hydropower to nuclear and solar power for many decades to develop renewable and sustainable ways to use energy. One of these energy sources is solar energy, which can be converted to electricity or thermal energy. Solar energy is clean and renewable, making it versatile for several applications such as solar water and air heaters [1].

The major considerations when designing a solar heater are cost, simplicity, and efficiency. The technical literature is filled with designs of solar water heaters. One of the simplest methods is a flat-plate collector, comprising black-painted tubes that absorb the heat of the sun and have a plastic cover or glazing overtop to reduce convection heat transfer [2]. Chekchek et al. [3] designed a flat-plate collector using plastic water bottles as glazing and tested it in M'sila, Algeria. Abdullahi et al. [4] also designed a flat-plate collector using water bottles in the same way and tested it in Zaria, Nigeria. Using recycled water bottles for the glazing makes the design simple, cost-effective, and environmentally sustainable.

Along with solar water heater designs, there are numerous designs for solar air heaters. Komolafe et al. [5] designed a solar air heater using copper tubes and rectangular rib roughness. Kalaiarasi et al. [6] designed a flat-plate solar air heater with an integrated heat storage system using copper tubing to store the heat with a flow rate of 0.028 kg/s. Gopi et al. [7] compared flat plate solar air heaters and determined that the efficiency of a solar air heater can be improved by increasing the area or adding cylindrical fins to the system. Kumar et al. [8] also performed an analysis of a solar air heater with cylindrical fins. They found that the efficiency increased to 23.5% with the addition of a wavy fin and determined the solar collector was ineffective for flow rates lower than 0.05 kg/s. Dhaundiyal and Gebremicheal's [9] design incorporated a carrier fluid, acrylic glass to prevent convection heat transfer, and a reflective surface. Abbas et al. [10] designed several low-cost flat-plate solar collectors and the one yielding the highest efficiency with a finned steel plate.

The primary purpose of this paper is the design, development, and testing of a cost-effective flat-plate solar heater using recycled water

bottles as glazing to heat water and air inside a copper tube. A size constraint of 8 ft by 4 ft was used to minimize the cost and keep the heater portable. Along with this constraint, considering not using elbows to minimize the cost, the copper tubing was only able to be bent at a 180° curve with a 6-in radius. Following these constraints and to maximize the amount of tubing to collect solar energy, a parallel-flow design was used, allowing for twice the amount of copper piping to construct the system. This design will also slow the flow rate of the fluid down by directing the flow between two parallel tube systems.

MATERIALS

The following materials were used in this project. Appendices A and B detail the material and testing information.

- 1-in × 6-in × 8-ft premium kiln-dried square edge whitewood common softwood boards
- 1-in × 3-in × 8-ft furring strip board
- 1½-in × 48-in × 8-ft R-5.78 EPS rigid foam board insulation
- Tubolit DGT01234S ½-in × ¾-in foam semi-split pipe insulation
- FOAMULAR NGX F-250 2-in × 4-ft × 8-ft SSE R-10 XPS rigid foam board insulation
- 1¼-in × 18-gauge brad nail glue collated
- Collected 0.5-L and 1.5-L plastic bottles
- Coleman Chiller Series 30-qt portable insulated container
- TWTADE 2pcs 2M K type mini-connector thermocouple temperature probe sensor measure range -50~250°C MT-2m
- Rust-Oleum Stops Rust gloss black spray paint 12 oz
- UDP 5/8-in ID × ¾-in OD × 10-ft clear vinyl tubing
- Zip ties
- ELECTRAPICK copper tubing 5/8-in OD × 9/16-in ID × 50-ft pure copper tube round pipe tubing metal tubing copper coil, air conditioning refrigerator & industry
- (8-Pack) Lidertik copper to PEX fittings ½-in, ½-in PEX F1807 × ½-in female sweat adapter brass
- SharkBite U860W25 PEX pipe ½-in, white, flexible water pipe tubing, potable water, push-to-connect plumbing fittings, 25 ft coil of piping
- Stainless steel PEX-B barb pinch clamp (10-pack)
- ½-in. brass PEX-B barb × ½-in female pipe thread adapter
- 1/2 in brass PEX-B barb 90 elbow (10-pack)

- ELEGOO UNO R3 board ATmega328P with USB cable (Arduino-compatible) for Arduino
- Breadboard jumper wire cables for Arduino
- ½-in water flow hall sensor switch flow meter counter 1-30L/min
- Little Giant "NO KORODE" 115-Volt, 1/150 HP, 210 GPH NK-1 mild acid, alkalis, and hard water submersible centrifugal pump
- Digital 4-channel thermocouple thermometer temperature recorder data logger AZ instruments multi-channel K Type thermometer thermocouple reader with 8G SD card 2 bead type K-thermocouple probe
- HUATO S220-T8 8-channel thermocouple data logger with external power supply and 3 points NIST traceable certificate, measuring range -200 to 1800°C

TESTING PROCEDURE

Figure 1 depicts the solar heater apparatus.

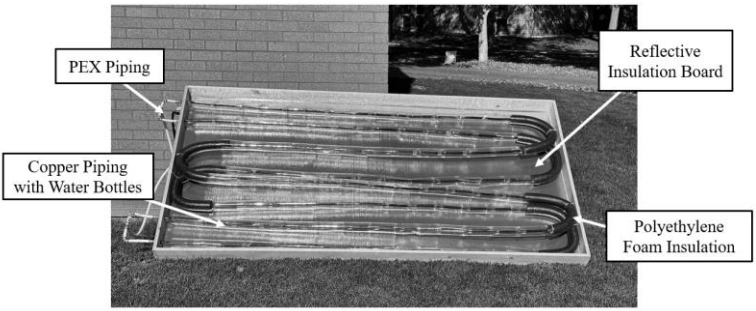

Figure 1. The solar heater apparatus.

Water

1. Turn the system normal to the sun and turn on the water pump.
2. Leave the water pump running until the temperatures of the tubing reach steady state.
3. Record the flow rate.
4. Remove the water bottles and repeat the procedure.

Air

1. Turn the system normal to the sun and turn on the air pump.
2. Start the air pump and let the system run for 30 minutes until the temperatures in the tubing reach steady state.
3. Measure the pressure change using a pitot tube and manometer placed at the outlet of the system to determine the flow rate of the air.

RESULTS AND DISCUSSION

Water

Four tests were conducted on October 19, 20, 21, and 23, 2023, in Cedar City, Utah, from 10:30 AM to 2:00 PM. In each closed-loop test, water was continually pumped through the system and into an insulated reservoir at a flow rate of 0.12 kg/s. The first two tests were conducted with glazing, and the last two tests were conducted without glazing. Thermocouples (TCs) were placed at the inlet and outlet of each path to ensure the temperatures were the same in both sets of parallel copper tubing to verify the systems were identical. TCs were placed in and on top of the insulated container to make sure the insulation was sufficient to minimize heat loss to the environment. After further study of the TC data, the temperatures of both sections of tubing were very similar. Figure 2 depicts the temperature versus time for the average of the tests with glazing.

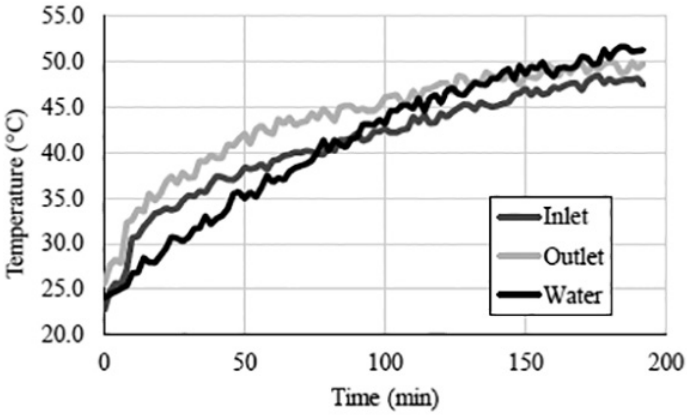

Figure 2. Temperatures with glazing.

The tests with the glazing reached an average copper tube inlet temperature of 47.8°C from the reservoir and an average outlet temperature of 49.5°C. The average water temperature in the reservoir was 51.3°C. The steady-state temperature of the reservoir was greater than the inlet and outlet tempetures of the copper tube. This discrepancy shows that the water in the reservoir gained some heat from the sun and the pump. At the beginning of the testing, the initial temperature of the water in the reservoir was 24.0°C, giving a final temperature increase of 27.3°C.

Two tests without glazing were then conducted in similar conditions (Fig. 3). The temperature distribution without glazing showed there were more inconsistencies or slight jumps in the data for the inlet and outlet temperatures. The tests without the glazing reached an average copper tube inlet temperature of 39.0°C, an average copper tube outlet temperature of 38.0°C, and an average water temperature of 41.5°C. This experiment also showed that the steady-state temperature of the reservoir was greater than the inlet and outlet temperatures of the copper tube.

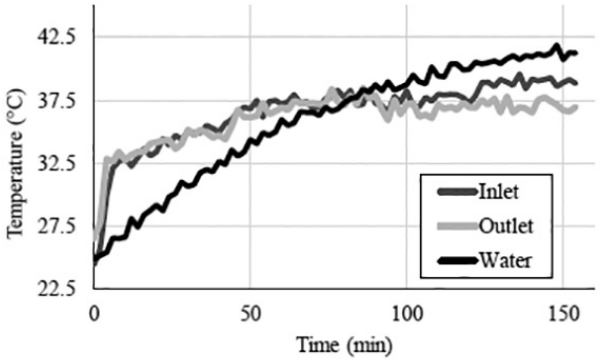

Figure 3. Temperatures without glazing.

As expected, the final temperatures for the tests with water bottle glazing were higher than the tests without, and the temperature increase of the water was drastically different. This shows the effectiveness of using glazing. Table 1 presents a summary of the ambient and average final temperatures for all four tests. The ambient temperature values varied by 1.3°C, showing the experiment was conducted in similar conditions, adding validity to the experiment.

Table 1. Average weather conditions and the final temperature (°C) values for all four tests				
Condition	**Ambient temperature**	**Inlet temperature**	**Outlet temperature**	**Water temperature**
With glazing	14.3	47.75	49.5	51.3
Without glazing	13.6	39	37.95	41.5

Air

One test was performed on February 22, 2024, in Cedar City, Utah, from 11:00 to 11:30 AM. TCs were placed on the copper tubing underneath the insulation on both tubes at the inlet and outlet to ensure both paths of the tubing had the same temperature throughout the experiment. Another TC was placed in the PEX piping at the outlet to measure the outlet air temperature. An air pump was used to pump the ambient air through the tubing at a flow rate of 0.00421 kg/s.

The steady-state condition was achieved in ~22 minutes. Both TCs from the tubes of the parallel paths had similar temperatures, verifying the temperature increase was consistent through each tube. The average temperatures of the copper tube inlet and outlet were 37.1°C and 53.8°C, respectively. The steady-state temperature difference between the inlet and outlet was 16.7°C, and the increase from the ambient air temperature was 32.8°C. Having the TC placed on the inlet underneath the insulation allowed for the measurement of the temperature of the air after it had passed through the air pump. The temperature difference between ambient air and the inlet was 17.1°C, showing considerable heat may have been added to the system from the air pump. Figure 4 depicts the temperature versus time for the inlet and outlet temperatures.

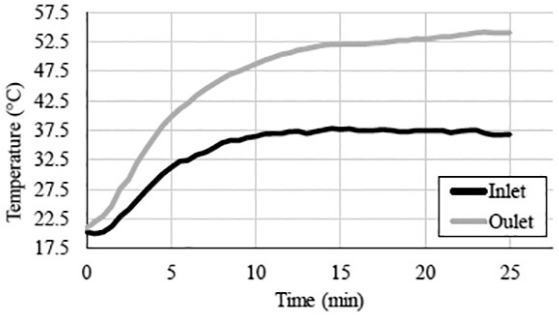

Figure 4. The temperature vs. time of the inlet and outlet of both copper tubes.

SOURCES OF ERROR

Water

One source of error could be from the pump adding heat into the water in the insulated container. Another potential source of error is that the reservoir was not fully insulated and gained some heat from Sun. The temperatures of the water in the insulated container were higher than both the inlet and outlet temperatures, which violates the Second Law of Thermodynamics, if the system was ideal. Another possible source of error was the slight gaps in the water bottle enclosures over the copper tubing. This may have impacted the data for the case where no convection heat loss was assumed, as gaps would allow for the ambient moving air to influence the convection heat transfer. However, the temperature increase followed the expected behavior, so this source of error can be deemed negligible. An error may have also occurred due to loose connections of the TCs in the data logger. This error combined with the accuracy rating of the TCs and data logger would impact the experimental results. No insulation was placed over the PEX or vinyl tubing connecting the insulated container to the copper tubing in the housing, which may have led to a loss of heat to the environment.

Air

As with the water tests, possible error may have occurred because of the accuracy of the TCs and data logger and loose connections in the TCs. The pump that was used likely added heat to the air that passed through it. Therefore, comparing final temperature values to the ambient temperature was not ideal because the heat added to the system by the pump was unknown.

CONCLUSION AND RECOMMENDATIONS

The purpose of this experiment was to design and test a cost-effective solar heater with recycleable water bottles as glazing to show the importance of using glazing to prevent convection heat transfer and to compare the temperature increases using water versus air. In the tests using water, the system was tested with and then without water bottles. The temperature increase of the water with the glazing was 28.7°C, while the temperature without the glazing was only 16.4°C. The steady-state temperatures were achieved after 3.5 hours. For the tests using air, insulation was added to the inlet and outlet tubing to prevent losses, and the system was repainted using matte black paint rather than gloss black paint to maximize absorption. The increase in

temperature of the air during this test was 32.8°C, and the temperatures reached steady-state after 22 minutes.

The solar heater cost $400 for all materials. The cost is too high to implement in a developing-world country, so it is recommended to experiment with more cost-effective materials, such as using old clothing in place of the insulation, old reflective wrappers in place of an insulation board with a reflective coating, and recycled wood for the frame.

For future experiments, it is recommended that a separate experiment be performed in a closed environment without solar exposure to determine the heat added to each system by both pumps. These values could then be taken into consideration in future experimentation with the solar water heater. Insulation should be placed over the PEX tubing to reduce any error from heat loss. It is recommended that air testing be performed in a closed environment to obtain more accurate results.

ACKNOWLEDGMENTS

This project would not have been possible without the support of the Department of Engineering and Technology at Southern Utah University. Contributions from them include assistance from the faculty and usage of University workspaces. We would also like to acknowledge the Utah NASA Space Grant Consortium for supporting this undergraduate research.

REFERENCES

[1] Solar Energy Industries Association. “About solar energy.” Retrieved November, 07, 2023, from https://www.seia.org/initiatives/about-solar-energy

[2] “Solar water heaters,” Energy.gov. Retrieved November 07, 2023, from https://www.energy.gov/energysaver/solar-water-heaters

[3] Chekchek, B., Salmi, M., Boursas, A., et al. (2021). Experimental study of the efficiency of a solar water heater construction from recycled plastic bottles. International Journal of Design & Nature and Ecodynamics, vol. 16, no. 2, pp. 121-126. https://doi.org/10.18280/ijdne.160201.

[4] Abdullahi, M., Oyinlola, M., Ahmed, A., Balogun, M. (2022). Investigating the performance of a solar collector with plastic bottles as glazing cover. 17th UK Heat Transfer Conference (UKHTC2021), April 4-6, 2022, Manchester, UK.

[5] Komolafe, C., Oluwaleye, I.O., Awogbemi, O., Osueke, C.O. (2019). Experimental investigation and thermal analysis of solar air heater having rectangular rib roughness on the absorber plate. Case Studies in Thermal Engineering, vol. 14, pp. 100442. https://doi.org/10.1016/j.csite.2019.100442.

[6] Kalaiarasi, G., Velraj, R., Vanjeswaran, M.N., Ganesh Pandian, N. (2020). Experimental analysis and comparison of flat plate solar air heater with and without integrated sensible heat storage," Renewable Energy, vol. 150, pp. 255-265. https://doi.org/10.1016/j.renene.2019.12.116.

[7] Gopi, R., Ponnusamy, P., Fantin Arokiaraj, A., Raji, A. (2021). Performance comparison of flat plate collectors in solar air heater by theoretical and computational method. Materials Today: Proceedings, vol. 39, pt. 1, pp. 823-826. https://doi.org/10.1016/j.matpr.2020.09.809.

[8] Kumar, A, Kumar, A, Bheemanna, G, Prasad, G. (2018). Thermal and pressure drop analysis of solar air heater with and without wavy fin. International Journal of Mechanical Engineering and Technology, vol. 9, no. 12, pp. 525-531.

[9] Dhaundiyal, A., and Gebremicheal, G.H. (2021). The effect of psychrometry on the performance of a solar collector. Environmental Science and Pollution Research International, vol. 29, iss. 9, pp. 13445-13458. https://doi.org/10.1007/s11356-021-16353-5.

[10] Abbas, S., Yuan, Y., Hassan, A., Zhou, J., Ji, W., Yu, T., Ul Rehman, U., Yousuf, S. (2022). Design a low-cost, medium-scale, flat plate solar air heater: and experimental and simulation study," Journal of Energy Storage, vol. 56, pt. A, pp. 105858. https://doi.org/10.1016/j.est.

APPENDIX A

Provided in this appendix are the materials needed to build and perform this experiment.

Item	Website for purchase	Date of purchase
Construction		
R-Tech 1½-in × 48-in × 8-ft R-5.78 EPS rigid foam board insulation 320817	https://www.homedepot.com/p/R-Tech-1-1-2-in-x-48-in-x-8-ft-R-5-78-EPS-Rigid-Foam-Board-Insulation-320817/202532855	Nov. 6, 2023
Tubolit DGT01234S ½-in × ¾-in foam semi-split pipe insulation, 210 lineal feet/carton, polyethylene	https://www.amazon.com/Tubolit-DGT01234S-Foam-Semi-Split-Insulation/dp/B00FQ562BA	Nov. 6, 2023
TWTADE 2pcs 2M K type mini-connector thermocouple temperature probe sensor measure range -50~250°C MT-2m	https://www.amazon.com/Mini-Connector-Thermocouple-Temperature-Measure-50-250°C/dp/B07MMLY3PZ	Nov. 6, 2023
Rust-Oleum Stops Rust gloss black spray paint 12 oz	https://www.acehardware.com/departments/paint-and-supplies/spray-paint/hobby-spray-paint/11878	Nov. 6, 2023
Ace ProLine 5/8-in ID × ¾-in OD × 10-ft L PVC vinyl tubing	https://www.acehardware.com/departments/plumbing/hoses-and-tubing/vinyl-tubing/4315578	Nov. 6, 2023
PEX/Copper		
ELECTRAPICK copper tubing 5/8-in OD × 9/16-in ID × 50-ft, pure copper tube round pipe tubing metal tubing copper coil	https://www.amazon.com/ELECTRAPICK-Copper-Conditioning-Refrigerator-Industry/dp/B0C7Q1JR2X	Nov. 6, 2023

Data logger		
HUATO S220-T8 8-channel thermocouple data logger with external power supply and 3 points NIST traceable certificate, measuring range -200 to 1800°C	https://www.amazon.com/HUATO-S220-T8-Thermocouple-Traceable-Certificate/dp/B07SJRG6Y8	Nov. 6, 2023
Water pump		
Little Giant 'NO KORODE' 115-Volt, 1/150 HP, 210 GPH NK-1 mild acid, alkalis, and hard water submersible centrifugal pump, black, 526003	https://www.amazon.com/Little-Outdoor-526003-Submersible-Centrifugal/dp/B000CDRZWG	Nov. 8, 2023
Air pump and addional recording devices		
Intex quick fill 120-volt AC electric 38.9 CFM inflatable float & air bed pump	https://www.amazon.com/INTEX-66643-QuickFill-Rechargeable-Electric/dp/B07F3S32TK	Mar. 18, 2024
Boundary layer probes	https://www.unitedsensorcorp.com/boundary.html	Dec. 11, 2023
Hti-Xintai digital manometer, dual port air pressure meter pressure gauge HVAC gas tester, differential pressure manometer with 5/16-in diameter pressure port	https://www.amazon.com/Manometer-Pressure-Differential-Diameter-Hti-Xintai/dp/B07R3J4ZJ4	Mar. 4, 2024

APPENDIX B

In this appendix, the experiment setup and building procedure are discussed. Figure B1 shows a close-up of the experimental setup with the water bottles around the tubing. Figure B2 shows the experimental setup without the water bottles and the inlet and outlet of the tubing. Figure B3 shows a diagram of the setup with the thermocouple placements.

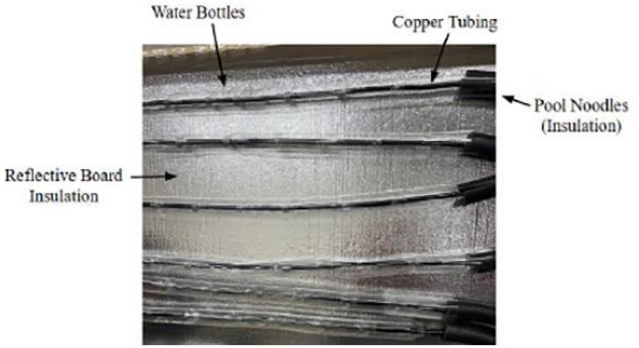

Figure B1. Close-up experimental set-up with water bottles.

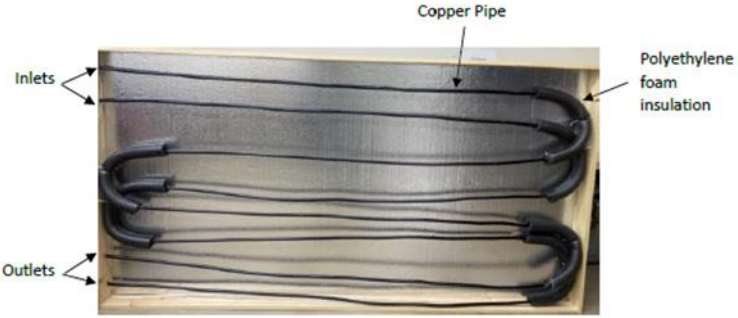

Figure B2. Experimental set-up without water bottles.

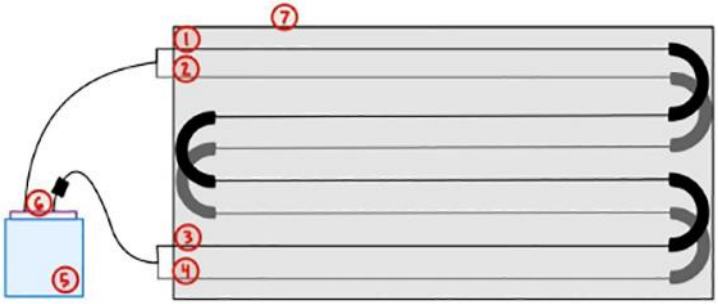

Figure B3. Thermocouple placement.

Building Procedure

The first part that must be built is the frame, which will act as the housing for the system. The directions are as follows:

1. Square off two pieces of 1-in × 6-in × 8-ft kiln-dried square edge whitewood board such that their total lengths are ~95⅞ in.
2. Cut down and square 2 of the same board type so they measure 49½ in.
3. Cut down and square 2 pieces of 1-in × 3-in × 8-ft furring strip board to 49½ in.
4. Cut down some excess of the furring strip board into 4 strips with 45-degree cuts such that the longer edge is 24 in.
5. Using 1¼-in × 18-gauge brad nail glue collated nails in a Brad nail gun, connect the longer 1-in × 6-in board pieces to the shorter pieces of the same board type. Ensure the shorter pieces are outside the longer board and flush to the other boards.
6. Attach the furring strip board on the bottom of the board frame with the two long strips being spaced equidistantly from the edge and the middle as well as the four 45-degree boards placed in the corners with the edges squared to the outer edge of the frame. Ensure all boards are flush to the outside of the initial box to keep the box having square corners.
7. Place one 1½-in × 48-in × 8-ft. EPS rigid foam board insulation with the reflective face placed opposite the boards just attached. The final frame and panel are shown in Fig. B4.

Figure B4. Finished frame with insulation board.

Once the frame is built, the tube must be bent, and 4 holes are to be drilled into the frame. The tubing should be placed 3 in away from the upper and lower wall, with ~6 in between each tube. The radius of the

bends being 6 in, and the tubing being suspended ~2 in above the foam board and 2½ in below the top of the housing.

8. Once the tubing is bent and holes drilled, insert the copper tubing through the holes into the housing.
9. Sweat on the 4 copper to PEX fittings with the ½-in brass female sweat adapter to both inlets and both outlets.
10. While the copper cools, cut slits in the tubing insulation and apply it to the curves of the copper tubing.
11. Cut 4 pieces of PEX piping to ~4 in and secure them to the inlets and outlets with the crimping clamps and crimping tool.
12. Attach a 90-degree elbow with the outlets facing towards each other and the outlets facing each other using crimping clamps.
13. Similarly, attach the inlets together and the outlets together using the ½-in PEX T fittings and crimping clamps.
14. Continue from the T fitting with 3-4 ft of PEX.
15. The correct setup of the T fitting and connections to the copper tubing lines is shown in Fig. B5.

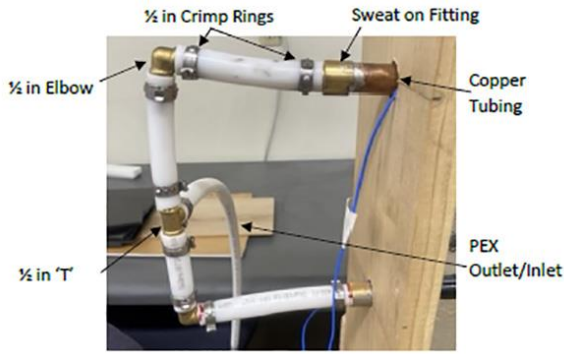

Figure B5. Inlet/outlet PEX layout.

16. From the outlet PEX line insert the flowmeter using two PEX to threaded female fittings.
17. Using the 2-in foam board and a foam cutter, trace and cut an appropriate size piece such that it fits snuggly over the insulated container once the lid has been removed.
18. Using the same foam cutter, create two holes in the top, each the size of the PEX or vinyl tubing.
19. Finally, connect the submersible pump through the 2-in foam board and to the inlet PEX line using the vinyl tubing.

One-Dimensional Heat Conduction Through Composite Walls

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ABSTRACT

One-dimensional (1D) heat transfer analysis is a fundamental assumption to make when the thermal behavior of a system is considered. This assumption states that if the thickness of a material is considerably less than the height and length, heat conduction can be assumed to be 1D. This assumption can be used to simplify the conduction heat transfer analyses, including that of a composite wall. In this experiment, a composite wall was considered with oak wood, polylactic acid, and acrylic materials in both parallel and series, and the temperatures at various points were measured to verify the validity of 1D heat transfer. The experimental temperature values were compared with transient analytical values obtained through an explicit finite difference method code executed in MATLAB, and steady-state analytical values were obtained by applying the thermal resistance concept. This experiment proved to be a success in validating 1D heat transfer, as the experimental temperature values were similar to both the transient and steady-state analytical values. Minimal error was observed in the experiment. Further uses of this experiment include a heat transfer laboratory demonstrating the 1D heat transfer concept.

NOMENCLATURE	
Symbol	**Description**
$\dot{E}$	Heat transfer (W)
$\dot{E}_{stored}$	Energy stored in material (W)
$\dot{q}$	Heat flux (W/m^2)
A	Area perpendicular to direction of heat transfer (m^2)
k	Thermal conductivity (W/m·K)
ρ	Density (kg/m^3)
c_p	Specific heat at a constant pressure (J/kg·K)
Δx	Distance between nodes (m)
t	Time (s)
T	Temperature (°C)
i	Time step
τ	Fourier number or time constant
α	Thermal diffusivity (m^2/s)
h	Convection heat transfer coefficient (W/m^2·K)
R	Thermal resistance (K/W)
L	Thickness of material (m)

INTRODUCTION

In the heat and mass transfer textbooks [1-2], the one-dimensional (1D) assumption states when heat transfer occurs in an object where the height and length are much greater than the thickness, heat transfer through solids can be assumed to be 1D across the thickness [1, p. 73]. Applying this assumption can be vital for a thermal engineer, because it can make the analysis process simpler in applications involving plane walls, cylindrical shells, or spheres. One such application is a composite wall, consisting of several plane walls intimately in thermal contact. These composite walls can be arranged in parallel or series, and the rate of heat transfer through the total structure is constant [2, p. 24] if no heat is wasted.

The primary objective of this paper is to design and build a composite wall composed of materials in parallel and in series to examine the assumption of 1D heat transfer is valid. The experimental temperature values will be compared with values obtained by applying the explicit finite difference method and developing a code in MATLAB (https://www.mathworks.com/products/matlab.html), as well as analytical values determined through a thermal resistance network method.

THEORY

Finite Difference Method

For a plane wall to be considered large, the length and height need to be much greater than the thickness. When this condition is satisfied, the heat conduction can be assumed to be 1D, as the heat transfer in the other directions may be ignored [1, p. 73]. To determine the heat transfer through the 1D plane wall, an energy balance can be performed across the thickness of the plane wall. Figure 1 shows a diagram of the 1D with no heat generation.

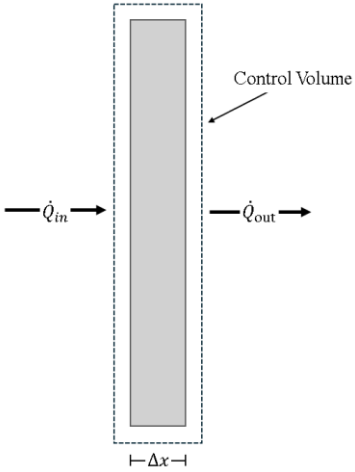

Figure 1. One-dimensional heat conduction through a plane wall.

Using the energy balance on the control volume depicted in Figure 1, the transient heat conduction can be written as [1, p. 11]

$$\dot{Q}_{in} - \dot{Q}_{out} = \dot{E}_{stored} \tag{1}$$

where $\dot{Q}_{in}$ is the heat transfer rate into the control volume (W), $\dot{Q}_{out}$ is the heat transfer rate out of the control volume (W), and $\dot{E}_{stored}$ is the energy stored in the solid (W).

When two or more plane walls of different materials are in intimate contact, it is called a composite wall configuration. To model a composite wall using a numerical method, the wall can be divided into equally spaced nodes and the energy balance method can be applied to each node to analyze the transient heat conduction. This technique is

referred to as the finite difference method [1, pp. 336-338]. Figure 2 shows a diagram of the 1D transient heat conduction through a composite wall made of materials A and B with five nodes. Nodes 1 and 5 are boundary nodes, node 3 is at the interface, and nodes 2-4 are internal nodes.

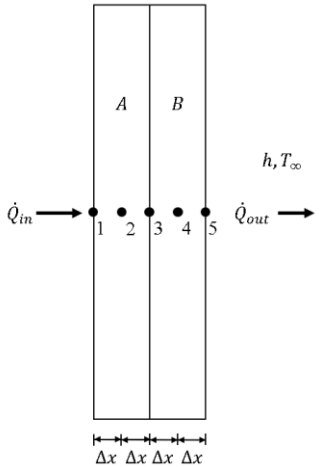

Figure 2. Heat transfer through a composite wall.

Assuming a constant heat flux at the left boundary and applying the energy balance, the transient heat transfer through node 1 may be expressed as [1, pp. 334-339]

$$-\dot{q}_{in}A - \left(-k_A A \frac{T_2^i - T_1^i}{\Delta x}\right) = \rho_A c_{p_A} A \frac{\Delta x}{2} \frac{T_1^{i+1} - T_1^i}{\Delta t} \tag{2}$$

where $\dot{q}_{in}$ is the constant heat flux (W/m^2), A is the area perpendicular to the heat transfer direction (m^2), k_A is the thermal conductivity of material A (W/m·K), T_2 is the temperature of node 2 (°C), T_1 is the temperature of node 1 (°C), Δx is the distance between nodes (m), ρ_A is the density of material A (kg/m^3), $c_{p\text{-}A}$ is the specific heat of material A (J/kg·K), Δt is the time interval (s), and i is the time step. Note that node 1 has only $\Delta x/2$ in the solid material. This equation can be rearranged and simplified to solve for the temperature of node 1 at the next time step as

$$T_1^{i+1} = 2\tau \dot{q}_{in} \frac{\Delta x}{k_A} + (1 - 2\tau) T_1^i + 2\tau T_2^i \tag{3}$$

where τ is the Fourier number or time constant defined as [1, p. 336]

$$\tau = \frac{k\Delta t}{\rho c_p \Delta x^2} = \frac{\alpha \Delta t}{\Delta x^2} \tag{4}$$

where α is the thermal diffusivity of the material (m^2/s). Using this same process, the energy balance of any internal node *m*, in either material A or B, can be written as [1, p. 336]

$$-kA\frac{T_m^i - T_{m-1}^i}{\Delta x} - \left(-kA\frac{T_{m+1}^i - T_m^i}{\Delta x}\right) = \rho c_p A \Delta x \frac{T_m^{i+1} - T_m^i}{\Delta t} \tag{5}$$

which can then be simplified to solve for T_m^{i+1} as

$$T_m^{i+1} = \tau T_{m-1}^i + (1 - 2\tau)T_m^i + \tau T_{m+1}^i \tag{6}$$

At the interface, the node between materials A and B, the energy balance can be presented to determine T_m^{i+1} as

$$T_m^{i+1} = \frac{k_A}{C_1}T_{m-1}^i + \left(1 - \frac{k_A}{C_1} - \frac{k_B}{C_1}\right)T_m^i + \frac{k_B}{C_1}T_{m+1}^i \tag{7}$$

where C_1 is defined as

$$C_1 = \left(\rho_A c_{p_A} + \rho_B c_{p_B}\right)\frac{\Delta x^2}{2\Delta t} \tag{8}$$

For the final node, exposed to convection, the energy balance can be written as [1, p. 337]

$$-k_B A\frac{T_{M-1}^i - T_M^i}{\Delta x} - h\left(T_M^i - T_\infty\right) = \rho_B c_{p_B} A\frac{\Delta x}{2}\frac{T_M^{i+1} - T_M^i}{\Delta t} \tag{9}$$

where *M* represents the final node, *h* is the convection heat transfer coefficient ($W/m^2 \cdot K$), and T_∞ is the ambient temperature (°C). Note that node five also has $\Delta x/2$ in the solid material. This equation can then be rearranged to solve for T_M^{i+1} as

$$T_M^{i+1} = \tau 2T_{M-1}^i + \left(1 - 2\tau - 2\tau h\frac{\Delta x}{k_B}\right)T_M^i + 2\tau h\frac{\Delta x}{k_B}T_\infty \tag{10}$$

For the explicit finite difference method, a time step (Δt) stability criterion must be applied [1, p. 338]. This criterion is determined by setting the coefficients of the node of interest in Eqs. (3), (6), (8), and (10) greater than or equal to zero. Then, Eq. (4) can be used to determine Δt. The stability criterion will be different for each node, and it is important to use the smallest Δt to make sure the stability criterion is satisfied for all nodes. Table 1 shows the necessary equations to calculate the Δt for each node.

Table 1. The minimum time equations for each node	
Node	**Time constraint equation**
1	$\Delta t \leq \frac{\Delta x^2}{2\alpha_A}$
Material A internal	$\Delta t \leq \frac{\Delta x^2}{2\alpha_A}$
Interface	$\Delta t \leq \left(\rho_A c_{p_A} + \rho_B c_{p_B}\right)\frac{\Delta x^2}{2(k_A + k_B)}$
Material B internal	$\Delta t \leq \frac{\Delta x^2}{2\alpha_B}$
5	$\Delta t \leq \frac{\Delta x^2}{2\alpha_B\left(1 + \frac{h\Delta x}{k_B}\right)}$

Thermal Resistance Concept

For any solid material, considering the steady state and 1D conduction heat transfer in a plane wall, the conduction resistance (K/W) can be represented as [1, p. 144]

$$R_{cond} = \frac{L}{kA} \tag{11}$$

where L is the thickness of the material (m). When a material at its boundary experiences a convective fluid, the convection resistance (K/W) can be represented as [1, p. 145]

$$R_{conv} = \frac{1}{hA} \tag{12}$$

Using the thermal resistance concept, thermal networks can be drawn for complex problems, such as composite wall structures. Figure 3 shows a composite wall with materials both in parallel and series and the corresponding thermal network.

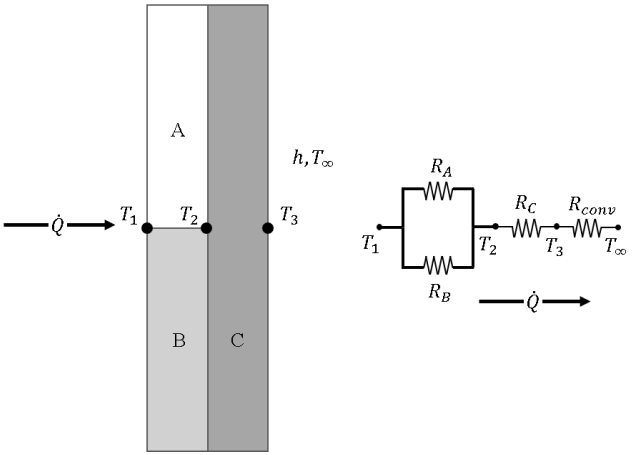

Figure 3. Composite wall with thermal resistance network.

Using the thermal network shown in Figure 3, and assuming no wasted heat loss, the steady-state heat transfer can be written as [1, p. 148]

$$\dot{Q} = \frac{T_1 - T_\infty}{R_{tot}} = \frac{T_2 - T_\infty}{R_C + R_{conv}} = \frac{T_3 - T_\infty}{R_{conv}} \tag{13}$$

where R_{tot} is the total resistance (K/W) of the composite wall and R_C is the conduction resistance (K/W) of material C. For multiple layers in contact with each other in series, the total resistance can be calculated by summing the resistances. However, for layers in parallel, as shown in Figure 3, the conduction resistance is evaluated as

$$R_{parallel} = \left[\frac{1}{R_A} + \frac{1}{R_B}\right]^{-1} \tag{14}$$

where R_A and R_B are the conductive resistances (K/W) of materials A and B, respectively. Thus, the total resistance can then be presented as

$$R_{total} = R_{parallel} + R_C + R_{conv} \tag{15}$$

Equation (13) can then be used to solve for T_1, T_2, and T_3 if $\dot{Q}$ and the resistances are known.

MATERIALS

The following materials were used in the experiment:

- Two 4-in × 8-in × 0.25-in sheets of polylactic acid (PLA)
- Two 4-in × 8-in × 0.25-in sheets of oak wood
- Two 8-in × 8-in × 0.25-in sheets of acrylic
- Thermocouples
- 8-in × 8-in heat pad
- HUATO S220-T8 data logger
- Two-inch Styrofoam insulation
- DC power supply

See Appendix A for details about where to purchase the materials.

To perform the experiment, the following procedure was followed:

1. Using thermal or electrical tape, attach thermocouples (TCs) as shown in Figure 4 to the experiment.

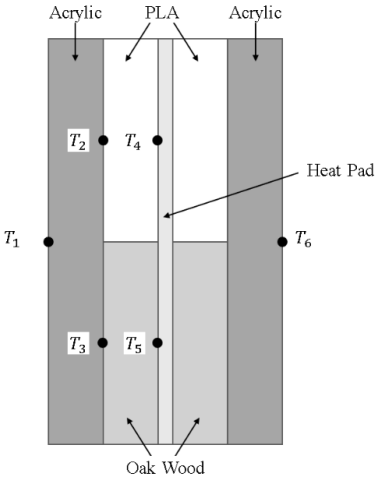

Figure 4. The composite wall setup and the thermocouple placements.

2. Place the oak wood and PLA sheets on top of the acrylic sheets.
3. Attach the heating pad to the PLA and oak wood.
4. Place the insulation to the top, bottom, and sides of the experiment with insulation, using rubber bands.
5. Attach two more TCs to the outside of the insulation.
6. Connect the DC power supply. Set the voltage to 2 V and record the current (2.43 A).
7. Turn on the data logger and record data until the temperatures reach steady state.

Identical setups were placed on both sides of the heating pad to minimize heat loss. Figure 5 shows the completed experimental setup.

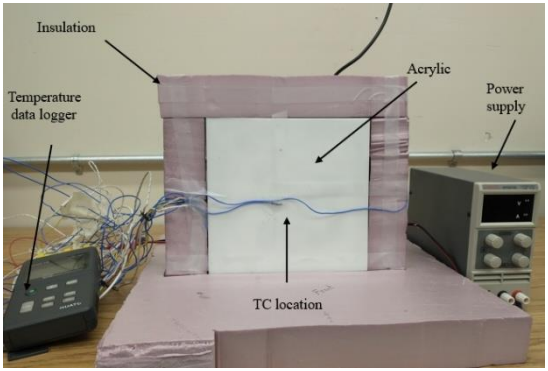

Figure 5. The completed experimental setup.

RESULTS AND DISCUSSION

Throughout the experiment, the temperatures of the TCs were recorded using the data logger until the system reached steady state. Seven TCs were placed throughout the system. Four TCs were located in between each material of the composite; one TC was placed on the acrylic of the second identical side to verify whether the heat transfer was consistent through both sides of the wall; and two TCs were placed on the sides of the insulation to verify there was minimal heat loss (see Fig. 4). Table 1 shows the final temperatures for each TC location. The initial temperature for each TC was 21.5°C.

Table 1. The experimental final temperatures of each TC

Materials	TC	Final temperature (°C)
A to C	T_1	25.3
	T_2	27.2
	T_4	29.8
B to C	T_1	25.3
	T_3	27.0
	T_5	29.6
	T_6	26.8

Because of the symmetry, it was expected that T_1 and T_6 would be the same once the state temperature was reached. However, T_1 had a final temperature of 25.3°C and T_6 had a final temperature of 26.8°C. This

shows that one side of the experiment may have been subjected to convection heat loss or that more heat was transferred to one side than the other.

Once the temperatures reached steady state, T_2 and T_3 were also expected to have similar final temperatures, which was the case as the temperatures were 27.2°C and 27.0°C, with an average of 27.1°C. The same was expected for T_4 and T_5, where the final temperatures were 29.8°C and 29.6°C, with an average of 29.7°C. The two TCs placed on the outside of the insulation had initial and final temperatures of 22.0°C and 21.8°C, respectively, showing there was insignificant heat loss through the insulation and verifying the assumption of 1D heat conduction.

The experimental data were then compared with the analytical transient data from the MATLAB code and the analytical steady-state data from the thermal network. In the MATLAB code, the transient analysis was performed between materials A and C and then B and C. The minimum time constraint was determined to be at the interface, for a value of 34 s. The final temperature values were then averaged, because when reaching steady state, the temperature values should be the same. To determine the $\dot{Q}$, the voltage and current recorded from the voltage supply were multiplied to get a total power of 4.86 W. This value was then divided by two, assuming the same amount of heat was transferred through each side, to get a heat of 2.43 W. The other values necessary for the calculations are given in Appendix B.

Equations (11-12) and (14-15) were used to calculate the thermal resistances (Table 2).

Table 2. The thermal resistances

Resistance	Value (K/W)
R_A	1.684
R_B	1.939
R_C	0.769
$R_{parallel}$	0.901
R_{conv}	1.614
R_{total}	3.284

Using the calculated resistance values, a $\dot{Q}$ value of 2.43 W, and T_∞ of 21.4°C, Eq. (13) was used to calculate T_1, T_2, and T_3 as 29.38°C, 27.24°C, and 25.32°C, respectively. Table 3 shows a summary of the experimental and analytical results. The average of the experimental temperatures given in Table 1 were used.

Table 3. Experimental and analytical steady state results			
TC	**Experimental temp. (°C)**	**MATLAB temp. (°C)**	**Thermal network temp. (°C)**
T_1	29.7	29.38	29.40
T_2	27.1	27.24	27.21
T_3	25.3	25.32	25.37

As shown in Table 3, the results for both analytical and experimental values were similar. For T_1, the temperature values were between 29.38 and 29.7°C. For T_2, the temperature values ranged between 27.1 and 27.24°C. For T_3, the temperature values ranged between 25.3 and 25.37°C. This further verifies the assumption of 1D heat transfer and shows both steady-state and transient analysis yield similar results with this assumption.

SOURCES OF ERROR

Possible sources of error in this experiment include the accuracy of the TCs, data logger, and DC power supply. The k-type TCs used in this experiment have an accuracy of ±0.75%, and the temperatures may have been off by ±2.5°C [3]. The data logger has an accuracy of 0.8 ± 2% [4]. Along with this, the data logger only has a resolution of 0.1°C, limiting the precision of the measurements [4]. The DC power supply has an accuracy of ±10% and a resolution of 0.01 V and 0.01 A, both of which may have affected the precision and accuracy of the measurements [5]. However, because the experimental data closely matched both analytical values, any error from instrumentation can be deemed negligible.

Another possible source of error is that the experiment was not placed in an isolated area. One side of the experiment was facing a wall exposed to thermal radiation heat transfer, while the other side may have been subjected to convection heat transfer. This may explain why the temperature values for T_1 and T_6 were not the same. However, T_1 was very similar to the analytical values, so this error could be deemed a random, negligible error.

CONCLUSION AND RECOMMENDATIONS

The purpose of this experiment was to design and build a simple composite wall composed of materials in parallel and series to verify the assumption of 1D heat transfer using both steady-state and transient analysis methods. The temperatures at various points on the composite wall were measured and compared with analytical values obtained by using the concept of thermal resistance as well as the explicit finite

difference method in MATLAB. The height and length of the wall were significantly greater than the thickness and the experimental values were very similar to both analytical values, verifying the assumption that 1D heat transfer is valid for a composite wall.

To reduce any possible error in the experiment, it is recommended to conduct the experiment in an isolated location where any heat loss due to convection can be minimized. Future modifications for this experiment include experimenting with different thicknesses of material with the same height and length to further examine the validity of 1D heat transfer and implementing the experiment in a heat transfer laboratory to demonstrate the concept of 1D heat transfer.

REFERENCES

[1] Cengel, Y.A., and Ghajar, A.J. (2015). *Heat and Mass Transfer: Fundamentals & Applications*, Fifth Edition, McGraw-Hill.

[2] Kreith, F. (2011). *Principles of Heat Transfer*. Wadsworth Cengage Learning.

[3] Spinelli, G., Kotsilkova, R., Ivanov, E., Georgieve, V., Naddeo, C., Romano, V. (2022). Thermal and dielectric properties of 3D printed parts based on polylactic acid filled with carbon nanostructures. Macromolecular Symposia, vol. 405, no. 1, pp. 202100244. https://doi.org/10.1002/masy.202100244.

[4] Orellana Barrasa, J., Ferrández-Montero, A., Ferrari, B., and Pastor, J.Y. (2021). Characterisation and modelling of PLA filaments and evolution with time. Polymers, vol. 13, no. 17, p. 2899. https://doi.org/10.3390/polym13172899.

[5] Zmeskal, O., Marackova, L., Lapcikova, T., Mencik, P., and Prikryl, R. (2020). Thermal properties of samples prepared from polylactic acid by 3D printing," AIP Conference Proceedings, vol. 2305, no. 1, pp. 020022. https://doi.org/10.1063/5.0033857.

[6] The Engineering Toolbox. (2004). Wood species - densities. Retrieved March 18, 2024, from https://www.engineeringtoolbox.com/wood-density-d_40.html.

[7] Evans, P. (2016). Specific heat capacity of materials. Retrieved March 18, 2024 from https://theengineeringmindset.com/specific-heat-

capacity-of-materials.

[8] Material Property Database. PMMA. Retrieved March 18, 2024, from https://www.mit.edu/~6.777/matprops/pmma.htm.

[9] Omnexus, SpecialChem. Density of plastics: Technical properties table. Retrieved March 18, 2024, from https://omnexus.specialchem.com/polymer-property/density.

APPENDIX A

Item	Website for purchase	Date of purchase
K-type thermocouple–ATB1 bead type thermocouple	https://www.trutechtools.com/ATB1	Feb. 5, 2024
USA import material 200×200-mm 200W 12V cube flexible silicone heater compatible with Voron 2.4 Prusa i3 RepRap 3D printer heated bed (12V)	https://www.amazon.com/Material-200X200mm-Flexible-Silicone-Printer/dp/B08SGW6MQ2	Mar. 30, 2024
Huato S220-T8 eight-channel thermocouple data logger with external power supply and 3 points NIST traceable certificate, measuring range -200 to 1800°C	https://www.amazon.com/HUATO-S220-T8-Thermocouple-Traceable-Certificate/dp/B07SJRG6Y8	Feb. 6, 2024
DC power supply adjustable (30V 10A), Eventek variable switching regulated digital power supply with alligator leads US power cord	https://www.amazon.com/Eventek-KPS3010D-Adjustable-Switching-Regulated/dp/B073TW8H2S	Feb. 6, 2024

APPENDIX B

This appendix presents the values used for the analytical calculations.

Table A1. The values for the analytical calculations			
	Property	**Units**	**Value**
Material A (PLA)	k_A	W/m·K	0.183 [3]
	ρ_A	kg/m^3	1240 [4]
	$c_{p\text{-}A}$	J/kg·K	1200 [5]
Material B (oak wood)	k_B	W/m·K	0.159 [1]
	ρ_B	kg/m^3	750 [6]
	$c_{p\text{-}B}$	J/kg·K	2380 [7]
Material C (acrylic)	k_C	W/m·K	0.2 [8]
	ρ_C	kg/m^3	1170 [9]
	$c_{p\text{-}C}$	J/kg·K	1466 [8]

Reframing Empathy

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Abstract

There are reasons to be skeptical that empathy understood as perspective taking can afford us knowledge about the mental states of others or generate care and motivate moral action. This paper will outline how self-oriented perspective taking and other-oriented perspective taking fall short of providing us with knowledge of others' mental states. In self-oriented perspective taking, the simulation ends up excluding crucial differences between the mental constitution of the empathizer and the target. Other-oriented perspective taking attempts to account for these differences but ultimately fails because the unconscious dispositions of a target are impossible to simulate. I will then address simulation's moral limitations by arguing that neither form of perspective taking is morally motivational. Self-oriented simulation leads to personal distress, which causes us to care about ourselves rather than the target and other-oriented simulation leads to misdirected care. Finally, I suggest that we should move towards a new picture of empathy informed by Kate Abramson and Adam Leite's idea of empathic responsiveness. This new picture will recast empathy as a mode of interaction that requires epistemic humility.

It seems intuitive that the better we understand someone, the better equipped we are to help them. We think that understanding fosters care and motivates moral action, hence the conventional belief that putting yourself in someone else's shoes will elicit compassion. Empathy, then, is often framed as an epistemic pursuit. It is the mechanism whereby we attain knowledge about other people's mental states. As such, it is taken by many to provide the understanding that motivates moral action. However, the privacy of mental experience challenges the extent to which we can know the content of another's mind. Is it possible to epistemically access other minds via an empathetic process? I will argue that no, empathy falls short of providing us with knowledge of others' minds. Moreover, empathy as an epistemic process does not generate care. Contrary to our intuition, seeking to understand someone's mental state does not dispose us to moral action. In light of these issues, we should reframe empathy as essentially non-epistemic. In fact, I will argue that it is morally superior to adopt a position of epistemic humility about empathetic states. Rather than characterizing empathy as an epistemic process, we should characterize it as a mode of interaction—specifically, an interaction that involves acknowledging the inaccessibility of other minds.

Although there are different ways to approach empathy as an epistemic pursuit, this paper focuses on simulation theory, which takes empathy to be an activity of imagination whereby we can come to know what it is like to be someone else.[1] Also known as perspective taking, this process generally involves imagining a situation from another person's point of view in order to replicate their mental state.[2] We attribute the resulting mental state that arises from our simulation to the subject and assume that it is representative of their internal experience. The goal of perspective-taking is epistemic access; if we can accurately simulate someone else's perspective, we will have knowledge about their mental state. The draw of simulation is clear; if it is possible, it would be a victory over the privacy of mental experience. For at least a moment, we could know what it is like to be someone else.

To break down the process of perspective-taking, empathy theorists often draw a distinction between two subcategories: self-oriented

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[1] Alternative theories include theory theory and narrative theory.

[2] Karen Shanton and Alvin Goldman et al. "Simulation theory." *WIREs Cognitive Science* 1, no. 4 (2010): 527–538, doi: 10.1002/wcs.33; Alvin Goldman, "Two routes to empathy: insights from cognitive neuroscience," in *Empathy: Philosophical and Psychological Perspectives*, ed. Amy Coplan and Peter Goldie (New York: Oxford University Press, 2011), 31–44; Derek Matravers, "Empathy as a route to knowledge" in *Empathy: Philosophical and Psychological Perspectives*, ed. Amy Coplan and Peter Goldie (New York: Oxford University Press, 2011), 19–30.

perspective-taking and other-oriented perspective-taking.[3] Self-oriented perspective-taking involves an empathizer imaginatively replacing the other person (hereafter called the "target") with themselves. In colloquial terms, the empathizer places themselves in the other person's shoes. The self-oriented empathizer explores the impact of a target's situation on their own mental state. Consider a relatively simple example: if I were attempting to empathize with an actor who forgot their line on stage, I would imaginatively replace the actor with myself and note the mental state that the situation prompts for me. I would imagine *myself* forgetting a line on stage—an incident that would likely cause me feelings of anxiety and embarrassment. Then, I assume that my own thoughts and feelings represent the actor's internal experience.

In contrast, as an other-oriented perspective taker, I would seek to bracket my own perspective and imagine the situation from the actor's point of view. I imagine how the target is experiencing the situation rather than how I would experience it in their place. Using the same actor example, perhaps the actor is a skilled improviser and feels comfortable speaking off the cuff. Because I imagine how the actor would respond rather than how I would respond, my simulation needs to exclude my own embarrassment and accommodate their level of confidence. I have to mentally become the actor, not just imagine myself in the actor's place.

Put simply, self-oriented perspective-taking captures how *I* would feel on stage, whereas other-oriented perspective-taking strives to capture how *the actor* would feel on the stage. However, there are reasons to be skeptical that either process can afford us knowledge about the target's mental state. I am also skeptical about their ability to generate care and motivate moral action. My argument will proceed as follows: in section 1, I will outline how self-oriented perspective-taking falls short of knowledge because the simulation ends up excluding crucial differences between the mental constitution of the empathizer and the target. Section 2 will cover how other-oriented perspective-taking attempts to account for these differences but ultimately fails because the

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[3] Amy Coplan "Understanding empathy: its features and effects," in *Empathy: Philosophical and Psychological Perspectives*, ed. Amy Coplan and Peter Goldie (New York: Oxford University Press, 2011), 3–18; Elisa Galgut, "Empathy, mentalization and meta-reflective capacities," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, ed. Derek Matravers and Anika Waldow (New York: Routledge, 2019), 45–59; Heidi Maibom, "What can we learn from taking another's perspective?" in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, ed. Derek Matravers and Anika Waldow (New York: Routledge, 2019), 74–90.

unconscious dispositions of a target are impossible to simulate.[4] I will then address simulation's moral limitations in sections 3 and 4 by arguing that neither form of perspective-taking is morally motivational. Self-oriented simulation leads to personal distress, which causes us to care about ourselves rather than the target, and other-oriented simulation leads to misdirected care. Finally, in section 5, I suggest that we should move towards a new picture of empathy informed by Kate Abramson and Adam Leite's idea of empathic responsiveness. This new picture will recast empathy as a mode of interaction that requires epistemic humility.

Limitations of Self-Oriented Perspective-Taking

First, I will demonstrate how self-oriented perspective-taking fails to provide us with knowledge about a target's mental state. To restate, self-oriented perspective-taking entails imaginatively replacing the target with oneself and exploring how the target's situation would impact one's own mental state. My objection to this form of perspective-taking is rather straightforward: When we replace the target with ourselves, we are no longer empathizing with the target at all. We are merely empathizing with ourselves in the target's situation.[5] Earlier, when I imagined how I would respond if I forgot a line on stage, the actor played no role in my simulation. Because I was imagining myself in their place, nothing about the actor was incorporated into my simulation besides their situation. When I imagined how I would respond in their situation, I learned nothing about how *they* would respond in their situation. Self-oriented perspective-taking fails as a route to knowledge because a given circumstance will not elicit the same mental state for everyone (e.g., forgetting a line on stage does not always lead to embarrassment).[6] How I mentally respond to forgetting a line on stage is not necessarily indicative of what the confident actor is experiencing. Therefore, it would be wrong for me to claim that, based on my self-oriented simulation, I know what it is like to be the actor in that moment.

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[4] I owe this idea to Peter Goldie ("Anti-empathy," in *Empathy: Philosophical and Psychological Perspectives*, 2011:309).

[5] We might reasonably wonder if this is empathizing at all. Amy Coplan, for example, characterizes self-oriented perspective-taking as "quasi-empathetic" because it collapses the other into the self ("Understanding empathy: its features and effects," in *Empathy: Philosophical and Psychological Perspective*, 2011:9).

[6] Talia Morag holds a similar position on the basis of emotional patterns being unreliable. That is, an individual can respond to the same situation in a different way ("An imaginative-associative account of affective empathy," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, 2019:169).

Take another example demonstrating how two people might have a drastically different mental response to the same situation. Say that my husband is trying to understand what it is like for me, a woman, to walk down the riverside path behind our apartment complex at night. My husband loves night walks, so if he were to imagine himself going on the stroll alone, he would likely report feeling relaxed and rejuvenated after the simulation. This, however, is far from what I would experience alone on the same night walk. My primary experience would be anxiety at the prospect of being uncomfortably approached or catcalled—the exact opposite of what my husband reported feeling. If my husband were to project his simulated mental state onto me, it would be a gross misrepresentation of my experience. The exercise fails to grant him knowledge about my mental state because our minds respond differently to the same night walk. Self-oriented simulation leaves him with knowledge about himself in my situation—he now knows that he would enjoy the riverside trail at night—but it does not get him any closer to understanding my internal experience.

Limitations of Other-Oriented Perspective-Taking

Self-oriented perspective-taking fails conceptually because it rests on the assumption that a target will respond to a situation in the same way that the empathizing agent would. Other-oriented perspective-taking appears to avoid the pitfalls of self-oriented simulation by accounting for differences in mental constitution between persons. Indeed, part and parcel of other-oriented perspective-taking is laying aside assumed similarities to fully inhabit the mind of the other. We imagine ourselves *as* the target rather than *in place of* the target, requiring us to suspend our own perspective, dispositions, judgments, values, beliefs, memories, desires—all of our personalized ways of perceiving—to fully attend to the differences of the other. This mode of simulation requires more creativity than its self-oriented counterpart because it challenges an empathizer to reach beyond the materials of their own mental content. In turn, it increases our chances of attaining actual, unbiased knowledge about a target's experience.

But the process is rather complex. Returning to the trail example, my husband would have to intentionally suppress his own favorable perspective towards night walks to simulate how the experience is different for me—a difficult task for him in at least a few respects. First, he would have to simulate my memories of being catcalled that color my perception. When I remember being catcalled on the night walk, I imaginatively reconstruct the experience, laced with all its accompanying sensations, thoughts, and feelings. In a sense, my memory

is a simulation. It is an imaginative reconstruction of what it was like to be catcalled. For my husband to reproduce my memory, he must simulate my memory of being catcalled within his simulation of my night walk. His simulation is two layers deep: He must imagine what it is like to be me on the night walk as I am imagining being catcalled.

Along with the complications of memory, another challenge for my husband would be simulating my thoughts during the night walk. Say that as I'm on the riverside trail, I'm thinking about a story I once heard from a former resident of our apartment complex. She claimed that the complex started offering free salon services after a sexual assault on the nearby trail scared off potential renters. The landlords hoped that the salon would draw renters back to the complex. Of course, it would not be too difficult for my husband to simulate my thoughts about the salon rumor so long as he was informed of them. What he cannot so easily grasp is the risk the story poses for me. My husband thinks of the story and finds it tragic, but I think of the story and find it personally relevant. The risk of sexual assault is much higher for me than for my husband. As I'm thinking about the salon rumor, it presents a real threat to my safety on the night walk. In other words, my husband correctly simulating my thoughts would not necessarily capture what those thoughts *mean* for me. The import of my thoughts is determined by factors outside of the propositional content, adding another layer of complexity to the simulation.

I have illuminated a few ways in which other-oriented perspective-taking is challenging but not necessarily impossible. Simulation optimists might still want to say that given enough information about the target, it is possible to adopt their perspective and produce an accurate representation of their mental content.[7] Theoretically, it is not impossible for my husband to simulate my memories and the import of a proposition for me. However, Peter Goldie argues that other-oriented perspective-taking will always fall short of epistemic access in a fundamental way: We can never know what it is like to be someone else because our imagination cannot accurately simulate the unconscious dispositions of a target.[8] For example, say that I was trying to understand someone who was rude to a customer-service employee. I don't consider myself to be a rude person, so if I were trying to simulate my target's experience, I would have to remain very conscious of the fact that my target is

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[7] Amy Coplan alludes to this. She claims that "empathy is subject to biases based on one's familiarity and identification with a target" ("Understanding empathy: its features and effects," in *Empathy: Philosophical and Psychological Perspectives,* 2011:13).

[8] See Goldie's "Anti-empathy" (in *Empathy: Philosophical and Psychological Perspectives,* 2011) for more objections.

someone who behaves rudely. A disposition towards rudeness would operate in the background of my target's mental state, but it would have to operate in the foreground of my simulation. Because rudeness is an unconscious influence on the target's mental state, it would be a misrepresentation of their experience for me to be consciously thinking about behaving rudely. I cannot say that I know what it is like to be the target if at every point in the simulation I am consciously suppressing my natural politeness and forcing myself to be rude. The rude customer behaves rudely without thinking about how their disposition should affect their actions. Therefore, other-oriented perspective-taking as a route to knowledge is a conceptual impossibility.

Moral Limitations of Self-Oriented Perspective-Taking

So simulation does not produce knowledge, but is it at least morally motivating in that striving for epistemic access leads us to care about the target? Again, both forms of perspective-taking fall short. Daniel Baton's work in social psychology demonstrates how self-oriented perspective-taking leads to personal distress and, in turn, care for oneself rather than the target. His study at the University of Kansas involved 60 participants listening to a recorded interview with a university student, Katie, whose parents had recently died in a car accident. Katie was managing her grief, supporting her two younger siblings, and trying to make it through her final year of college. Participants were divided into three groups and asked to listen to the interview with one of three perspectives: objective, imagine-self, and imagine-other.

The objective group was asked to be "as objective as possible about what happened to the person interviewed and how it has affected his or her life." The imagine-self group was asked to "imagine how you yourself would feel if you were experiencing what has happened to the person being interviewed and how this experience would affect your life." Finally, the imagine-other group was asked to "imagine how the person being interviewed feels about what has happened and how it has affected his or her life." After listening to the interview, the subjects were presented with a questionnaire to assess both their levels of personal distress and their distress *for* Katie. Those in the imagine-self group reported higher levels of personal distress than the imagine-other and objective groups whereas those in the imagine-other and objective groups reported more distress for Katie than personal distress.[9] These

[9] Daniel Batson, Shannon Early and Giovanni Salvarani. "Perspective-taking: imagining how another feels versus imagining how you would feel," *Personality and Social Psychology Bulletin* 23, no. 7 (1997): 751–758, doi: 10.1177/014616729723700.

results are not surprising given the nature of self-oriented perspective-taking. If I were to imagine what it would be like for me in Katie's situation (i.e., losing my parents), it would be harder to remain emotionally distant from the simulation.[10]

The fact that self-oriented perspective-taking leads to personal distress calls into question its ability to foster care for the target. If I cared about the target, I would feel distress on their behalf rather than personal distress. Consider again the case of the actor forgetting their line on stage. As I imagined what it would be like for me to forget a line on stage, I felt embarrassed and anxious. Say that because of the embarrassment, my cheeks flush, I start to fidget in my seat, and I pull out my phone to distract myself. These bodily symptoms indicate that *I* feel distressed—not that I feel distressed *for* the actor. Similarly, they indicate that I care about my own discomfort in the situation rather than the actor's. I might start willing the actor to remember their line not because I care about what the actor is experiencing, but because I want my own embarrassment about the situation to dissipate. Self-oriented perspective-taking motivates me to care about alleviating my own discomfort instead of leading me to care about the actor. It fails to promote moral behavior because my actions are self-focused.

Moral Limitations of Other-Oriented Perspective-Taking

Other-oriented perspective-taking is equally incapable of leading us to care about a target. Derek Matravers's crucial observation about the "object of empathetic emotion" demonstrates how other-oriented perspective-taking will lead to care for the target's focus rather than the target. To explain, he describes the process of empathizing with a friend whose dog has recently died. Because I am engaging in an other-oriented simulation, I take on my friend's perspective. From my friend's perspective, the object of care is the dog. I adopted their focus by taking on their perspective and will therefore develop a sense of care for the dog.[11] However, caring about the dog does not guarantee that I will care

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[10] Coplan, Amy, "Understanding empathy: its features and effects," in *Empathy, Philosophical and Psychological Perspectives*, ed. Amy Coplan and Peter Goldie (New York: Oxford University Press, 2011), 3–18.

[11] Nancy Snow speaks to this difference as one of sympathy and empathy. Caring for the target would be sympathetic, whereas caring for the dog is empathetic. Although I do not speak to the difference between sympathy and empathy in this paper, if we accept her definition then sympathy is the moral aim (*American Philosophical Quarterly* 2000:6).

about the target. My simulation generates care for the target's focus, namely the dog, but it completely excludes the target.[12]

Matravers's distinction has important implications for moral action insofar as our actions are directed towards the object of care. Because I developed care for the dog, my moral actions will be directed towards the dog instead of my friend. This is especially problematic in instances of grief. When my friend is grieving the loss of their dog, the situation calls for me to care *that* my friend cares for the dog rather than only caring for the dog. However, without an intimate connection to the dog, matching my friend's grief would look, if not inappropriate, at least odd or misplaced. Although an appropriate response might include some grief for the dog, the main object of care should be my friend. Other-oriented perspective-taking cannot elicit this response because it results in misplaced care; in taking the target's perspective, the object that we develop care for will never be the target themselves.

Empathic Responsiveness and Epistemic Humility

Seeing that simulation fails in two respects, first to produce knowledge and second to generate care or moral action, we are in need of a different conception of empathy. Kate Abramson and Adam Leite suggest that we move away from models like simulation, which focus on the importance of sharing mental states, and move towards a picture that emphasizes empathetic interaction. Under their conception of empathy, care and moral action are not tied up in understanding the target. Instead of empathy being about replicating a target's mental state, it is about being "attuned to [a target's] emotional needs."[13] They argue that responding sensitively to a target's emotional needs has no necessary connection to sharing their mental state.[14] Empathy, as they say, is like ball and socket joints; we tailor our response to their specific needs. For example, they describe how a doctor would respond empathetically to an anxious patient. The doctor need not share in the patient's anxiety to address the situation sensitively, and it is in fact better for the doctor to

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[12] Derek Matravers, "The object of an empathetic emotion," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, ed. Derek Matravers and Anika Waldow (New York: Routledge, 2019), 60–73.

[13] Kate Abramson and Adam Leite, "Empathy without sharing empathetic responsiveness in psychoanalysis and politics," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, ed. Derek Matravers and Anika Waldow (New York: Routledge, 2019), 144–166.

[14] See Daniel D. Hutto and Alan Jurgens' paper "Exploring enactive empathy, actively responding to and understanding others" for a similar argument (in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges* 2019).

remain collected when they are speaking with the patient. Even though the doctor does not know what it is like to struggle with anxiety, we would characterize the experience as empathetic because the doctor provides what the situation calls for by calming the patient and offering them appropriate medical resources.

Because situations and needs vary, Abramson and Leite admit that there is no formula for empathetic interaction. An empathetic response will depend on context and the ability of an empathizer to judge a target's needs. However, I suggest that there is a feature of empathetic interaction that must remain consistent despite the fact that circumstances and people differ. Undergirding every truly empathetic interaction is an attitude of epistemic humility. In order to respond sensitively and appropriately to someone else's needs, we must understand that we do not fully understand each other. When we erroneously think that we know what it is like to be someone else, we close ourselves off from exploring the needs of a target.

Empirical data suggests that the need for epistemic humility is real and pressing. We think that we are very good at empathizing (i.e., in the epistemic sense of sharing mental states), when in reality we are not. We quite often wrongly assume that we have knowledge about what it is like to be someone else. Heidi Maibom summarizes a few empirical studies that demonstrate our propensity to jump to unwarranted epistemic conclusions:

> Averaging over the relatively small number of studies which have been carried out on so-called empathic accuracy, we are right about what people relatively unknown to us, but with whom we briefly interact, think or feel about 20% of the time or less, and right about people close to us around 33% of the time according to some or only 20% according to others. These numbers are not impressive unless, of course, you thought people were even worse at it to begin with. Do people generally think they are bad at understanding others (as bad as the data suggests they are)? I don't think so. Why? Because when I present the numbers, people in the audience are usually shocked and horrified, and many refuse to believe them.[15]

At least 66% of the time, we are wrong about what someone is thinking or feeling. But more significantly, Maibom finds that people are

[15] Heidi Maibom, "What can we learn from taking another's perspective?" in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, ed. Derek Matravers and Anika Waldow (New York: Routledge, 2019), 74–90.

shocked by the data. We think that the margin between what people experience and what we can know is much smaller. The shock of the audience further indicates that we are epistemically overconfident in our interactions with others. We behave as if we understand more about people than we actually do.

Epistemic overconfidence inhibits our ability to interact empathetically because it causes us to respond to a target with the assumption that we already understand their needs. For example, say that the anxious patient only reported one symptom to the doctor: frequent headaches. The doctor might hastily assume that he knows the cause of the headaches and prescribe a medication for migraines. However, if the doctor had asked more questions about the patient's life or other possible symptoms, he would have discovered the patient's real need. There is no empathetic interaction that cannot be improved by adopting a position of epistemic humility. Assuming that the experimental data is correct, about 66% of the time, there is more that we can learn about a target's situation before responding. Epistemic humility leads to curiosity about the target and a better understanding of how to address their needs.

Returning to the riverside trail example once again, the empathetic reaction I need from my husband would be something of this sort: "I don't understand your experience, but I want to hear more about it." My husband does not need to share my mental experience to respond empathetically. In fact, it is better that he admits to *not* understanding in this instance.[16] If he claimed to understand, I would feel as though he'd collapsed my painful experience into his inaccurate representation. His attempt to gain epistemic access trivializes my experience and does not get him any closer to real understanding. What I need is an acknowledgment of the uniqueness of my personal experience and a genuine desire on his behalf to learn more. This, rather than a false claim that he knows what I am going through, opens us up to each other. My needs are met because I feel that he cares about my experience, and he gains knowledge as he sincerely listens. When we set aside our epistemic assumptions and allow the target to speak to their own mental state, we are better equipped to engage with them empathetically.

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[16] Abramson and Leite briefly speak to the need for acknowledging difference in their discussion on racism and empathetic responsiveness. They quote Ashleigh Nicole Black saying, "Black and White people have very different experiences in this country. That is just true. If we pretend it isn't true, we can't fix it" ("Empathy without sharing empathetic responsiveness in psychoanalysis and politics," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges* 2019:156).

Conclusion

I have proposed that we reframe empathy as a mode of interaction that stems from a place of epistemic humility. In order to develop epistemic humility, we must confront the ways in which simulation fails to grant us knowledge. This makes arguments against simulation practical rather than solely theoretical. In arguing against self- and other-oriented perspective-taking, my purpose is not to sound like an insufferable skeptic about the inaccessibility of other minds. Rather, I am suggesting that acknowledging their limitations puts us in a position to develop epistemic humility. Maibom's findings suggest that we need a healthy dose of skepticism; we think that perspective-taking grants us knowledge when, in fact, it does not. When we shed the narrative that putting ourselves in other people's shoes leads to understanding, we can move towards a more productive model of empathy. Empathy is about responding to someone's needs, not understanding their perspective. And we will be more effective at addressing other people's needs if we assume that we do not know what they are experiencing. We ought to consider the fact that other people's shoes are not ours to wear.

Bibliography

Abramson, Kate, and Adam Leite. "Empathy without sharing empathetic responsiveness in psychoanalysis and politics," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges,* edited by Derek Matravers and Anika Waldow, 144–166. New York: Routledge, 2019.

Batson, Daniel, Shannon Early, and Giovanni Salvarani. "Perspective taking: Imagining how another feels versus imagining how you would feel." *Personality and Social Psychology Bulletin* 23, no. 7 (1997): 751–758, doi: 10.1177/014616729723700.

Coplan, Amy. "Understanding empathy: its features and effects," in *Empathy: Philosophical and Psychological Perspectives,* edited by Amy Coplan and Peter Goldie, 3–18. New York: Oxford University Press, 2011.

Galgut, Elisa. "Empathy, mentalization and meta-reflective capacities," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges,* edited by Derek Matravers and Anika Waldow, 45–59. New York: Routledge, 2019.

Goldie, Peter. "Anti-empathy," in *Empathy: Philosophical and Psychological Perspectives*, edited by Amy Coplan and Peter Goldie, 302–317. New York: Oxford University Press, 2011.

Goldman, Alvin. "Two routes to empathy: insights from cognitive neuroscience," in *Empathy: Philosophical and Psychological Perspectives*, edited by Amy Coplan and Peter Goldie, 302–317. New York: Oxford University Press, 2011.

Hutto, Daniel, and Alan Jurgens. "Exploring enactive empathy," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, edited by Derek Matravers and Anika Waldow, 144–166. New York: Routledge, 2019.

Maibom, Heidi. "What can we learn from taking another's perspective?" in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, edited by Derek Matravers and Anika Waldow, 70–90. New York: Routledge, 2019.

Matravers, Derek. "Empathy as a route to knowledge," in *Empathy: Philosophical and Psychological Perspectives*, edited by Amy Coplan and Peter Goldie, 19–30. New York: Oxford University Press, 2011.

Matravers, Derek. "The object of an empathetic emotion," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, edited by Derek Matravers and Anika Waldow, 60–73. New York: Routledge, 2019.

Morag, Talia. "An imaginative-associative account of affective empathy," in *Philosophical Perspectives on Empathy, Theoretical Approaches and Emerging Challenges*, edited by Derek Matravers and Anika Waldow, 167–184. New York: Routledge, 2019.

Shanton, Karen, and Alvin Goldman. "Simulation theory." *WIREs Cognitive Science* 1, no. 4 (2010): 527-538, doi: 10.1002/wcs.33.

Snow, Nancy E. "Empathy." *American Philosophical Quarterly* 37, no. 1 (2000): 65–78. http://www.jstor.org/stable/20009985.

Synthesis of (*E*)-Phenylocten-3-ol from 1-Octyn-3-ol: Use of a TBS Protecting Group in the 9-BBN-Catalyzed Hydroboration of a Terminal, Alkyl Alkyne with Pinacolborane

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Abstract

The 9-borobicyclo[3.3.1]nonane (9-BBN) catalyzed hydroboration reaction of terminal alkynes with pinacolborane enables the synthesis of aryl- and alkyl-substituted vinylboronic acid pinacol esters. The tolerance of the 9-BBN-catalyzed hydroboration reaction of pinacolborane with 1-octyn-3-ol, a terminal, alkyl alkyne bearing an alcohol functional group, was studied. The free alcohol was not an effective substrate in the reaction. However, the TBS ether of 1-octyne-3-ol was easily synthesized in 98% yield and effectively underwent the 9-BBN-catalyzed hydroboration reaction with pinacolborane in 61% yield. The synthetic utility of the vinylboronic acid pinacol ester product was then demonstrated in a palladium-catalyzed Suzuki-Miyaura cross-

coupling reaction with bromobenzene in 66% yield. The silicon-protecting group could then be readily removed by treatment with tetra-N-butylammonium fluoride to provide the final product (E)-phenyloctен-3-ol in 95% yield.

Introduction

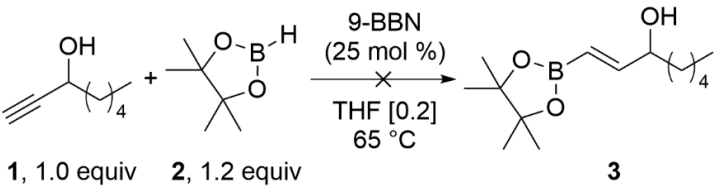
Organic synthesis requires the discovery, development, and application of chemical reactions. Reactions must be found to prepare the compounds needed in the future. The synthesis of challenging molecular targets identifies the limits of state-of-the-art organic chemistry. New reactions that break and form bonds between elements in unknown ways may need to be discovered. Indeed, the methodical study of known reactions allows practitioners to determine whether a transformation can be used on a substrate of interest. Therefore, the thorough exploration of the scope of a reaction's utility is important to the technology of chemical synthesis.

The 9-borobicyclo[3.3.1]nonane (9-BBN) catalyzed hydroboration reaction of terminal alkynes with pinacolborane enables the synthesis of aryl- and alkyl-substituted vinylboronic acid pinacol esters.[1-3] The vinylboronic acid pinacol ester products are useful reagents in palladium-catalyzed Suzuki-Miyaura cross-coupling reactions.[4,5] Moreover, cross-coupling reactions are commonly used in the synthesis of pharmaceuticals and fine chemicals.[6,7] Previously, we reported the effects of different *para*-substituents of terminal, aromatic alkynes on the 9-BBN-catalyzed hydroboration reaction with pinacolborane.[2] Herein, we report the tolerance of the 9-BBN-catalyzed hydroboration reaction of pinacolborane with a terminal, alkyl alkyne bearing an alcohol or silyl ether functional group.

Results and Methods

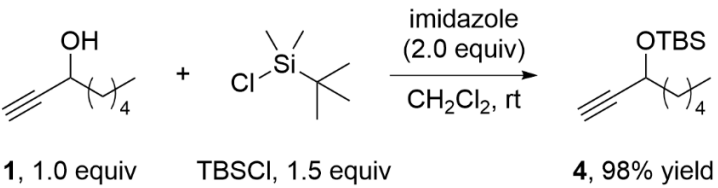
Our study of the functional group tolerance of the 9-BBN-catalyzed hydroboration reaction began with evaluation of the commercially available 1-octyne-3-ol **1** (Scheme 1). This substrate features a terminal alkyne, secondary alcohol and hydrophobic alkyl chain. The substrate **1** (0.146 mL, 1.0 mmol, 1.0 equiv) was subjected to the reaction conditions of **2** (0.174 mL, 1.2 mmol, 1.2 equiv) and 9-BBN (0.500 mL, [0.5] in THF, 0.25 mmol, 25 mol%) in refluxing THF (5 mL). The reaction was monitored by removal of a reaction aliquot that was washed with water, extracted with ethyl acetate, and analyzed by TLC and GC-MS. The GC method (GC Method 1) involved injections onto a Hewlett-Packard HP1 (30-m × 0.32-mm) capillary column. Injector temperature was 250°C

with He carrier gas flow of 1.2 mL/min. The column temperature program was as follows: 50°C initial temperature, then ramp 30°C/min to 300°C, then hold for 0.7 min, for a total run time of 14.0 min. This reaction did not consume the starting material or produce the desired product **3** after a prolonged 4-hour reaction time.



Scheme 1

The failure of free alcohol **1** to successfully undergo hydroboration led us to evaluate a protected alcohol derivative. The *tert*-butyldimethylsilyl (TBS) ether-protected derivative **4** was chosen because of the ease of protection and deprotection and its stability to a variety of reaction conditions (Scheme 2).[8] Substrate **4** was synthesized by addition of **1** (1.458 mL, 10 mmol, 1.0 equiv) and methylene chloride (33 mL) to a oven-dried, 100-mL round-bottomed flask, containing a magnetic stir-bar, equipped with a septum, and purged with argon.[9] The mixture was stirred at room temperature until a homogeneous solution was obtained. In a separate oven-dried flask, imidazole (1.38 g, 20 mmol, 2.0 equiv) and *tert*-butyldimethylsilyl chloride (TBSCl, 2.26 g, 15 mmol, 1.5 equiv) were added with a minimal amount of methylene chloride (10 mL), stirred until homogeneous, and then added to the flask containing **1**. The reaction was then stirred for 45 minutes at room temperature. The reaction was determined to be complete after a reaction aliquot was taken, washed with water, extracted with ethyl acetate, and analyzed by GC-MS. The reaction was quenched with a saturated solution of ammonium chloride (75 mL).



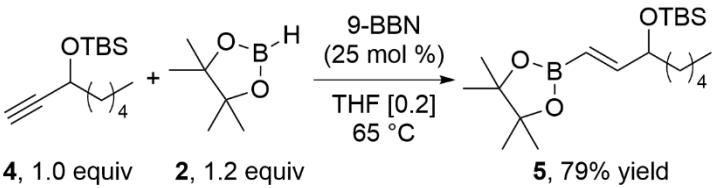
Scheme 2

The organic phase was washed with water (100 mL) and brine (50 mL), dried with anhydrous sodium sulfate until flocculent, filtered, and the solvent was removed *in vacuo*. The crude product was filtered through a short silica plug (25 g) and eluted with 2% Et_2O/hexane (100 mL). Concentration *in vacuo* provided 2.35 g (98%) of **4** as a yellow-tinged oil.

*Data for 3-(tert-Butyldimethylsiloxy)-1-octyne **4***[10]

^{1}H NMR:	(400 MHz, $CDCl_3$)
	4.33 (td, J = 6.5, 2.0 Hz, 1H), 2.38 (d, J = 2.0 Hz, 1H), 1.70-1.63 (m, 2H), 1.47-1.37 (m, 2H), 1.36-1.24 (m, 4H), 0.91-0.89 (m, 12H), 0.13 (s, 3H), 0.11 (s, 3H).
^{13}C NMR:	(101 MHz, $CDCl_3$)
	85.8, 71.8, 62.8, 38.6, 31.4, 25.8, 24.8, 22.6, 18.2, 14.0, -4.6, -5.1.
IR:	(neat, ATR)
	3312 (w), 2955 (m), 2929 (m), 2857 (m), 1742 (w), 1609 (w), 1572 (w), 1472 (m), 1405 (w), 1361(w), 1250 (m), 1119 (m), 1088 (m), 1044 (m), 1005 (m), 963 (w), 938 (w), 835 (s), 775 (s), 726 (m), 653 (m), 626 (m), 558 (m), 491 (w), 467 (w), 436 (w).
MS:	(EI, 70 eV)
	166 (6), 165 (37), 163 (16), 157 (13), 155 (20), 153 (5), 141 (25), 140 (6), 139 (36), 137 (14), 135 (5), 129 (7), 128 (10), 127 (35), 126 (5), 125 (17), 123 (29), 116 (5), 115 (61), 114 (80), 113 (100), 112 (24), 111 (52), 109 (13), 108 (6), 107 (57), 103 (5), 101 (29), 100 (7), 99 (50), 98 (7), 95 (7), 93 (6), 91 (8), 89 (8), 87 (7), 85 (38), 84 (31), 83 (100), 81 (6), 79 (25), 77 (37), 76 (49), 75 (100), 74 (19), 73 (100), 71 (6), 69 (11), 67 (12), 65 (8), 61 (19), 60 (8), 59 (40), 58 (12), 57 (29), 56 (8), 55 (74), 53 (9), 52 (5).
GC:	t_R: 9.04 min (GC Method 1)
TLC:	R_F 0.47 (100% hexane) [silica gel, $KMnO_4$]

The tolerance of the 9-BBN-catalyzed hydroboration reaction with the TBS-protected alcohol **4** could then be studied (Scheme 3). The reaction was carried out by addition of **4** (0.481 g, 2.0 mmol, 1.0 equiv), **2** (0.348 mL, 2.4 mmol, 1.2 equiv), 9-BBN (1.00 mL, [0.5] in THF, 0.5 mmol, 25 mol%), and THF (10 mL) to an oven-dried, 50-mL round-bottomed flask, containing a magnetic stir-bar, equipped with a reflux



Scheme 3

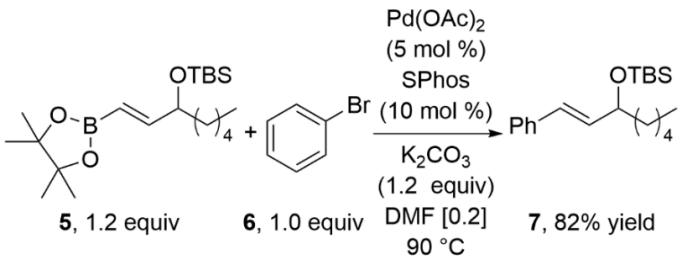
condenser capped with a septum, and purged with argon.[2] Half of the solvent (5 mL) was added first while the rest was used to rinse the reflux condenser and flask following the addition of the other reagents. The reaction mixture was heated to 65°C in a preheated oil bath. The reaction was then stirred for 2.5 hours. The reaction was determined to be complete after a reaction aliquot was taken, washed with water, extracted with ethyl acetate, and analyzed by TLC (100% hexane, $KMnO_4$ stain) and GC-MS (GC Method 1). The crude reaction mixture was diluted with ethyl acetate, washed with water and brine, dried with anhydrous sodium sulfate until flocculent, filtered, and the solvent was removed *in vacuo*. The crude product was purified by column chromatography in a 1×20-cm column containing 30 g of normal-phase silica gel and eluted with hexane (100 mL) followed by 2% EtOAc/hexane (100 mL). Concentration *in vacuo* provided 0.578 g (79%) of **5** as a yellow-tinged oil.

*Data for 2-[(1E)-3-[[(1,1-Dimethylethyl)dimethylsilyl]oxy] -1-octen-1-yl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **5***[11,12]

^{1}H NMR:	(400 MHz, $CDCl_3$)
	6.56 (dd, *J* = 18.0, 4.8 Hz, 1H), 5.57 (dd, *J* = 18.0, 1.6 Hz, 1H), 4.17-4.12 (m, 1H), 1.50-1.42 (m, 2H), 1.34-1.19 (m, 18H), 0.93-0.85 (m, 12H), 0.03 (s, 3H), 0.01 (s, 3H).
^{13}C NMR:	(101 MHz, $CDCl_3$)
	156.4, 83.1, 74.1, 37.6, 31.9, 25.9, 24.9, 24.7, 22.7, 18.2, 14.1, -4.4, -4.9.
IR:	(neat, ATR)
	2980 (w), 2955 (m), 2932 (m), 2859 (m), 1643 (m), 1475 (w), 1461 (w), 1391 (m), 1360 (m), 1338 (m), 1317 (m), 1248 (m), 1218 (s), 1144 (s), 1089 (m), 1005 (m), 965 (m), 870 (m), 834 (s), 774 (s), 668 (m), 579 (w).

MS:	(EI, 70 eV)
	367 ([M-1]$^+$, 0.5), 353 ([M-Methyl]$^+$, 8), 313 (6), 312 (23), 311 (100), 310 (26), 298 (13), 297 (61), 296 (16), 212 (5), 211 (30), 210 (8), 169 (9), 155 (6), 145 (5), 141 (5), 117 (9), 113 (5), 109 (28), 103 (10), 101 (10), 85 (5), 83 (12), 81 (5), 75 (25), 73 (27), 69 (5), 59 (5), 57 (5), 55 (5).
GC:	t_R: 11.58 min (GC Method 1)
TLC:	R_F 0.27 (100% hexane) [silica gel, $KMnO_4$]

The synthetic utility of **5** was then demonstrated in a palladium-catalyzed cross-coupling reaction with bromobenzene (Scheme 4). The reaction was carried out by the addition of potassium carbonate (0.166 g, 1.2 mmol, 1.2 equiv), SPhos (0.041 g, 0.1 mol, 10 mol%), and palladium acetate (0.0112 g, 0.05 mmol, 5 mol%) to a mixture of dimethylformamide (DMF, 5 mL) and **5** (0.442 g, 1.2 mmol, 1.2 equiv) to an oven-dried, 50-mL round-bottomed flask, containing a magnetic stir-bar, equipped with a septum, and purged with argon for 5 minutes.[3] Bromobenzene **6** (0.105 mL, 1.0 mmol, 1.0 equiv) was added to the purged solution, and the reaction was heated to 90°C in a preheated oil bath. The reaction was then stirred for 1.5 hours. The reaction was determined to be complete after a reaction aliquot was taken, washed with water, extracted with ethyl acetate, and analyzed by TLC (100% hexane, UV light, and ceric ammonium molybdate (CAM) stain) and GC-MS (GC Method 1). The resulting product was diluted with ethyl acetate, washed with water and brine, dried with anhydrous sodium sulfate until flocculent, filtered, and the solvent was removed *in vacuo*. The crude product was purified by column chromatography in a 1×20-cm column with 15 g of normal-phase silica gel and a gradient eluent that began with 100% hexane (100 mL) followed by 2% EtOAc/hexane (100 mL) and ending with 4% EtOAc/hexane (100 mL). Concentration *in vacuo* provided 0.262 g (82%) of **7** as a yellow-tinged oil.

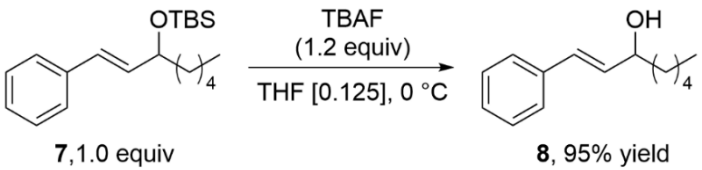


Scheme 4

*Data for [(1E)-3-[[(1,1-Dimethylethyl)dimethylsilyl]oxy]-1-octen-1-yl]benzene **7***

^{1}H NMR:	(400 MHz, $CDCl_3$) 7.38-7.36 (m, 2H), 7.33-7.29 (m, 2H), 7.24-7.20 (m, 1H), 6.47 (d, *J* = 15.9 Hz, 1H), 6.17 (dd, *J* = 15.9, 6.5 Hz, 1H), 4.28-4.23 (m, 1H), 1.61-1.51 (m, 2H), 1.36-1.22 (m, 8H), 0.92-0.87 (m, 12H), 0.08 (s, 3H), 0.05 (s, 3H).
^{13}C NMR:	(101 MHz, $CDCl_3$) 137.4, 133.8, 128.9, 128.7, 127.4, 126.5, 73.8, 38.6, 32.0, 26.1, 25.1, 22.8, 18.5, 14.2, -4.1, -4.6.
IR:	(neat, ATR) 2955 (w), 2927 (m), 2856 (m), 1495 (w), 1458 (m), 1447 (w), 1363 (m), 1248 (m), 1131 (m), 1069 (m), 1004 (m), 963 (m), 937 (m), 874 (m), 834 (s), 808 (m), 774 (s), 745 (m), 691 (s), 668 (m).
MS:	(EI, 70 eV) 318 ([M]$^+$, 5), 262 ([M-*tert*-Butyl]$^+$, 5), 261 (22), 249 (6), 248 (22), 247 (100), 205 (5), 187 (15), 185 (14), 135 (6), 131 (8), 130 (7), 129 (13), 128 (8), 117 (42), 115 (19), 91 (22), 77 (5), 76 (7), 75 (93), 73 (35).
GC:	t_R: 11.92 min (GC Method 1)
TLC:	R_F 0.41 (100% hexane) [silica gel, UV light, CAM stain]

The TBS-protecting group was removed from the cross-coupling product **7** to reveal the hydroxyl functional group and complete the synthesis of (*E*)-phenylocten-3-ol **8** (Scheme 5). The reaction was carried out by the addition of THF (3 mL) and **7** (0.238 g, 0.75 mmol, 1.0 equiv) to an oven-dried, 25-mL round-bottomed flask, containing a magnetic stir-bar, equipped with a septum, and purged with argon.[13] A solution of tetra-*N*-butylammonium fluoride (TBAF, 0.235 g, 0.9 mmol, 1.2 equiv) dissolved in a minimal amount of THF (3 mL) was then added dropwise. The reaction was stirred at room temperature for 4 hours.



Scheme 5

The reaction was determined to be complete after a reaction aliquot was taken, washed with water, extracted with ethyl acetate, and analyzed by TLC (5% EtOAc/hexane, UV light, and CAM stain) and GC-MS (GC Method 1). The resulting product was diluted with ethyl acetate, washed with water and brine, dried with anhydrous sodium sulfate until flocculent, filtered, and the solvent was removed *in vacuo*. The crude product was purified by column chromatography in a 1×20-cm column with 15 g of normal-phase silica gel, and eluted with a gradient that began with 100% hexane (100 mL) followed by 2% EtOAc/hexane (100 mL) and ending with 4% EtOAc/hexane (100 mL). Concentration *in vacuo* provided 0.145 g (95%) of **8** as a yellow-tinged oil.

*Data for (E)-1-Phenyl-1-octen-3-ol **8***

^{1}H NMR:	(400 MHz, $CDCl_3$) 7.44-7.41 (m, 2H), 7.37-7.33 (m, 2H), 7.30-7.27 (m, 1H), 6.60 (d, J = 15.8 Hz, 1H), 6.26 (dd, J = 15.9, 6.8 Hz, 1H), 4.15 (q, J = 15.8, 6.7 Hz, 1H), 2.09 (s, 1H), 1.70-1.59 (m, 2H), 1.42-1.26 (m, 6H), 0.95-0.91 (m, 3H).
^{13}C NMR:	(101 MHz, $CDCl_3$) 136.9, 132.7, 130.4, 128.7, 127.8, 126.6, 73.3, 37.5, 31.9, 25.3, 22.8, 14.2.
IR:	(neat, ATR) 3324 (w, broad), 3083 (w), 3061 (w), 2957 (w), 2929 (m), 2859 (w), 1495 (w), 1447 (m), 1377 (m), 1246 (m), 1134 (m), 1049 (m), 1028 (m), 963 (s), 909 (m), 876 (m), 831 (m), 746 (s), 692 (s), 552 (m).
MS:	(EI, 70 eV) 204 ($[M]^+$, 3), 148 (19), 134 (10), 133 (100), 131 (10), 130 (24), 129 (8), 128 (7), 116 (5), 115 (38), 106 (5), 105 (44), 104 (18), 103 (15), 99 (15), 91 (35), 79 (8), 78 (7), 77 (18), 71 (9), 55 (26).
GC:	t_R: 11.7 min (GC Method 1)
TLC:	R_F 0.23 (5% EtOAc/95% hexane) [silica gel, UV light, CAM stain]

Discussion

The study of the 9-BBN-catalyzed hydroboration reaction of 1-octyn-3-ol **1** and its TBS-derivative **4** provided insight into the functional group tolerance and utility of the reaction. The unprotected alcohol evaluated was an incompatible substrate in the reaction. Likely, the alcohol functional group undergoes an acid–base reaction with the 9-

BBN catalyst and deactivates it. Noteworthy is the successful utilization of **5** in a palladium-catalyzed cross-coupling reaction with bromobenzene. Moreover, **5** intercepts a patented synthesis of prostaglandin analogs.[11]

Conclusion

(*E*)-Phenylocten-3-ol **8** was successfully synthesized in 4-steps from 1-octyn-3-ol **1**. The functional group tolerance of the 9-BBN-catalyzed hydroboration reaction of **2** was studied with **1** and its silyl ether–protected derivative **4**. The free alcohol of **1** was found to inhibit productive hydroboration reaction. The silyl ether **4** was easily synthesized in high yield (98%) and provided the desired hydroboration product **5** in 79% yield. The usefulness of the vinylboronic acid pinacol ester **5** was showcased in a palladium-catalyzed Suzuki-Miyaura cross-coupling reaction with bromobenzene. The cross-coupling product **7** was isolated in 82% yield. The silicon-protecting group could then be readily removed from **7** by treatment with TBAF to provide (*E*)-phenylocten-3-ol **8** in 95% yield. The entire 4-step synthetic sequence resulted in a 60% overall yield.

Acknowledgments

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References

1. Rau, H.H.; Werner, N.S. *Bioorganic Med. Chem. Lett.* 2018, *28*, 2693–2696.

2. Ruesch, G.L.; Rowley, S.L.; Mifflin, M.C.; Werner, N.S. *A. J. U. R.* 2020, *13*, 3–12.

3. Mukai, S.; Werner, N.S. *A. J. U. R.* 2023, *20*, 39–48.

4. Miyaura, N. Metal-catalyzed cross-coupling reactions of organoboron compounds with organic halides, in *Metal-Catalyzed Cross-Coupling Reactions*, 2nd ed. (de Meijere, A., Diederich, F., Eds.); Wiley-VCH, Weinheim, 2004; 41–123.

5. Miyaura, N.; Suzuki, A. *Chem. Rev.* 1995, *95*, 2457–2483.

6. Kar, S.; Sanderson, H.; Roy, K.; Benfenati, E.; Leszczynski, J. *Chem. Rev.* 2022, *122*, 3637–3710.

7. Devendar, P.; Qu, R.-Y.; Kang, W.-M.; He, B.; Yang, G.-F. *J. Agric. Food Chem.* 2018, *66*, 8914–8934.

8. Kocienski, P.J. Hydroxyl protecting groups. *Protecting Groups*, 3rd ed. Georg Thieme Verlag: Stuttgart, 2005; 188–229.

9. Nicolaou, K.C.; Rhoades, D.; Lamani, M.; Pattanayak, M.R.; Kumar, S.M. *J. Am. Chem. Soc.* 2016, *138*, 7532–7535.

10. Schwartz, F.; Carr, D.B.; Hansen, R.T.; Dayrit, F.M. *J. Org. Chem.* 1980, *45*, 2925–3142.

11. Henschke, J.P.; Wu, P.; Wu, H.; Wen, W. WO Patent 2016/005943 A1, 14 January 2016.

12. Syu, J.F.; Wang, Y.T.; Liu, K.C.; Wu, P.Y.; Henschke, J.P.; Wu, H.L. *J. Org. Chem.* 2016, *81*, 10832–10844.

13. Barbie, P.; Kazmaier, U. *Org. Lett.* 2016, *18*, 204–207.

Sacrificial Micropatterning of PDMS for Filtration and Hydrophobicity

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ABSTRACT

We have developed a method to pattern polydimethylsiloxane (PDMS) by mixing sacrificial magnesium particles with the PDMS, followed by sonication in hydrochloric acid. Using this method, we have fabricated PDMS membranes that are the inverse of traditional glass frits, as well as PDMS thin coatings to increase the hydrophobicity of surfaces. Our PDMS membranes exhibit abilities to remove cells and large molecules from solution, showing the ability to exclude microalgae and medium proteins (BSA) with rejection rates up to 99.3%. The PDMS flexes under applied pressure, changing the observed flow rate and subsequent particle exclusion, possibly offering unique diversity to the filtration capacity of the device. The thin (micrometer-scale thickness) PDMS layers are hydrophobic, because of the pillared nature of the surface. These thin PDMS layers are made by spinning a PDMS, magnesium, and hexane slurry onto substrates. Hydrophobicity and layer clarity can be manipulated between around 90° and 150° as measured by water contact angle by adjusting magnesium and hexane concentrations.

INTRODUCTION

Membranes have received increased attention because of their applicability in numerous industries.[1] For example, membranes are commonly used in medicine,[2,3] protein purification,[3,4] and water treatment.[2,5] Membrane technology has become popular because of its simplicity and diverse filtration capabilities.[1] Several methods of membrane fabrication have been successfully utilized, including photolithography,[6,7] electrospinning,[1] phase inversion,[4,8–11] and sacrificial patterning.[12–15]

Sacrificial fabrication techniques are of particular interest to membrane design because of their low-cost and scalable production steps.[13] In this technique, glass or a polymer is mixed with a sacrificial material that is later removed through chemical etching.[12-15] The result of this method is a patterned device where the sacrificial material serves as a template.[12-15] Previous research groups have seen success in creating nanochannels and other well-defined structures through the use of sacrificial techniques.[12-18]

As mentioned, sacrificial techniques result in the patterning of materials. It is known that patterned surfaces can demonstrate hydrophobic and superhydrophobic characteristics.[19-25] Super-hydrophobicity allows for the precise control of water on surfaces, which has many practical applications.[19,20] For example, superhydrophobic surfaces have shown self-cleaning and anti-icing properties.[26-29] Additionally, superhydrophobic layers can be used in microfluidics, cell arrays, and sensors.[19,20,24,30] The versatility of superhydrophobic layers has led to increased research in their development.[25]

In our research, Mg metal microparticles are used as a sacrificial material to develop novel polydimethylsiloxane (PDMS)-based membranes with PDMS nanochannels that exhibit ultrafiltration capabilities. Additionally, the same fabrication method used to make membranes can be utilized to create thin layers of hydrophobic PDMS.

MATERIALS & METHODS

PDMS Membrane Fabrication

PDMS was prepared by mixing base and curing agent in a 10:1 ratio, respectively, followed by placement in a vacuum for 10 minutes (to remove air bubbles generated from mixing). The PDMS was mixed with Mg particles in a defined mass:mass ratio until homogeneous (Fig. 1a). Various sizes of mesh Mg were used including 60-80, 125-200, and 325 (corresponding to around 250-μm, 100-μm, and 50-μm diameter

particles, respectively). The ratios of Mg:total mass (g Mg + g PDMS) used during fabrication ranged from 25% to 65% Mg.

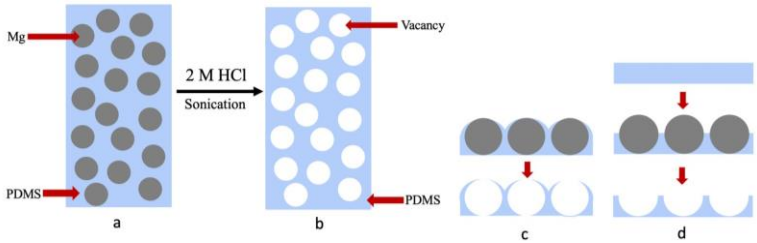

Figure 1. Fabrication schematics. (a,b) Membrane fabrication. (a) PDMS and Mg are mixed and polymerized. The composite is sonicated in HCl to dissolve the Mg, forming (b) a PDMS inverse frit, with vacant holes formerly occupied by Mg. (c) Thin-layer PDMS method 1. On top, Mg, hexanes, and PDMS are mixed, spun onto a glass slide, and polymerized. The composite is sonicated in HCl to dissolve the Mg, forming (on bottom) a thin-layer of patterned PDMS with vacant holes formerly occupied by Mg. (d) Thin-layer PDMS method 2. On top, hexanes and PDMS are mixed and spun onto a glass slide and coated with a thin layer of Mg. The PDMS is polymerized. The composite is sonicated in HCl to dissolve the Mg, forming (on bottom) a thin layer of patterned PDMS with vacant holes formerly occupied by Mg.

The Mg-PDMS mixture was deposited in a 1-mm-thick layer on a glass slide and placed in an oven set at 65°C overnight to cure. Once cured, the membrane was placed in a beaker of 2 M HCl and sonicated until all Mg was dissolved. The complete dissolution of Mg varied from a few hours to a few weeks and was determined by observation. The final result was a porous PDMS membrane, which is essentially an inverse frit: a membrane that exhibits holes where beads are (glass frit) or Mg used to be (PDMS membrane), rather than beads/Mg attached to each other (Fig. 1b).

Membranes were also constructed with two layers of different compositions, called double-layer (DL) membranes. First, a filtering layer was formed as described above and baked for a few minutes (until it was solid but still sticky). The membrane was then removed from the oven and a second layer was deposited as a slurry on top of the original membrane. This second membrane layer had a higher percentage of Mg and larger Mg particles and was mixed with hexane in approximately a 1:3 PDMS:hexane ratio. The membranes were baked and sonicated in hydrochloric acid as described above.

PDMS Membrane Characterization and Testing

The membranes were characterized using a Phenom ProX scanning electron microscope (SEM). This allowed the surface topology, pore structure, and PDMS connectivity to be roughly assessed.

Membranes were tested for permeability with water, followed by tests for particle rejection using solutions of microalgae (*Chlorella* spp.) or Texas Red–labeled bovine serum albumin (TR-BSA). During test runs, the frits were placed in 3D-printed testing adaptors. The adaptors connected the membrane to a syringe to which pressure was applied. The adaptor and syringe were filled with the testing solution (water, algae, or TR-BSA) and connected by thin tubing.

When testing for permeability, the flux of water through the membrane was measured over set time intervals. During filtration tests, the solution (algae or TR-BSA) that passed through the membrane was collected and measured using UV-VIS spectroscopy. The level of particle rejection achieved was determined by comparison of UV-VIS absorbance measurements of the solution before and after passage through the membrane.

Thin-Layer PDMS Fabrication

One-Step Method

PDMS was prepared by mixing as described above. The mixed, vacuumed PDMS was combined with hexane and Mg particles at desired dilution factors, then mixed until homogeneous. The PDMS-hexane-Mg slurry was then spin-coated onto a glass slide at ~1000 rpm. The coated glass slide underwent an overnight baking at 65°C. After baking, the slide was sonicated in HCl for a minimum of 2 hours to dissolve the Mg (Fig. 1c).

Two-Step Method

PDMS was prepared by mixing base and curing agent in a 10:1 ratio, respectively, followed by placement in a vacuum for 10 minutes (to remove air bubbles generated from mixing). The PDMS was combined with hexane, at various dilution factors, and mixed until homogeneous. The PDMS-hexane slurry was then spin-coated onto a glass slide at ~1000 rpm and covered with a thin layer of Mg particles. The coated glass slide underwent an overnight baking process at 65°C. After baking, the slide was sonicated in HCl for a minimum of 2 hours to dissolve the Mg (Fig. 1d).

Surface Characterization of Thin-Layer PDMS

The surface morphology and chemical composition analysis of thin-layer PDMS surfaces was analyzed using an SEM. Deionized water contact angle measurements were performed using a goniometer. Optical clarity analysis was performed using a laser light scattering instrument built in house.

RESULTS & DISCUSSION

PDMS Membranes

The PDMS surrounding each cavity creates an interconnected PDMS nanochannel system that enables membranes to exclude particles smaller than the nanochannels connecting the cavities (Fig. 2a). SEM images of membranes of 50-µm Mg powder at ratios of 45, 55, and 65% Mg powder to PDMS by mass showed cavities created by the sacrificial Mg powder used during the fabrication process (Fig. 2b-d) ranging from ~50 to 150 µm in size. Connections between 50-µm cavities are difficult to resolve with SEM images but must be present for removal of Mg during sonication and release of the hydrogen gas produced to occur.

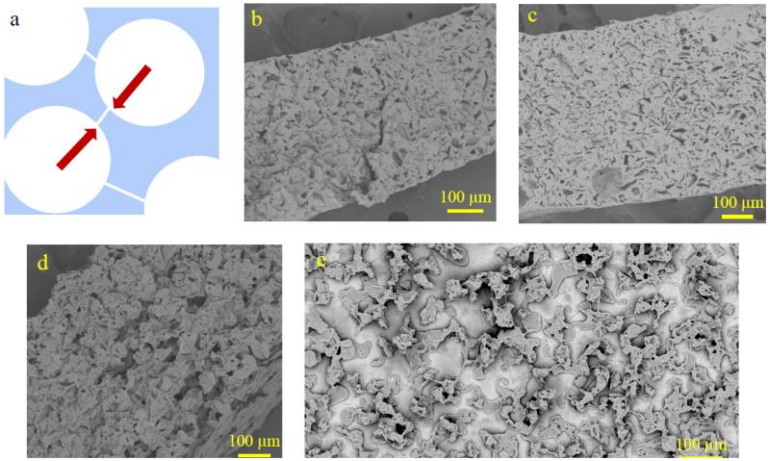

Figure 2. (a) Schematic of PDMS nanochannels created by cavities generated by Mg powder used during fabrication. White circles represent cavities where the Mg particles once were. Blue represents PDMS, and arrows point to PDMS nanochannels that form between each cavity. (b-d) SEM images of membranes fabricated with 50-µm Mg powder at various Mg:PDMS mass percentages: (b) 45% Mg; (c) 55% Mg; (d) 65% Mg. (e) SEM image of two-step thin-layer PDMS with 3:1 ratio of hexane to PMDS to show regularity of patterning.

The number and size of cavities within the membranes increased as the percent of Mg powder used during the fabrication process increased (Fig. 2b-2d). Membranes composed of 65% Mg powder (Fig. 2d) were extremely fragile whereas membranes composed of 45% and 55% Mg had greater PDMS connectivity and were more durable (Fig. 2b,c).

PDMS is an elastomer, thus when pressure is applied to the membrane, the membrane flexes, typically resulting in greater cavity and nanochannel sizes. Water flow rates for a membrane composed of 45% 50-µm Mg powder by mass are shown in Figure 3a. As the pressure applied to the membrane increased, the flow rate exhibited an exponential-like curve. The increase in nanochannel size when pressure is applied suggests multiple particle rejection capabilities for a single membrane.

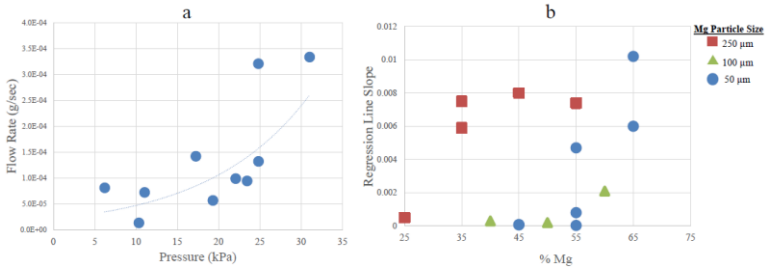

Figure 3. (a) Water flow rate for a membrane composed of 45% 50-µm Mg powder. As the pressure increases, the flow rate increases in an exponential-like fashion (the line shown is a guide for the eye). (b) Flow rate slopes vs. percentage of Mg used during membrane fabrication for 250 (red)-, 100 (green)-, and 50 (blue)-µm Mg powder. The flow rates increased as the percentage of Mg used increased for frits composed of 100- and 50-µm Mg. Frits composed of 250-µm Mg had a high flow that did not change significantly with the amount of Mg used during fabrication.

The slopes of flow rate graphs of membranes were plotted against the mass percentage of magnesium used during fabrication (Fig. 3b). As the percentage of Mg in membranes composed of 50-µm and 100-µm Mg increased, the flow rate increased. Membranes composed of 250-µm Mg exhibited a high flow rate that did not change significantly as the percentage of magnesium used during fabrication increased, indicating flow was relatively unrestricted.

A membrane composed of 50-µm Mg powder at a mass percent of 55%, along with two DL membranes with filtering layers of 60% and 55% 50-µm Mg were tested for particle rejection with a solution of algae at a pressure of 28 kPa. The total algae rejection achieved by these frits

were 96%, 63.7%, and 99.3%, respectively (Fig. 4a). As might be expected, when more Mg is added to the membrane the degree of connectivity of the channels through the membrane is such that the filtration abilities of the membrane suffers, as can be seen by comparing the 60% Mg membrane with the two 55% Mg membranes. The advantages of the DL membranes are also illustrated in Figure 4a, as the large standard deviation of the 55% single-layer membrane is largely due to membrane obstruction resulting in only a few tens of microliters of filtered solution being collected, resulting in significant variation in measured absorbances. The DL membranes successfully filtered several milliliters of solution without clogging. The membranes were able to reject particles smaller than the cavities created by the sacrificial Mg powder used, supporting the notion that PDMS nanochannels provide the basis of membrane filtration.

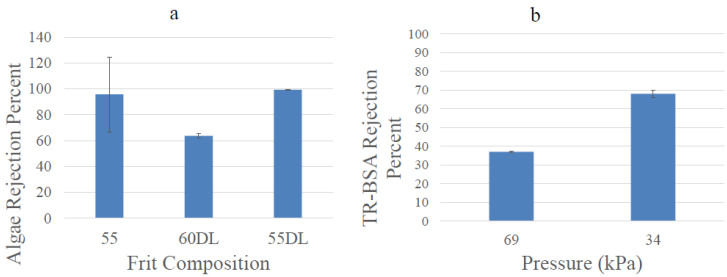

Figure 4. Membrane filtration performance. (a) Percent rejection of algae solution filtered with frit compositions of 55%, 60%DL, and 55% DL Mg by mass. DL indicates the membrane had a second filtering layer—a double layer—with larger holes to reduce membrane clogging. Solution absorbance was measured at 275 nm. From left to right, the percent algae rejection rates are 96%, 63.7%, and 99.3%. (b) Percent rejection of TR-BSA on a frit composed of 45% Mg by mass. From left to right, the percent TR-BSA rejection rates are 37% at 69 kPa and 68% at 34 kPa.

A membrane composed of 45% Mg powder by mass was tested for filtration with a solution of TR-BSA. Two test runs were performed at pressures of 69 kPa and 34 kPa that resulted in rejection rates of 37% and 68%, respectively (Fig. 4b). The lower TR-BSA rejection rate observed at 69 kPa is likely due to the membrane flexing under the high pressure, resulting in increased nanochannel sizes that allowed more protein to flow through the membrane compared with the test run maintained at 34 kPa. These data suggest that one membrane could be used to filter particles of various sizes from a solution by increasing the applied pressure during the filtration process. Considering the overall

filtering capabilities of PDMS membranes, applications in water filtration to remove cells, macromolecule agglomerates (such as viruses), and even macromolecules are possibilities.

Thin-Layer Patterning

The regular patterning of PDMS observed in the SEM images in Figure 2 led to the development of thin-layer PDMS, as patterned surfaces can exhibit hydrophobic characteristics.[19,25] Figure 2e shows a thin-layer of PDMS using the two-step method with a 3:1 ratio of hexane to PDMS. The 50-μm Mg creates regularly spaced semi-fractal features. These features mimic the pillars that multiple groups have used to make superhydrophobic surfaces.[22,31-34] Water droplet contact angle measurements were performed to measure the effect of the pillared surface.

Figure 5 shows the contact angles of water on the patterned thin-layer PDMS as a function of the percent magnesium in the mixture for one-step synthesis (Fig. 5a) and the ratio of PDMS to solvent in the mixture for two-step synthesis (Fig. 5b). Thin-layer PDMS prepared using the one-step method were made by varying the mass ratio of Mg to PDMS. As percent Mg increased so did water contact angle as can be seen in Figure 5a. This is because increased magnesium resulted in a more patterned and thus a more hydrophobic surface.

As shown in Figure 5b, the two-step method resulted in an overall greater water contact angle. This is likely due to a more uniform patterning (Fig. 2e) that forms when Mg particles are distributed across the top of the PDMS layer, whereas the one-step method is prone to both removing portions of PDMS during sonication and burying features beneath a smooth PDMS surface. Using the two-step method, only a single layer of Mg is in contact with the PDMS and thus is able to pattern the PDMS beneath it. Therefore, changing the amount of Mg used had no observable effect on the patterning. With the two-step method, the water contact angle can be manipulated by adjusting PDMS/solvent ratios. As the ratio of PDMS to solvent increased, the contact angle increased because the layer got thicker and thus the patterned features got taller, as seen in Figure 5c.

As seen in Figure 5b, when the data for hexane, octane, and decane solvents are compared, we see that the increase in contact angle as a function of mass percent PDMS for octane and decane are relatively linear. Hexane has a steeper slope at the beginning and then plateaus at higher contact angles/lower amounts of hexane. We attribute this behavior to the relatively high rate of hexane evaporation compared to that of octane and decane. As a slide is spun, the hexane evaporates out,

which increases the viscosity of the liquid and thus the thickness of the final layer (Fig. 5c). The less hexane present, the sooner a high-viscosity solution is reached, and thus the differences seen when more hexane is present are much greater than those seen when less hexane is initially present. The slides were also tested for optical transparency and, as might be expected, thicker PDMS layers were found to reduce optical clarity.

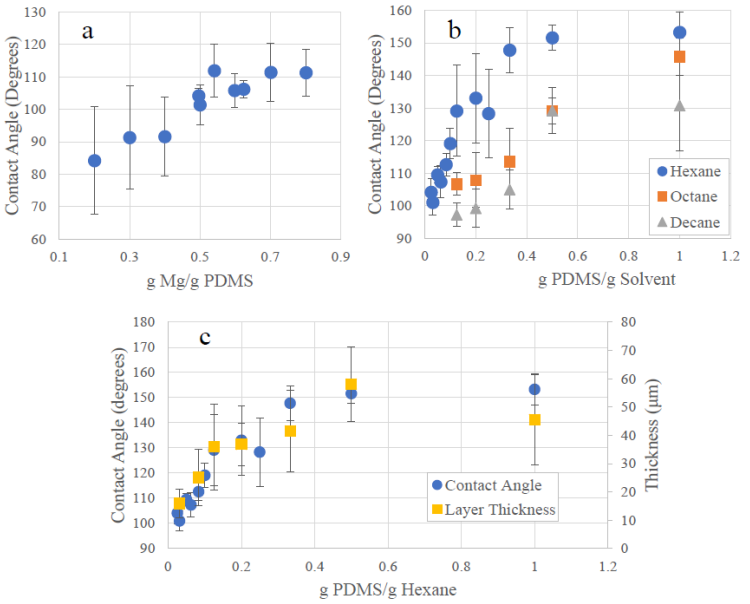

Figure 5. Thin-layer PDMS contact angle data. (a) One-step method. The coating solution was prepared using a dilution of 8:1 hexane to PDMS and varying mass percent Mg. (b) Two-step method. The coating solution was prepared by varying dilution factors of PDMS to hexane, octane, or decane and subsequently coating with a layer of Mg particles. (c) The contact angle of hexane dilutions (left axis) is shown with the thickness of the hexane layers measured via light microscopy (right axis).

CONCLUSION

Both membranes and thin-layer PDMS can be made by mixing PDMS and sacrificial Mg particles. Whereas other methods of membrane design offer more precise control over pore size and structure, patterning PDMS using this sacrificial technique provides a simple, efficient, and economical method of fabricating PDMS membranes. Micro-sized cavities throughout the membranes are connected by thin

nanochannels through the PDMS; the nanochannels provide PDMS membranes the ability to achieve exclusion of small particles such as algae and protein. Frit filtration test runs with a solution of algae resulted in a 99.3% rejection rate, while test runs with solutions of TR-BSA resulted in rejection rates of 37% (at 69 kPa) and 68% (at 34 kPa). The amount of pressure applied to the frits during filtration impacts internal cavity and PDMS nanochannel sizes, suggesting our frits have the ability to change excluded sizes by changing the applied pressure.

Thin-layer PDMS coatings on glass slides can result in very hydrophobic surfaces, approaching superhydrophobic surfaces under the best of conditions, with water contact angles varying from around 90° to over 150° in a predictable fashion. The highest contact angles are obtained using a two-step method optimized to produce thicker surfaces and place the Mg patterning agent at the surface of the PDMS. The patterns produced are somewhat fractal in nature, which contributes to the high contact angles achievable with this relatively simple patterning method.

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REFERENCES

1. Wu, D.; Feng, Q.; Li, M.; Wei, A.; Li, J.; Liu, C.; Xu, H.; Cheng, W. Preparation and protein separation properties of the porous polystyrene/ethylene–vinyl acetate copolymer blend nanofibers membranes. ACS Omega 2019, 4 (23), 20152–20158. https://doi.org/10.1021/acsomega.9b01946.

2. Jackson, E.A.; Hillmyer, M.A. Nanoporous membranes derived from block copolymers: from drug delivery to water filtration. ACS Nano 2010, 4 (7), 3548–3553. https://doi.org/10.1021/nn1014006.

3. Schreiner, T.G.; Tamba, B.I.; Mihai, C.T.; Lőrinczi, A.; Baibarac, M.; Ciobanu, R.C.; Popescu, B.O. Nanoporous membranes for the filtration of proteins from biological fluids: biocompatibility tests on cell cultures and suggested applications for the treatment of Alzheimer's disease. J. Clin. Med. 2022, 11 (19), 5846. https://doi.org/10.3390/jcm11195846.

4. Arshad, F.; Aubry, C.; Zou, L. Highly permeable MoS 2 nanosheet porous membrane for organic matter removal. ACS Omega 2022, 7 (2), 2419–2428. https://doi.org/10.1021/acsomega.1c06480.

5. Hampu, N.; Werber, J.R.; Chan, W.Y.; Feinberg, E.C.; Hillmyer, M.A. Next-generation ultrafiltration membranes enabled by block polymers. ACS Nano 2020, 14 (12), 16446–16471. https://doi.org/10.1021/acsnano.0c07883.

6. Ding, Y.; Maruf, S.; Aghajani, M.; Greenberg, A.R. Surface patterning of polymeric membranes and its effect on antifouling characteristics. Sep. Sci. Tech. 2017, 52 (2), 240–257. https://doi.org/10.1080/01496395.2016.1201115.

7. Zhang, S.; Zhou, J.; Wang, Z.; Xia, J.; Wang, Y. Preparation of polysulfone-based block copolymer ultrafiltration membranes by selective swelling and sacrificing nanofillers. Front. Chem. Sci. Eng. 2022, 16 (5), 745–754. https://doi.org/10.1007/s11705-021-2038-x.

8. Blagojevic, N.; Müller, M. Simulation of membrane fabrication via solvent evaporation and nonsolvent-induced phase separation. ACS Appl. Mater. Interfaces 2023, 15 (50), 57913–57927. https://doi.org/10.1021/acsami.3c03126.

9. Ghobadi Moghadam, A.; Hemmati, A. Improved water purification by PVDF ultrafiltration membrane modified with GO-PVA-NaAlg hydrogel. Sci Rep 2023, 13 (1), 8076. https://doi.org/10.1038/s41598-023-35027-5.

10. Rahmati, A.; Mozafari, I. Ultrafiltration mixed matrix nanocomposite membranes fabricated using functionalized MWCNT/nanoclay/polyvinylidene fluoride for BSA separation. Iran Polym J 2022, 31 (5), 573–585. https://doi.org/10.1007/s13726-02101017-5.

11. Vilakati, G.D.; Mtsetfwa, A.S.; Mafu, L.D.; Mamba, G.; Dlamini, D.S.; Motsa, M.M. probing the separation efficiency of sulfur-doped graphitic carbon nitride (g-C3N4)/polysulfone low-pressure ultrafiltration mixed matrix membranes. Polym. Bull. 2023, 80 (8), 8759–8782. https://doi.org/10.1007/s00289-022-04465-y.

12. Keller, A.; Zainulabdeen, K.; Warren, H.; in het Panhuis, M. Fabrication of porous PDMS sponges using spontaneously self-removing sacrificial templates. MRS Advances 2022, 7 (23–24), 495–498. https://doi.org/10.1557/s43580-021-00196-w.

13. Kumar, S.; Xuan, J.; Lee, M.L.; Tolley, H.D.; Hawkins, A.R.; Woolley, A.T. Thin-film microfabricated nanofluidic arrays for size-selective protein fractionation. Lab Chip 2013, 13 (23), 4591. https://doi.org/10.1039/c3lc50869b.

14. Lee, C.; Yang, E.-H.; Myung, N.V.; George, T. A nanochannel fabrication technique without nanolithography. Nano Lett. 2003, 3 (10), 1339–1340. https://doi.org/10.1021/nl034399b.

15. Peeni, B.A.; Lee, M.L.; Hawkins, A.R.; Woolley, A.T. Sacrificial layer microfluidic device fabrication methods. Electrophoresis 2006, 27 (24), 4888–4895. https://doi.org/10.1002/elps.200600399.

16. Kumar, S.; Xuan, J.; Lee, M.L.; Tolley, H.D.; Hawkins, A.R.; Woolley, A.T. Thin-film microfabricated nanofluidic arrays for size-selective protein fractionation. Lab Chip 2013, 13 (23), 4591–4598. https://doi.org/10.1039/c3lc50869b.

17. Hamblin, M.N.; Hawkins, A.R.; Murray, D.; Maynes, D.; Lee, M.L.; Woolley, A.T.; Tolley, H.D. Capillary flow in sacrificially etched nanochannels. Biomicrofluidics 2011, 5 (2), 021103. https://doi.org/10.1063/1.3602858.

18. Mayya, K.S.; Gittins, D.I.; Dibaj, A.M.; Caruso, F. Nanotubes prepared by templating sacrificial nickel nanorods. Nano Lett. 2001, 1 (12), 727–730. https://doi.org/10.1021/nl015622c.

19. Chakraborty, A.; Gottumukkala, N.R.; Gupta, M.C. Superhydrophobic surface by laser ablation of PDMS. Langmuir 2023, 39 (32), 11259–11267. https://doi.org/10.1021/acs.langmuir.3c00818.

20. Chen, H.; Li, X.; Li, D. Superhydrophilic–superhydrophobic patterned surfaces: from simplified fabrication to emerging applications. Nanotechnol. Precis. Eng. 2022, 5 (3), 035002. https://doi.org/10.1063/10.0013222.

21. Jiang, Y.; Xu, Z.; Li, B.; Li, J.; Guan, D. Soft wetting: droplet receding contact angles on soft superhydrophobic surfaces. Langmuir 2023, 39 (43), 15401–15408. https://doi.org/10.1021/acs.langmuir.3c02667.

22. Jiao, Y.; Zhang, T.; Ji, J.; Guo, Y.; Wang, Z.; Tao, T.; Xu, J.; Liu, X.; Liu, K. Functional microtextured superhydrophobic surface with excellent anti-wear resistance and friction reduction properties. Langmuir 2022, 38 (43), 13166–13176. https://doi.org/10.1021/acs.langmuir.2c01959.

23. Varol, H.S.; Seeger, S. Droplet size-assisted polysiloxane architecting. Langmuir 2023, 39 (1), 377–388. https://doi.org/10.1021/acs.langmuir.2c02607.

24. Yong, J.; Chen, F.; Yang, Q.; Zhang, D.; Du, G.; Si, J.; Yun, F.; Hou, X. Femtosecond laser weaving superhydrophobic patterned PDMS surfaces with tunable adhesion. J. Phys. Chem. C 2013, 117 (47), 24907–24912. https://doi.org/10.1021/jp408863u.

25. Zhi, J.; Wang, S.; Zhang, J.; Duan, X.; Wang, J. Unveiling the relationship of surface roughness on superliquid-repelling properties with randomly distributed rough surface structures. Langmuir 2022, 38 (42), 12841–12848. https://doi.org/10.1021/acs.langmuir.2c01778.

26. De Vera, J.S.; Venault, A.; Chou, Y.-N.; Tayo, L.; Chiang, H.-C.; Aimar, P.; Chang, Y. Self-cleaning interfaces of polydimethylsiloxane grafted with pH-responsive zwitterionic copolymers. Langmuir 2019, 35 (5), 1357–1368. https://doi.org/10.1021/acs.langmuir.8b01569.

27. Liu, D.; Liu, R.; Cao, L.; Wang, L.; Saeed, S.; Wang, Z.; Bryanston-Cross, P. Superhydrophobic antifrosting 7075 aluminum alloy surface with stable Cassie–Baxter state fabricated through direct laser interference lithography and hydrothermal treatment. Langmuir 2024, 40 (1), 950–959. https://doi.org/10.1021/acs.langmuir.3c03144.

28. Mohd, G.; Majid, K.; Lone, S. Synergetic role of nano-/microscale structures of the trifolium leaf surface for self-cleaning properties. Langmuir 2023, 39 (17), 6178–6187. https://doi.org/10.1021/acs.langmuir.3c00317.

29. Zeng, C.; Shen, Y.; Tao, J.; Chen, H.; Wang, Z.; Liu, S.; Lu, D.; Xie, X. Rationally regulating the mechanical performance of porous PDMS coatings for the enhanced icephobicity toward large-scale ice. Langmuir 2022, 38 (3), 937–944. https://doi.org/10.1021/acs.langmuir.1c02205.

30. Liu, H.; Dong, J.; Zhou, H.; Yang, X.; Xu, C.; Yao, Y.; Zhou, G.; Zhang, S.; Song, Q. Real-time acid rain sensor based on a triboelectric nanogenerator made of a PTFE–PDMS composite film. ACS Appl. Electron. Mater. 2021, 3 (9), 4162–4171. https://doi.org/10.1021/acsaelm.1c00608.

31. Jaishree, S.; Bhandari, A.; Khatri, N.; Singh, B.; Jangra, S.; Husain, A.; Kumar, A.; Goyat, M.S. Advancement of analytical model for hydrophobic rectangular pillared array on Al-surface and its experimental validation. Int. J. Precis. Eng. Manuf. 2024. 25, 947-958. https://doi.org/10.1007/s12541-024-00969-x.

32. Yeh, K.-Y.; Chen, L.-J.; Chang, J.-Y. Contact angle hysteresis on regular pillar-like hydrophobic surfaces. Langmuir 2008, 24 (1), 245–251. https://doi.org/10.1021/la7020337.

33. Gao, J.; Zhao, J.; Liu, L.; Xue, W. Dimensional effects of polymer pillar arrays on hydrophobicity. Surf. Eng. 2016, 32 (2), 125–131. https://doi.org/10.1179/1743294414Y.0000000431.

34. Zhou, X.; Wang, H.; Zhang, Q.; Tian, Y.; Deng, Q.; Zhu, X.; Ding, Y.; Chen, R.; Liao, Q. Droplet impact on sparse hydrophobic pillar surface: impact phenomena, spreading mode, and droplet breakup. Phys. Fluids (1994). 2022, 34 (11), 112101. https://doi.org/10.1063/5.0111786.

Quantum Game Theory and Genuine Quantum Advantage

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Abstract

In recent decades, principles of quantum physics, or the theory of microscopic phenomena, have been applied to game theory, or the study of strategic interactions between rational actors. As a result, classical games such as the penny flip and the prisoner's dilemma have been modeled with quantum systems. In such models, players may employ quantum principles of superposition or entanglement as they attempt to maximize their payoff. Motivating the development of this quantum game theory, D.A. Meyer claimed that the use of quantum strategies rewards a player with a 100% chance of victory against a classical player within the PQ penny flip game, which he devised. We investigated the following question: Can this quantum advantage be attributed to the use of quantum strategies, or is it more appropriately attributed to the arbitrary design of the penny flip game? As it stands, the quantum player enjoys a greater number of plays than the classical player. Utilizing online resources such as Qiskit, IBM quantum computers, and IBM quantum simulators to model the penny flip game, it will be shown that a classical player possesses a far lesser chance of victory than the quantum player in certain scenarios when given the same advantage of multiple plays,

thereby proving that quantum advantage is genuine within the penny flip game.

Introduction

Game Theory

Game theory, first formulated in the mid-20th century, concerns the study of strategic interaction between rational actors [1]. These actors, with access to a defined set of strategies for a given interaction, attempt to maximize their payoff by encouraging an outcome with a pre-established reward. These interactions include games such as the penny flip game, the prisoner's dilemma, or even chess.

By analyzing various strategies within these small confrontations, economists, political scientists, and military strategists can maximize their payoff, leading to victory in the stock market [2], on the campaign trail [3], and even on the battlefield [4]. As such, the scope of game theory's application is wide.

Quantum Computing

In recent years, the application of quantum mechanics to computational challenges has become more common. Now, a quantum system refers to any microscopic system whose states take on only discrete or quantized values. For example, the spin of an electron is described by quantum mechanics because it may only take on discrete values of ±½. In contrast, macroscopic objects can "spin" or self-rotate at any value of angular momentum.

In many instances, the development of quantum computing has been validated. Shor's quantum algorithm, for instance, solves the problem of prime factorization exponentially faster than its classical counterpart [5]. Grover's algorithm, a quantum search algorithm for unsorted databases, outperforms its classical equivalent by a quadratic amount [6]. Quantum superiority, at least in some cases, seems unquestionable, motivating the development of other methods of quantum computation and hardware as well as the widening of its application.

Quantum Game Theory

One development within quantum computing was instigated in 1998 by D. A. Meyer. Ultimately, he built a bridge between game theory and quantum computing, asserting that one may not only successfully

represent interactions between rational actors with quantum systems, but one may find promising new strategies in these systems as well [7]. These new strategies incorporate quantum principles of superposition, entanglement, and uncertainty, ultimately providing a quantum player with access to strategies that a classical player cannot claim, conferring upon them a certain "quantum advantage."

Meyer first introduced quantum game theory with a simple penny flip game, a game lucid enough to clearly illustrate the advantages of employing quantum strategies. Other games have also been "quantized," such as Prisoner's Dilemma [8] and even Rock, Paper, Scissors [9]. In such games, however, the plays do not build off one another, and the players do not manipulate a central object, making the application of superposition and other quantum principles more difficult. The current work is centered around the penny flip game, its quantum representation first devised by Meyer, and the advantage a quantum player enjoys. First, the classical description of the game will be given. Then, an introduction to quantum principles and some quantum formalism will be presented, followed by details regarding the quantum representation of the penny flip game. At that point, Meyer's findings will be critically discussed and followed by an analysis of the limitations of quantum advantage.

The Classical Penny Flip

The classical penny flip game involves two players, which we will call C and Q for later convenience. There is a penny between the two players, whose initial state is heads, which is known to both participants. The penny, however, is then hidden from both players in a box. Both players have access to the following strategies: Flip the penny so that the other side is facing up (F) or don't flip the penny (N). After the penny is placed in the box, one game includes three moves, including an opening move from Q, a move from C, and a closing move from Q. After these three moves, the penny is revealed. If the final state of the penny is heads-up, then Q wins. Otherwise, C wins. With the details of the game set forth, we now turn to an explanation of essential quantum principles and concepts.

The Quantum Penny Flip

In classical descriptions, any state may be represented as a collection of bits. For our penny, the states Heads ($|H\rangle$) and Tails ($|T\rangle$) can be defined as follows, utilizing Dirac notation and matrix representations [10]:

$$|H\rangle = |0\rangle = \begin{bmatrix}1\\0\end{bmatrix}, \qquad |T\rangle = |1\rangle = \begin{bmatrix}0\\1\end{bmatrix}.$$

In quantum mechanics, however, each state is represented as a linear combination of basis states. Generally, a complex two-dimensional vector space with orthonormal basis vectors $|0\rangle$ and $|1\rangle$ is used within quantum computing. Our case is no different.

We can then represent our penny $|\Psi\rangle$ in this complex vector space as follows, where α and β are complex numbers:

$$|\Psi\rangle = \alpha|H\rangle + \beta|T\rangle.$$

With this description, use is made of superposition, where a probability ($|\alpha|^2$ or $|\beta|^2$) is associated with each basis state. For this reason, it must be the case that

$$|\alpha|^2 + |\beta|^2 = 1.$$

The system, however, exists between these two basis states until measured. Imagine our penny standing on its edge rather than being purely characterized as heads or tails.

In a classical setting, any state is manipulated with matrix multiplication. For example, the classical play of F is applied to $|H\rangle$ as a matrix operation, producing $|T\rangle$:

$$F|H\rangle = |T\rangle \quad \text{or} \quad \begin{bmatrix}0 & 1\\1 & 0\end{bmatrix}\begin{bmatrix}1\\0\end{bmatrix} = \begin{bmatrix}0\\1\end{bmatrix}.$$

The other available classical play N is given by the identity matrix and does not alter the state of the penny:

$$N|H\rangle = |H\rangle \quad \text{or} \quad \begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}\begin{bmatrix}1\\0\end{bmatrix} = \begin{bmatrix}1\\0\end{bmatrix}.$$

In a quantum setting, similarly, operators must take a physical state as an input and then produce a physical state as an output. In other words, the magnitude of a vector in the complex vector space cannot be compromised by any application of an operator. As such, any operator must be unitary, meaning that its inverse must be equal to its conjugate transpose. A quantum play could then be given by a Hadamard matrix, an intrinsically quantum matrix that produces superposition in a system. Such matrices have rows that are mutually orthogonal, have entries limited to ±1, and may be devised with the Paley construction [11]:

$$U_H = \frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}.$$

It is important to note that players limited to classical strategies may select only one of two plays (F or N), both of which are inherently unitary, whereas a quantum player has access to unlimited plays, given that their matrix equivalent is unitary.

Meyer showed that the application of the above quantum strategy (U_H) renders victory for our quantum player regardless of the play that is made by our classical player [7]. This is because the Hadamard operator, when applied as the opening and closing moves of the penny flip game, ultimately eliminates the action of the classical player.

This is shown as follows:

$$U_H \, F \, U_H \, |H\rangle = |H\rangle,$$

$$U_H \, N \, U_H \, |H\rangle = \; |H\rangle.$$

Such a result from Meyer, it seems, is a mighty display of the advantages of quantum information exchange over its classical counterpart. However, could one more appropriately attribute the advantage not to quantum strategies but to the arbitrary construction of the penny flip game? After all, the quantum player is given two turns, including the opening and closing plays, while the classical player is given only one. Such is the central question of this work.

Verification of Quantum Advantage

To verify that the advantage of our quantum player is actually derived from quantum strategies, the construction of the penny flip game was altered and ideal quantum strategies identified. The probability of quantum victory was then assessed to determine whether quantum advantage was preserved despite added biases in favor of our classical player. These biases included the alteration of the initial state of the penny as well as the number of moves granted to each player.

Initial State of Tails

Firstly, the initial state of the penny was altered to begin as $|T\rangle$ rather than $|H\rangle$, seemingly giving the classical player a subtle advantage that the quantum player once enjoyed. An ideal quantum strategy in response to this was identified with ease:

$$U_{Q1} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix}.$$

When applied, this strategy guarantees quantum victory as before, strengthening the assumption that the advantage of our quantum player is derived primarily from the use of quantum strategies:

$$U_{Q1}\, F\, U_{Q1}\, |T\rangle = |H\rangle,$$

$$U_{Q1}\, N\, U_{Q1}\, |T\rangle = |H\rangle.$$

Two for Classical, One for Quantum

The game was then further biased against our quantum player. Specifically, the classical player was granted the opening and closing plays, leaving our quantum player with only one move. In this case, however, the beginning state of the penny was $|H\rangle$ once again. Within this game construction, two scenarios were investigated: one in which there was a 50% chance of the classical player flipping the penny during each of their turns and one in which the classical plays were correlated. We begin by considering the former.

Uncorrelated Classical Plays

To model this situation and produce a strategy for our quantum player, Qiskit was utilized to create quantum circuits and interact with IBM quantum computers and simulators [12]. As shown in Figure 1, the quantum circuit included one qubit—the quantum equivalent of a bit—to function as the penny. Three operators or gates were also included to function as each play in the game. The gate below labeled as "Unitary" on the line associated with the Penny qubit signifies the quantum play.

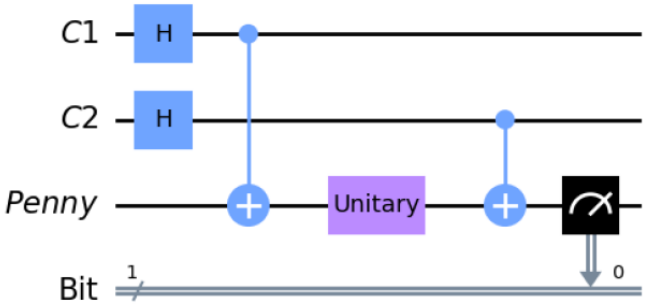

Figure 1: Quantum circuit for uncorrelated classical plays.

The two blue "+" operators, also known as controlled-not or CNOT operators, function as the classical moves. At the very end of the circuit, the penny is measured, indicated by the black measurement icon, while its final state is stored in a classical bit on the bottom line, indicating the game's victor. Also, notice the other two qubits C1 and C2 included above the Penny qubit. These qubits function as random number generators to approximate the behavior of a classical player that chooses randomly between the F and N plays. Using Hadamard operators, indicated by the blue "H" icons, both C1 and C2 are placed in a superposition of both $|0\rangle$ and $|1\rangle$. They are then individually measured using the CNOT gates, possessing a 50% of being $|0\rangle$. Based on the outcome of each measurement, the penny is either flipped or not affected.

For this scenario, the circuit was run 100 times with a unique and randomly produced quantum play. With the intent of identifying the quantum operator that produced the greatest likelihood of quantum success, results for each quantum operator were compared. For each of the one hundred operators, however, the simulator produced the results illustrated in Figure 2:

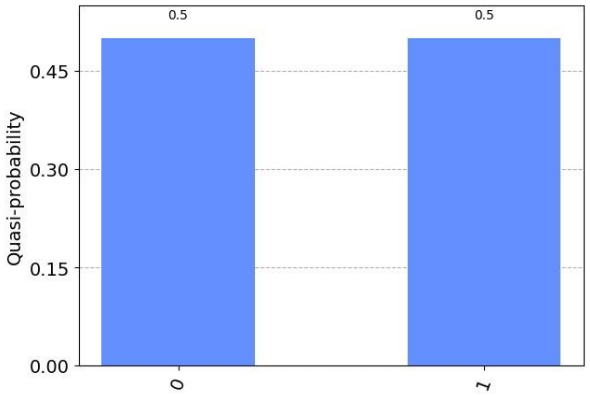

Figure 2: Uncorrelated classical plays.

The leftmost column relates to the $|0\rangle$ or $|H\rangle$ state and the other to the $|1\rangle$ or $|T\rangle$ state. The magnitude of each column reflects the probability that each state is found to be the final state of the penny. Clearly, the likelihood of quantum victory is 50%, regardless of the quantum operator utilized. This makes sense. The best the quantum player can do is put the penny into a superposition of $|H\rangle$ and $|T\rangle$, making the probability of each state 50%. Had they been given the last play, they could also pull the penny out of the superposition into the $|H\rangle$ state as

before. Hence, in this case, any quantum operator produces the maximum chance of quantum victory, which is 50%. With this result, it appears that the advantage of two plays outweighs the advantage provided by quantum strategies.

Correlated Classical Plays

We now consider the case in which the classical plays are correlated. Now, correlated plays may be identical to one another or the opposite of each other. Of these two, we first consider the case in which the classical plays are the same. Hence, the classical plays are either both F or both N. Removing the C2 qubit and having C1 act as the control qubit for both CNOT gates allows us to represent the scenario in which the plays of the classical player are identical. The resulting quantum circuit is given as follows:

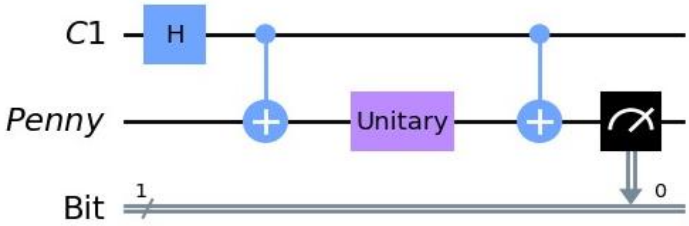

Figure 3: Quantum circuit for correlated classical identical plays.

Once again, the circuit was run 100 times on an IBM quantum simulator, with a randomly produced unitary operator acting as the quantum play. Then, the operator producing the greatest chance of quantum victory was recorded. It was found that a quantum strategy does exist that guarantees quantum victory in the case in which the plays made by the classical player are identical. The ideal strategy is given as follows:

$$U_{Q2} = \begin{bmatrix} -0.59021396 + 0.80351867i & -0.02145772 - 0.07446331i \\ 0.05446345 - 0.05512667i & -0.13393704 - 0.98795529i \end{bmatrix}.$$

For verification, this operator was inserted as the “Unitary” gate on the quantum circuit of Figure 3 and run another hundred times. For each iteration, a 99% chance of quantum victory was discovered.

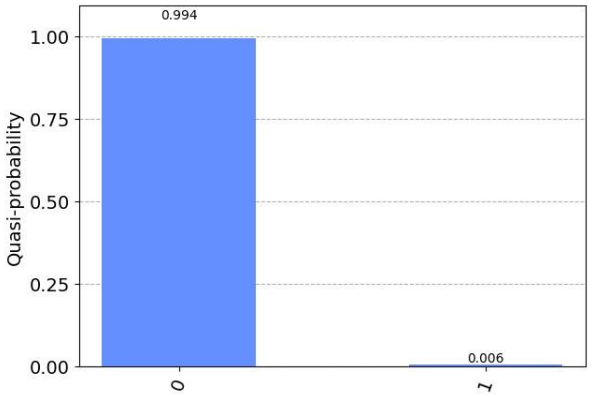

Figure 4: Correlated classical identical plays.

In the other case of correlated classical plays, the opening and closing moves are dissimilar. The quantum circuit was only slightly modified to discover an ideal quantum operator. Specifically, an X-gate was added to the C1 qubit path between the two CNOT gates. This guarantees that the opening and closing classical plays are opposites.

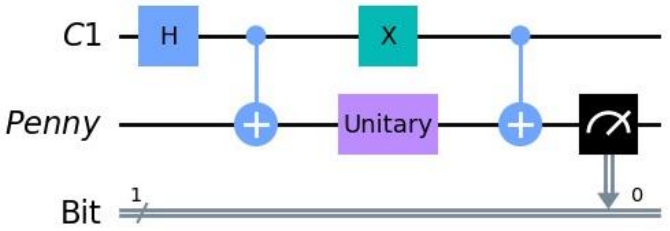

Figure 5: Quantum circuit for correlated classical plays – opposite.

Again, the circuit was run one hundred times with a unique and random quantum operator. From the one hundred histograms produced, an ideal quantum operator was identified:

$$U_{Q3} = \begin{bmatrix} -0.18287237 - 0.00699522349i & -0.38743878 + 0.903548534i \\ 0.35143341 + 0.918152122i & -0.18300595 - 0.000236252265i \end{bmatrix}.$$

This ideal operator was then plugged directly into the circuit of Figure 5 and run another 100 times. The verified histogram, showing a 96.7% chance of quantum victory, was produced as shown in Figure 6.

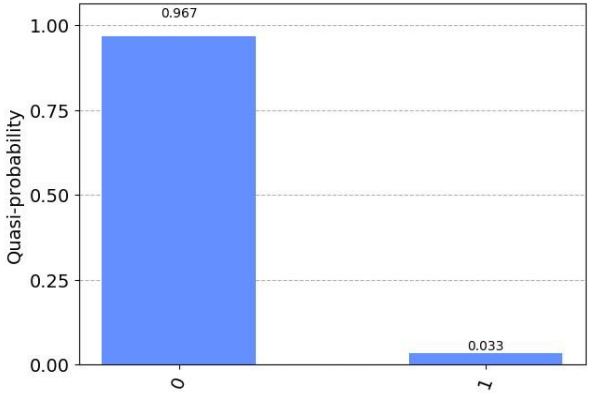

Figure 6: Correlated classical opposite plays.

So, in the case in which the classical player has both the opening and closing moves, the quantum player has a probability of victory of 50%–100%, ultimately depending on whether the classical moves are correlated. It should be noted, however, that in the case of correlated classical plays, a quantum player may only increase their chance of victory to nearly 100% if they know which of the two ideal operators to employ. That is, they must have some valid prediction as to the behavior or strategy of the classical player. Guessing randomly between the two strategies found above in the case of correlated classical plays, the quantum player has only a 50% chance of victory.

Generalization of Results

It is possible to generalize the above findings to other variations of the penny flip game. To that end, we first expand the penny flip game to an arbitrary number of moves.

Multi-Play Games

We divide all possible games into those of an odd number of plays and those with an even number of plays. The plays alternate between players Q and C as before.

Odd-Play Games	Chance of QV	Even-Play Games	Chance of QV
$U_Q U_C U_Q \|H\rangle = \|H\rangle$	100%	$U_Q U_C \|H\rangle = \|H\rangle$	50%
$U_C U_Q U_C \|H\rangle = \|H\rangle$	50%	$U_C U_Q \|H\rangle = \|H\rangle$	50%
$U_Q U_C U_Q U_C U_Q \|H\rangle = \|H\rangle$	100%	$U_Q U_C U_Q U_C \|H\rangle = \|H\rangle$	50%
$U_C U_Q U_C U_Q U_C \|H\rangle = \|H\rangle$	50%	$U_C U_Q U_C U_Q \|H\rangle = \|H\rangle$	50%
⋮		⋮	

Figure 7: Multi-play games. QV=quantum victory.

As seen in Figure 7, the likelihood of quantum victory depends heavily on the number of moves within the game. It is a known fact that the product of any two unitary matrices is another unitary matrix. Hence, in an odd-play game, all moves between the opening and closing quantum moves can be collapsed into a single unitary operator. This yields the three-play game in which an ideal strategy has already been found. Within games of an even number of plays, the quantum player may only guarantee a 50% chance of victory, regardless of whether they possess the opening or closing move. Once again, the quantum player cannot place the penny in a superposition of $|H\rangle$ and $|T\rangle$ and still pull it back into the heads state without interference from the classical player. Therefore, within the penny flip game of an arbitrary number of moves, the quantum player has a 50%–100% chance of victory.

Multi-sided Pennies

We now consider games of three plays involving an abstract penny of an arbitrary number of sides. Specifically, we discuss a four-sided penny but later show how the results may be generalized. Our penny then becomes a quantum state involving four basis states that we will associate with color for simplicity: Red ($|R\rangle$), Yellow ($|Y\rangle$), Green ($|G\rangle$), and Blue ($|B\rangle$). Our penny is then shown as follows:

$$|\Psi\rangle = \alpha|R\rangle + \beta|Y\rangle + \gamma|G\rangle + \delta|B\rangle,$$

where

$$|\alpha|^2 + |\beta|^2 + |\gamma|^2 + |\delta|^2 = 1.$$

In a game such as this, the classical play of flipping may be equated with altering the color of the penny. The classical player may convert the color from red to yellow, for example. These classical moves are easily defined in a matrix in which the transpose of the target state is placed in the same row as the "1" that appears in the state that is being

manipulated. Similarly, the transpose of the state that is being manipulated is placed in the same row as the "1" that appears in the target state. The remaining rows are filled out such that "1" occurs only once in each row and column. Operators defined this way satisfy the requirements of unitary matrices. For example, define $|R\rangle$ and $|Y\rangle$ as follows:

$$|R\rangle = \begin{bmatrix}1\\0\\0\\0\end{bmatrix}, \qquad |Y\rangle = \begin{bmatrix}0\\1\\0\\0\end{bmatrix}.$$

The classical operator to convert $|R\rangle$ to $|Y\rangle$ is easily produced, following the guidelines above.

$$\begin{bmatrix}0&1&0&0\\1&0&0&0\\0&0&0&1\\0&0&1&0\end{bmatrix}\begin{bmatrix}1\\0\\0\\0\end{bmatrix} = \begin{bmatrix}0\\1\\0\\0\end{bmatrix}$$

If we are to follow the strategies already discussed above, then supplying a Hadamard matrix as our quantum strategy will guarantee victory in a three-play game. We find this to be exactly the case. In four dimensions, the Hadamard is constructed and applied as follows, placing our penny into a superposition of $|R\rangle$, $|Y\rangle$, $|G\rangle$ and $|B\rangle$:

$$\frac{1}{\sqrt{4}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&1&-1&-1\\1&-1&-1&1\end{bmatrix}\begin{bmatrix}1\\0\\0\\0\end{bmatrix} = \begin{bmatrix}1\\1\\1\\1\end{bmatrix}$$

With this strategy, given the opening and closing moves of a three-play game, our quantum player is able to nullify any move made by the classical player, making them victorious 100% of the time. It follows that our quantum player may guarantee victory when there exists a Hadamard operator in the dimension that matches the number of basis states that describe our penny. It is a known fact that there exists an N*N Hadamard matrix, where N = 1, 2, or 4k, for $k \in \mathbb{Z}$ [12]. Hence, victory is guaranteed for our quantum player in any game involving an N-sided penny.

Conclusions

The advantage enjoyed by the quantum player in Meyer's penny flip game is generally authentic, being derived from quantum principles rather than the arbitrary construction of the penny flip game. When the penny begins in state $|T\rangle$, the desired final state for our classical player, there exists a quantum operator that guarantees quantum victory. When

the classical player is given two plays, there exist operators that provide a 50%–100% chance of victory for our quantum player, depending on the assumption made by the quantum player as to the correlation of the classical plays. This is far greater than the 0%–50% chance of victory that the classical player possesses when the quantum player is given the same two-play advantage.

Quantum victory is also guaranteed in modified games of an odd number of plays in which the quantum player is given both the opening and closing plays. The same guarantee of quantum victory persists in games involving an abstract penny with N basis states, where N = 1, 2, or 4k, for $k \in \mathbb{Z}$.

Hence, quantum representations of competitive exchanges of information provide strategies that are generally superior to their classical counterparts, not only for Meyer's penny flip, but also for its more general variations. Shor's algorithm [6], Grover's algorithm [7], and others have already provided examples of the superiority of quantum computation over classical information exchange. Yes, quantum mechanics serves well to find the prime factorization of large integers and search through unsorted databases. However, we may now also say that quantum mechanics provides superior strategies for specific scenarios in game theory, bringing us one step closer to the application of these strategies to competitive environments wherein game theory is already applied, including the stock market, the campaign trail, and even the battlefield.

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References

1. J.V. Neumann, "Zur theorie der gesellschaftsspiele," Math Ann, 100(1), 295–320 (1928). doi: 10.1007/bf01448847

2. L. Samuelson, “Game theory in economics and beyond,” Vopr Ekon, (5), 89–115 (2017). doi: 10.32609/0042-8736-2017-5-89-115

3. N. McCarty, & A. Meirowitz, “Political game theory: An introduction,” Cambridge University Press (2014).

4. E. Ho, A. Rajagopalan, A. Skvortsov, S. Arulampalam, & M. Piraveenan, “Game theory in defence applications: A review,” Sensors, *22*(3), 1032 (2022). doi: 10.3390/s22031032

5. P.W. Shor, “Polynomial-time algorithms for prime factorization and discrete logarithms on a quantum computer,” SIAM J Comput, *26*(5), 1484–1509 (1997). doi: 10.1137/s0097539795293172

6. LK. Grover, “A fast quantum mechanical algorithm for database search,” Proceedings, 28th Annual ACM Symposium on the Theory of Computing (STOC), 212-219, (1996). doi: 10.48550/arXiv. quant-ph/960504.

7. D.A. Meyer, “Quantum strategies,” Phys Rev Lett, 82(5), 1052–1055 (1999). doi: 10.1103/physrevlett.82.1052

8. J. Eisert, M. Wilkens, & M. Lewenstein, “Quantum games and quantum strategies,” Phys Rev Lett, 83(15), 3077–3080 (1999). doi: 10.1103/physrevlett.83.3077

9. K. Becker, “Quantum rock paper scissors,” (2023). Retrieved April 15, 2024, from https://gist. github.com/primaryobjects/f58e5528e3b183b6bfcb8d7a9dc34934.

10. P.A.M. Dirac, “A new notation for quantum mechanics,” *Math Proc Camb Philos Soc, 35*(3), 416–418 (1939). doi: 10.1017/s0305004100021162

11. R.E.A.C. Paley, “On orthogonal matrices,” J Math Phys, 12(1-4), 311–320 (1933). doi: 10.1002/sapm1933121311

12. IBM, “IBM quantum documentation,” Retrieved August 15, 2023, from https://docs.quantum. ibm.com/

The Impact of Winter Deicing Materials on Water Quality in Weber County, Utah

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Abstract

In winter 2022-23, the Utah Department of Natural Resources reported that the state measured a record-breaking 30 inches of snow water equivalent, which is 216% of the average. As a result, the Utah Department of Transportation used more than 370,000 gallons of deicing material were used on Utah roads to improve transportation safety. In this study, we investigated whether deicing materials applied to roadways impact the water quality of Ogden Valley and Ogden Canyon in Northern Utah. The primary water source for Ogden is Pineview Reservoir, which is located in the less-populated Ogden Valley. We collected in-situ measurements and water samples from the South Fork and Middle Fork of the Ogden River that flow into Pineview Reservoir and along a transect of the Ogden River, which flows out of the Pineview Reservoir through the heavily trafficked Ogden Canyon to assess the impact of deicing materials on water quality between October 2022 and September 2023. Water samples were analyzed on an inductively coupled plasma mass spectrometer (ICP-MS) for sodium,

magnesium, calcium, potassium (major components of deicing materials), and additional trace elements. All elements met the U.S. Environmental Protection Agency drinking standard limits, but their levels were two to three times higher in the Ogden River in Fall 2022 and Spring 2023 compared with Pineview Reservoir and its inflow streams. This suggests that the deicing material impacts water quality. The concentrations of deicing materials decreased in Fall 2023, which we suggest is due to a substantial input of water to the watershed due to spring snowmelt and is supported by water discharge recorded at the Ogden River U.S. Geological Survey Gauge Site. We propose that extreme snowfall plays an important role in flushing the watershed of contaminants and improving water quality. As climate changes and if snowfall in Northern Utah is reduced as projected, this could result in deteriorating water quality in the region.

Introduction

In the winter of 2022-2023, Utah experienced record-breaking snowfall; recording around 216% of the average amount. This is the highest amount of snow water equivalent (SWE) since measurements began in the 1920s (Utah Department of Natural Resources, 2023). The Weber/Ogden River Basin recorded 50 inches of SWE, which is 30% more than the 30-year average (Utah Division of Water Resources, 2024). In the winter, deicing materials in the form of road salt and brine are regularly applied to the roads to keep ice from forming, which improves on-road safety for drivers. The material is composed of 90%-98% sodium chloride (NaCl), 0.30%-1.40% calcium chloride (CaCl), 0.20%-0.40% potassium chloride (KCl), and 0.06%-0.20% magnesium chloride (MgCl) (Redmond Incorporated, 2015). During the record-breaking winter in 2022-2023, over 370,000 gallons of deicing material were applied to Utah roadways in a single season (Utah Department of Transportation, 2023). With a large amount of material applied to the roadways, it is inevitable that the deicing materials (which include sodium, chloride, magnesium, potassium, and calcium) enter the watershed and surrounding ecosystem. Increased concentrations of these elements are a concern because they can impact drinking water quality, ecosystem health, and have corrosive effects on cars, bridges, and other man-made structures (Jackson and Jobbagy, 2005; Ramakrishna and Viraraghavan, 2005; Kelly et al., 2008).

Studies investigating the impact of deicing materials have been conducted in the northeastern United States, but studies focused on the semi-arid Western United States, and specifically Utah, are less

extensive and needed. In Maryland, New York, and New Hampshire, chloride concentrations were measured in streams during the winter and summer as a method for assessing the impact deicing materials had on stream water quality. Kaushal et al. (2005) found that chloride levels in rural watersheds had strong increases in the baseline concentration of chloride over the last 30 years with chloride concentrations as high as 25% of the concentration of seawater in the winter. They also observed that the chloride levels in urban and suburban streams were 100 times greater than in forest streams that were not directly impacted by the application of deicing materials. This suggests that the application of deicing materials is impacting water quality in the region and that additional chloride remains in the watershed after each winter season (Kaushal et al., 2005). Kelly et al. (2008) also found that sodium and chloride concentrations and exports increased over a 19-year period in a rural stream in New York. Using a mass balance model that integrated chloride dynamics, they concluded that 91% of the increase of sodium chloride to the watershed came from deicing materials applied to the roadways. This implied that water salinization in this region was largely due to the input of deicing material (Kelly et al., 2008).

The application of deicing materials to roadways also has important implications for soil, ecosystem health, and the economy. As the salinity increases, the water becomes less effective for domestic use as well as use for agriculture (Williams, 2001; Davis et al., 2003). This can negatively impact the economy because the agriculture industry will struggle with potable water shortages in an already drought prone regions. From an ecosystem health perspective, microbiota that are not halotolerant (salt tolerant) will be replaced by halotolerant microbiota and overall biodiversity will decrease as rivers, streams, and wetlands become more saline (Williams, 2001; Davis et al., 2003). Additionally, sodium can exchange with the calcium and magnesium in soils which will break down the soil structure and mobilize organic matter and increase stream turbidity (Oberts et al., 2000). Utah is especially susceptible to salinization of water and soil because of its semi-arid, drought-prone climate and extensive agricultural land use.

In this study, we investigated the impact that the application of deicing material had on water quality in Weber County, Utah, from October 2022 through September 2023. In Weber County, our study sites are located in the more rural Ogden Valley and more trafficked Ogden Canyon area. The Pineview Reservoir in the more rural Ogden Valley is the primary water source for Ogden City. The water in Pineview Reservoir comes from the North, Middle, and South Forks of the Ogden River, and water is released through the Ogden River to the east and flows through Ogden Canyon. In Ogden Canyon, Ogden Canyon Road

(SR-39) follows the river and is one of the three roads that provide access to Ogden Valley and local ski resorts. Therefore, SR-39 is heavily trafficked throughout the year and well maintained in the winter. This gave us the opportunity to examine the impact of deicing materials in the region by comparing more rural sites in Ogden Valley (Middle and South Fork Rivers and Pineview Reservoir) with more developed and maintained areas in Ogden Canyon (Ogden River). We hypothesized that concentrations of major deicing cations and conductivity would be elevated in the Ogden River if deicing materials were impacting water quality.

Methods

Study Sites and Field Sampling

To investigate the impact of deicing material on the watershed, we made in-situ measurements and collected water samples from the South Fork and Middle Fork of the Ogden River, which input water into the Pineview Reservoir from the southeast and northeast, respectively (Figure 1). The North Fork of the Ogden River also inputs water to the Pineview Reservoir, but it was dry when sampling began in October 2022, and thus data from this location are not included in the study. The sampling location of the South Fork of the Ogden River in October 2022 was dry in October 2023, and therefore sampling took place at a location closer to Pineview Reservoir in October 2023 (Figure 1). The input

Figure 1. A map of sites in the Ogden Valley and Ogden Canyon where water samples and measurements were collected.

streams to Pineview Reservoir are all located in the more rural Ogden Valley, which is less populated and not as extensively managed for transportation in the winter by the Utah Department of Transportation (UDOT). We also sampled the Pineview Reservoir itself and the Ogden River, which outflows from Pineview Reservoir. In October 2022, we sampled at a single location in the Ogden River (OR 2), and in February and September 2023, we sampled a transect of the Ogden River along Ogden Canyon (5 sites) (Figure 1). Our goal of choosing these study sites was to identify what material was input to Pineview Reservoir, what was in Pineview Reservoir itself, and what was output from Pineview Reservoir through the Ogden River. This allowed us to establish baseline concentrations and assess how the application of road salt and brine along SR-39 influenced water quality in the Ogden River.

Direct measurements were collected in the field at each location. In October 2022 and February 2023, temperature and conductivity were measured using an InSitu Multiparameter TROLL 9500. In September 2023, we used an InSitu AquaTROLL 600 Multiparameter Sonde measured temperature, conductivity, dissolved oxygen, redox/oxidative potential, and turbidity at each site. Both InSitu Multiparameter sondes were calibrated in the laboratory according to instrument standards before use in the field.

Water samples were also collected at each site. Water samples were filtered in the field in October 2022 and September 2023 using a 20- or 60-mL sterilized syringe and a 0.2-µm filter. Samples collected along the Ogden River transect in February 2023 were filtered in the laboratory with a 20-mL sterilized syringe and 0.2-µm filter immediately after collection because of inclement weather conditions. The water samples were filtered into 125-mL acid-washed (5% nitric acid, HNO_3) containers and acidified with HNO_3 to 2% by volume in the laboratory directly after collection. Samples were acidified to keep the analytes of interest in solution. The acidified water samples were refrigerated at 4°C until sample analysis, which occurred within 1 month of collection.

Sample Analysis

Samples were analyzed on an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) at Weber State University using SPEX CertiPrep standards that were prepared through serial dilution. The elements analyzed were Na, Mg, Ca, K, Be, La, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Sr, Mo, Ag, Cd, Sb, Ba, Hg, Pb, Tl, Th, and U. In this study, we focus on the elements that are major components of deicing rock salt and brine, which include Na, Mg, Ca, and K. The data presented here were analyzed on an ICP-MS, but we also analyzed all samples

using inductively coupled plasma optical emission spectroscopy (ICP-OES) at Weber State University to validate the measurements. The ICP-OES measurements verified the ICP-MS results within an error of 1 ppm.

Results

Conductivity

In-situ measurements of conductivity were taken at each site during field sampling. Measurements in October 2022 indicated that conductivity was 272.3 µS/cm and 183.8 µS/cm in the inflow streams to Pineview Reservoir (South Fork and Middle Fork), respectively. The conductivity at Pineview Reservoir was also lower with a value of 327.1 µS/cm. Conductivity was higher in the Ogden River, with a value of 399.1 µS/cm (Figure 2)

In February 2023, conductivity at Pineview Reservoir was lower than in October 2022, with a value of 203.9 µS/cm (Figure 2). We hypothesize that this could be due to Pineview Reservoir being frozen over. This meant we had to drill through the ice using an auger to make measurements and collect samples. Conductivity at the Ogden River sites was high with values ranging from 289.7 µS/cm to 321.3µS/cm.

In September 2023, conductivity measurements at the inflow streams and Pineview Reservoir were low: South Fork conductivity was 216.6 µS/cm, Middle Fork conductivity was 169.5 µS/cm, and Pineview Reservoir conductivity was 236.1 µS/cm. Conductivity at the Ogden River sites was also low, with values ranging between 193.0 µS/cm and 221.0 µS/cm (Figure 2).

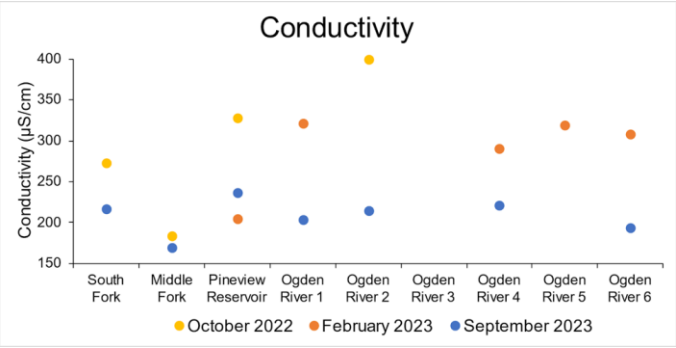


Figure 2. Conductivity measurements taken at each site using an In-Situ Multiparameter Troll. October 2022 data are represented by yellow circles, February 2023 data by orange circles, and September 2023 data by blue circles.

Sodium

Water samples were collected during each field sampling expedition and were analyzed on the ICP-MS for major cations present in deicing materials. Sodium measurements from October 2022 indicate that sodium was low in the inflow streams, with values of 8.23 ppm at South Fork and 11.11 ppm at Middle Fork (Figure 3). The Pineview Reservoir sodium level was slightly higher than in the inflow streams but still relatively low at 12.28 ppm. The concentration of sodium was higher in the Ogden River, with a value of 18.73 ppm.

In February 2023, samples were collected from Pineview Reservoir and along the transect of the Ogden River (Figure 3). At Pineview Reservoir, sodium concentration was similar to that in October 2022, with a value of 12.75 ppm. The sodium concentrations were higher in the Ogden River, with values ranging between 19.01 ppm and 19.77 ppm.

During September 2023, sodium concentrations were similar to the measurements made in October 2022 in the inflow streams, with South Fork at 8.46 ppm and Middle Fork at 10.40 ppm (Figure 3). In Pineview Reservoir, sodium concentrations were low, with a value of 8.25 ppm. Likewise, sodium concentrations in the Ogden River were low, with values ranging from 7.85 ppm to 9.03 ppm. This differed from measurements during October 2022 and February 2023, which indicated higher sodium concentrations. The sodium concentrations show a similar pattern to the conductivity measurements, validating the data.

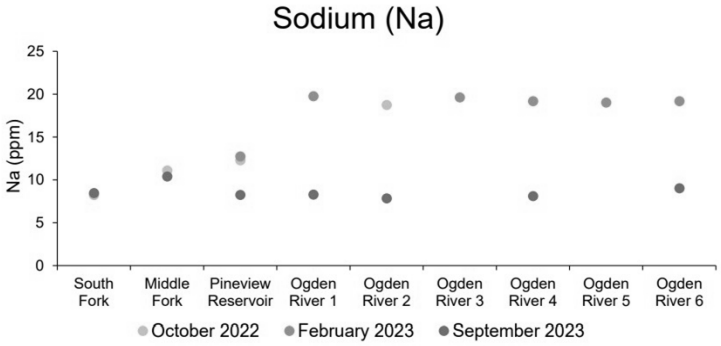


Figure 3. Sodium concentrations analyzed on ICP-MS. October 2022 data are represented by yellow circles, February 2023 data by orange circles, and September 2023 data by blue circles.

Magnesium

Magnesium concentrations in October 2022 were high at South Fork, with a concentration of 18.70 ppm (Figure 4). We attribute this to the local geology in the area, which is dominated by dolomite and therefore rich in magnesium and calcium. In Middle Fork and Pineview Reservoir, magnesium concentrations were low, with values of 5.48 ppm and 12.28 ppm, respectively. Magnesium concentrations were higher in the Ogden River at 16.19 ppm.

In February 2023, magnesium concentrations were low in Pineview Reservoir, with a value of 12.77 ppm, similar to the October 2022 concentration (Figure 4). Concentrations in the Ogden River were higher, with values ranging from 15.96 ppm to 17.64 ppm.

In February 2023, magnesium concentrations at South Fork were high, similar to the October 2022 values, with a concentration of 16.86 ppm. Magnesium concentrations were low in Middle Fork and Pineview Reservoir with values of 5.10 ppm and 7.99 ppm, respectively. Magnesium concentrations in the Ogden River remained low with values ranging from 7.81 ppm to 9.70 (Figure 4).

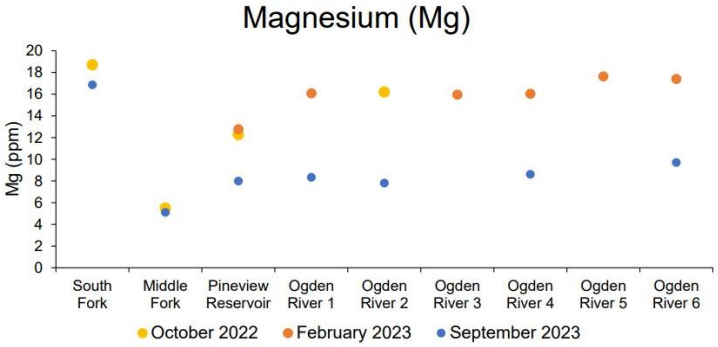


Figure 4. Magnesium concentrations analyzed on ICP-MS. October 2022 data are represented by yellow circles, February 2023 data by orange circles, and September 2023 data by blue circles.

Calcium

In October 2022, calcium concentrations were elevated at South Fork, with a value of 32.16 ppm, which we attribute to the dolomite found in the area around the South Fork watershed. Calcium concentrations were lower at Middle Fork and Pineview Reservoir, with values of 21.81 ppm and 31.83 ppm. Calcium was higher at the Ogden River, with a value of 37.30 ppm (Figure 5).

During February 2023, the calcium concentrations in Pineview Reservoir were 32.00 ppm, and the Ogden River had values ranging from 33.17 ppm to 36.92 ppm (Figure 5).

In September 2023, the concentrations at South Fork were high, with a value of 44.14 ppm. At Middle Fork and Pineview Reservoir, the concentrations were lower, with values of 20.91 ppm and 26.10 ppm, respectively. Along the Ogden River transect, the concentrations remained low, with values ranging from 24.50 ppm to 26.30 ppm (Figure 5). Overall, calcium concentrations followed a similar trend as sodium and magnesium, although the trend is less pronounced.

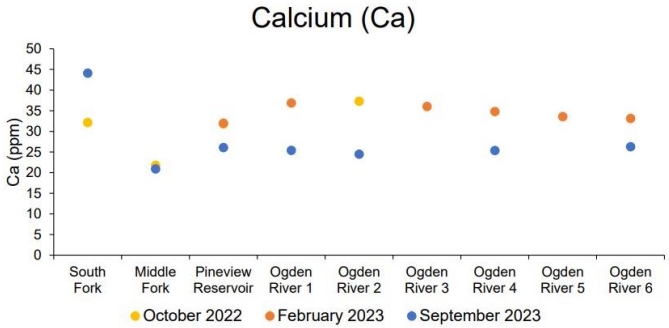


Figure 5. Calcium concentrations analyzed on ICP-MS. October 2022 data are represented by yellow circles, February 2023 data by orange circles, and September 2023 data by blue circles.

Potassium

Potassium was analyzed because it is also a component of deicing chemicals. Potassium concentrations followed similar trends to those seen with sodium, magnesium, and calcium. In the measurements from February 2023 the differences between the inflow rivers and Pineview Reservoir compared with Ogden River were not as pronounced as those seen with sodium and magnesium (Figure 6). This is attributed to potassium being a less abundant element in deicing materials used on Utah roads, suggesting it would have a less significant impact on water quality in the area.

During sampling in October 2022, potassium concentrations were low at South Fork and Middle Fork, with values of 1.09 ppm and 0.62 ppm, respectively. The potassium concentration at Pineview Reservoir was 1.53 ppm. The concentrations were higher at the Ogden River at 2.35 ppm (Figure 6).

In February 2023, the concentrations of potassium at Pineview Reservoir were similar to those from October 2022, with a value of 1.60 ppm. At the Ogden River, the concentrations were slightly higher, with values ranging from 1.79 ppm to 2.19 ppm (Figure 6).

In September 2023, the potassium concentration at South Fork was high, with a value of 3.20 ppm. The potassium concentrations at Middle Fork and Pineview Reservoir were similar when compared with October 2022, with concentrations of 0.78 ppm and 1.44 ppm, respectively. Potassium concentrations at the Ogden River transect in September 2023 were lower than at Pineview Reservoir, ranging from 1.29 ppm to 1.42 ppm (Figure 6).

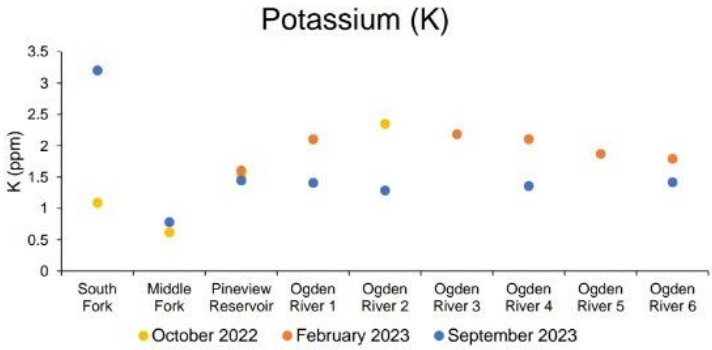


Figure 6. Calcium concentrations analyzed on ICP-MS. October 2022 data are represented by yellow circles, February 2023 data by orange circles, and September 2023 data by blue circles.

Discussion

A previous study measuring chloride levels as a proxy for deicing materials in rural streams in Maryland, New York, and New Hampshire came to the conclusion that deicing materials remained persistent and increased over time in the watersheds where they were applied (Kaushal et al, 2005). On the basis of those findings, we hypothesized that if deicing materials impact water quality, then concentrations of deicing materials (Na, Mg, Ca, K) should be elevated in the Ogden River, which is next to a heavily trafficked and well-maintained SR-39 in Ogden Canyon. Ogden Valley, where the inflow streams of South Fork and Middle Fork and Pineview Reservoir are located, is more rural and the roads are less maintained, thus we hypothesized concentrations of deicing materials should be lower at these sites. Our results indicate that sodium and magnesium, as well other deicing components calcium and

potassium to a somewhat lesser extent, were found in higher concentrations in the Ogden River when compared with South Fork, Middle Fork, and Pineview Reservoir in October 2022 and February 2023. This supports the hypothesis that deicing materials that have been applied to the road running along the Ogden River could be affecting the local water quality in the area and could increase the background concentrations in the streams during average snowfall years and in periods of drought.

In September 2023 after a record-breaking snow year, we expected the concentrations of sodium, magnesium, calcium, and potassium to be higher than in the previous years because of the increased application of deicing materials, which totaled around 370,000 gallons (UDOT, 2023). However, the data from September 2023 showed the that concentrations of sodium, magnesium, calcium, and potassium were not elevated in the Ogden River and were lower at all sites along the Ogden River transect when compared with Pineview Reservoir and its inflows, South Fork and Middle Fork. We suspect that because of a high streamflow from snowmelt throughout spring 2023, the deicing chemicals were flushed out or diluted from the system, returning it to a lower baseline salt concentration than in previous years.

The SWE in 2023 was 216% of average (Utah DNR, 2023), suggesting increased input of water to the Ogden River (Figure 7). In 2022, the SWE was similar to the median and three times less than in 2023 (Figure 7), when concentrations of sodium, magnesium, calcium, and potassium were higher.

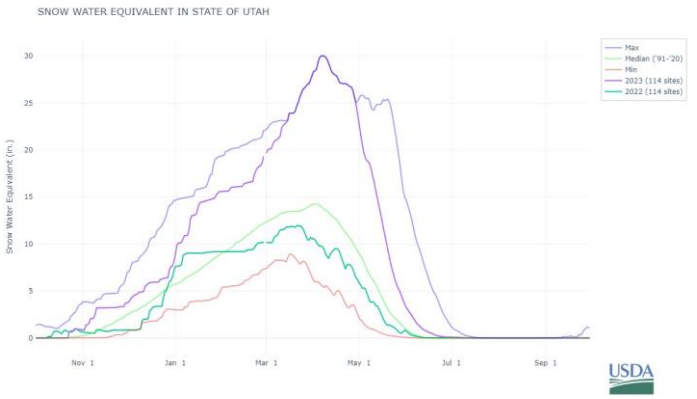
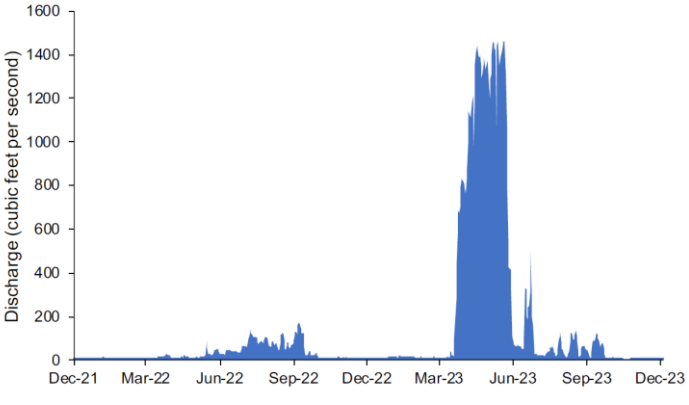


Figure 7. Snow water equivalent for the water years 2022 (dark green) and 2023 (purple). The median calculated from the water years 1991 to 2020 is shown in light green. The lowest SWE is shown in red, and the highest SWE is shown in light purple (United States Department of Agriculture, 2024).

We propose that the lower SWE does not provide enough water to fully flush the system of the deicing materials, which allows for accumulation of the major cations (Na, Mg, Ca, and K) in the watershed. To verify our hypothesis, we analyzed stream flow and discharge data from the United States Geological Survey (USGS) gauge site in Ogden River near Huntsville, Utah, where our sampling site, Ogden River 1 (OR 1), is located. The discharge data show that the highest flow in 2023 was 1,460 cf/s, whereas the highest flow in 2022 was 169 cf/s (Figure 8). This indicates that the discharge in 2023 was over eight times higher than in 2022, which supports our hypothesis that the lower concentrations of sodium, magnesium, calcium, and potassium in September 2023 were due to a flushing or dilution effect caused by the melting of the record-breaking snowpack.

Figure 8. Water discharge data, in cubic feet per second, from the United States Geological Survey (USGS) gauge site on Ogden Riv



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(USGS, 2023).

This study shows that the application of deicing materials on roads during winter months resulted in increased levels of sodium, magnesium, calcium, and potassium above background level, and the elevated concentrations remained persistent months after they were applied. This study also indicates that anomalous record-breaking snowpacks are vital to maintaining a healthy watershed because of the increased input of water to the system, which flushes out or dilutes these deicing materials and other pollutants. This is especially important in Northern Utah, which has a semi-arid climate that is prone to drought. This is a cause of concern as the climate in Northern Utah continues to warm because of

climate change. It is projected that at higher elevations of western mountain ranges, including the Rocky Mountain region and the Intermountain West, snowfall will be replaced by rainfall during previously strongly snow-dominated months such as November, March, and April (Klos et al., 2014). This will lead to substantial decreases in the snowpack in these areas in the future. Furthermore, SWE and SWE/P (a measure of how much snow persists through the winter season) are expected to decline by 40-70% depending on different carbon emission scenarios in the western U.S. (Pierce and Cayan, 2013). The lower estimate of 40% is projected if carbon emissions peak by 2040 and then decline (a moderate scenario), whereas the upper estimate of 70% is projected in a "business as usual" scenario. We suggest that if the winter snowpack and subsequent snowmelt decrease as predicted, watersheds in Utah will not experience the occasional flushing or dilution effect that is important for maintaining water quality and a healthy ecosystem. Northern Utah, therefore, could be at risk of accumulation of sodium, magnesium, calcium, potassium, and chloride from deicing materials in addition to heavy metals and contaminants from other sources, which will likely impact water quality and increase salinization of the soils.

Conclusions

This study monitored the concentrations of sodium, magnesium, calcium, and potassium and in-situ conductivity in the South and Middle Forks of the Ogden River, the Pineview Reservoir, and Ogden River Ogden Canyon in Weber County, Utah from October 2022 to September 2023 to assess whether deicing materials applied to roadways were impacting water quality. Data collected in October 2022 and February 2023 showed elevated concentrations of sodium, magnesium, calcium, potassium, and conductivity at Ogden River compared with the other sites, supporting our hypothesis that deicing materials applied to roadways influence water quality in heavily trafficked areas. This study captured the unique record-breaking snow year of 2022-23, which highlighted the importance of occasional above-average snowpacks. The record-breaking snowpack led to enormous spring snow melt, which is seen in the Ogden River discharge data collected at the USGS Gauge Site on the Ogden River near Huntsville. The melting of the 2022-23 snowpack flushed or diluted sodium, magnesium, calcium, and potassium (and likely heavy metals and other containments) from the Ogden River, improving water quality and returning the Ogden River to a new lower baseline concentration of these elements. In the semi-arid climate of Northern Utah, these events are important in helping maintain water quality. In the future as the climate continues to change, it is

projected that SWE and SWE/P will decline substantially, reducing the likelihood of these flushing events occurring in the future. On the basis of the results of this study, we suggest that reduced SWE and SWE/P could lead to deteriorating water quality and increased salinization of the watershed and soils in Northern Utah.

Acknowledgments

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References

Davis, J.A.; McGuire, M.; Halse, S.A.; et al. (2003). What happens when you add salt: predicting impacts of secondary salinization on shallow aquatic ecosystems by using an alternative-states model. Australian Journal of Botany, 51(6), 715-724. doi: 10.1071/BT02117

Jackson, R.B.; Jobbágy, E.G. (2005). From icy roads to salty streams. Proceedings of the National Academy of Sciences, 102(41), 14487–14488. doi: 10.1073/pnas.0507389102

Kaushal, S.S.; Groffman, P.M.; Likens, G.E.; et al. (2005). Increased salinization of fresh water in the northeastern United States. Proceedings of the National Academy of Sciences, 102(38), 13517-13520. doi: 10.1073/pnas.0506414102

Kelly, V.R.; Lovett, G.M.; Weathers, K.C.; et al. (2008). Long-term sodium chloride retention in a rural watershed: legacy effects of road salt on streamwater concentration. Environmental Science and Technology, 42(2), 410-415. doi: 10.1021/es071391ll

Klos, P.Z; Link, T.E.; Abatzoglou, J.T. (2014). Extent of the rain-snow transition zone in the western U.S. under historic and projected climate. Geophysical Research Letters, 41(13), 45604568. doi: 10.1002/2014GL060500

Oberts, G.; Marsalek, J.; Viklander, M. (2000). Review of water quality impacts of winter operation of urban drainage. Water Quality Research Journal, 35(4), 781–808. doi: 10.2166/wqrj.2000.042

Pierce, D.W.; Cayan, D.R. (2013). The uneven response of different snow measures to human-induced climate warming. Journal of Climate, 26(12), 41484167. doi: 10.1175/JCLI-D-12-00534.1

Ramakrishna, D.M.; Viraraghavan, T. (2005). Environmental impact of chemical deicer—A review. Water, Air, Soil Pollution, 166, 49–63. doi: 10.1007/s11270-005-8265-9

Redmond Incorporated. (2015). Ice Slicer Super Blend: Complex Chloride. Sodium chloride (7647-14-5), potassium chloride (7447-40-7), magnesium chloride (7791-18-6), calcium chloride (10043-52-4) [Online]. Retrieved February 14, 2024, from https://iceslicer.com/hubfs/Ice%20Slicer%20Images/Resources/Ice-Slicer-RS-GHS-SDS.pdf.

United States Department of Agriculture (USDA). (2024). Snow Water Equivalent in State of Utah. Retrieved April 23, 2024, from http://nwcc-apps.sc.egov.usda.gov/awdb/basinplots/POR/WTEQ/assocHUCut3/state_of_utah.html.

United States Geological Survey (USGS). (2023). Ogden River BL Pineview Res NR Huntsville, UT–10140100. Retrieved December 8, 2023, from https://waterdata.usgs.gov/monitoring-location/10140100.

Utah Department of Natural Resources. (2023). Utah Water Conditions Update. Retrieved April 23, 2024, from https://water.utah.gov/utah-water-conditions-update-4.

Utah Department of Transportation. (2023) Deicing Dashboard. Retrieved November 16, 2023, from https://www.udot.utah.gov/connect/about-us/technology-innovation/maintenance-facilitiesmanagement/deicing-dashboard/.

Utah Division of Water Resources. (2024). Precipitation Graphs. Retrieved April 23, 2024, from https://water.utah.gov/precipitationgraphs/.

Williams, W. (2001). Anthropogenic salinisation of inland waters. Hydrobiologia, 466, 329–337. doi: 10.1023/A:1014598509028.

Synthesis and Further Characterization of $[(Ir(ppy)_2)_2dpm]Cl_2$

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Abstract

This work investigates the synthesis and characterization of $[(Ir(ppy)_2)_2dpm]Cl_2$, a bimetallic Ir complex. Unlike previous studies, we have included cyclic voltammetry and UV-vis data to enhance understanding of the complex's electronic properties. This additional data is crucial for supporting future research.

Introduction

In recent decades, the use of fluorescent and phosphorescent complexes have increased, due to the development of organic light emitting devices (OLEDs) for televisions[1-4] as well as photochemical sensors for biological applications.[5-13] Many examples employ metals such as iridium (Ir^{III}),[14-16] rhodium (Rh^{III}),[17,18] and ruthenium (Ru^{II})[19-21] because of their fluorescent and phosphorescent properties.[22] Since the pioneering work of Serroni et al.[23] in 1994, research on fluorescent and phosphorescent Ir complexes involving cyclometallated 2-

phenylpyridine (ppy) ligands has expanded, encompassing many homonuclear bimetallic complexes.[24-33]

In 2007, Auffrant et al.[34] reported the synthesis of bimetallic Ir-ppy complexes with laterally connected N^N chelates (Figure 1a). Additionally, Mazzanti reported the use of a terpyridine derivative as a bridge between two $Ir(ppy)_2$ centers.[35] This was followed by the work of Yao et al.[36] in 2016, who synthesized enantiomerically pure binuclear Ir complexes such as $[(Ir(ppy)_2)_2dpm](PF_6)_2$ (**complex 1**) by using a chiral auxiliary ligands to explore enantioselectivity (Figure 1b). This research provided a foundation to explore the electronic properties of Ir centers by synthesizing derivatives with various electron-donating and -withdrawing substituents, but lacked key sets of data such as cyclic voltammetry and UV-Vis spectroscopy. As such, we envisioned the need to synthesize the same dipyrimidine complex 1 prior to the exploration of derivatives and obtain further data (Figure 1c).

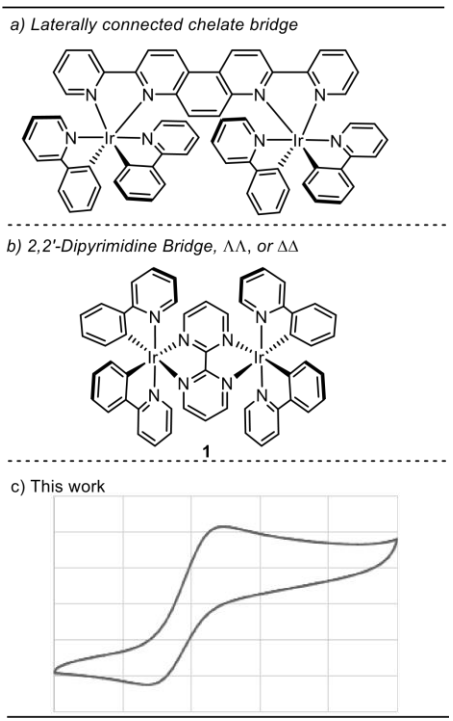
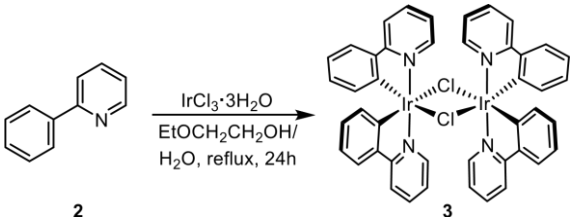


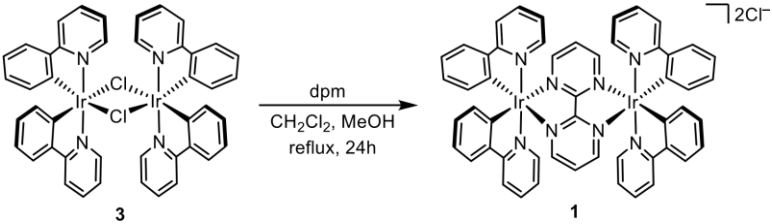
Figure 1. Literature precedent. (a) Laterally connected bimetallic complex reported by Auffrant at al.[34] (b) Ir complex described by Yao et al.[36] (complex 1) (c) Cyclic voltammetry of product 1.

Experimental Data and Results

Our synthesis of product 1 involved a two-step process. The first step followed a modified Nonoyama cyclometallation method reported by Sprouse et al. and others with 2-phenylpyridine (2, ppy) and Ir^{III} chloride to yield a bright yellow solid (Scheme 1).[37-40] Following the synthesis of product 3, the bridging chlorides were then substituted for 2,2'-dipyrimidine (dpm) to synthesize 1.



Scheme 1. First step toward the synthesis of 1, cyclometallation of ppy with Ir. Nanoyama cyclometallation method.



Scheme 2. Second step in the synthesis. Dipyrimidine (dpm) is introduced.

Following a modified procedure, a second experiment was performed using 2-2'-bipyrimidine (52 mg, .33 mmol, 2.0 equiv), $[Ir(ppy)_2Cl]_2$ (190 mg, 0.16 mmol, 1.0 equiv), 8.0 mL of dichloromethane, and 10 mL of methanol. These were mixed in a 50-mL round-bottom flask, and then a 24-h reflux was done under Ar gas. Once the reflux was completed, the solution was concentrated under vacuum. This crude product was then purified by silica gel chromatography (gradient elution, CH_2Cl_2 → 9:1 CH_2Cl_2:CH_3OH) to yield 0.182 g of product of a red/orange solid. Spectroscopic results are as follows: ^1H NMR (400 MHz, $CDCl_3$) δ 9.35 (dd, *J* = 4.8, 2.1 Hz, 2H), 8.28 (dd, *J* = 5.5, 2.0 Hz, 2H), 8.18 (t, *J* = 5.4 Hz, 2H), 7.98 (d, *J* = 8.1 Hz, 2H), 7.86 (td, *J* = 7.6, 1.5 Hz, 2H), 7.78 (d, *J* = 5.4 Hz, 2H), 7.72 (dd, *J* = 7.9, 1.1 Hz 2H), 7.20 (t, *J* = 6.5 Hz, 2H), 7.09 (t, *J* = 7.6 Hz, 2H), 6.96 (t, *J* = 7.3

Hz, 2H), 6.30 (d, *J* = 7.6 Hz, 2H). IR : 3335, 3041, 1606, 1570, 1476, 1403, 1267, 1031, 754, 727 cm^{-1} MS obtained on an Advion Expression CMS with APCI ionization source: Calculated: 579.1 m/z (M^{2+}–Cl2), 580.1 m/z. Observed: 579.6 m/z, 580.3 m/z.

Cyclic Voltammetry

Cyclic voltammetry was performed on a CHI630D in acetonitrile with 0.1 M tetrabutylammonium bromide and 5.0 mM concentration of racemic product 1. Scan rates ranging from 50 mV/s to 2000 mV/s were used. The working electrode was glassy carbon, the counter electrode was platinum wire, and the quasi-reference electrode was silver wire, with a true reference of ferrocene conducted at the end of the experiment. As the scan rate increased, the anodic peak became more apparent, with a peak difference of 200 mV. The appearance of the return peak with faster scan rates suggests that the Ir^{III}/Ir^{II} couple is quasi reversible as shown in Figure 2.

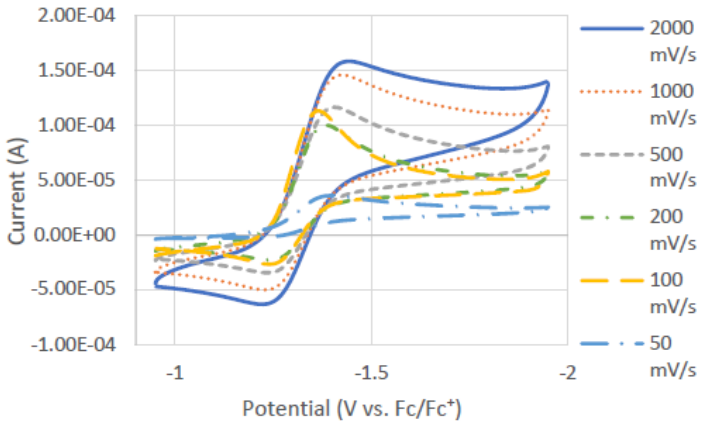


Figure 2. Cyclic voltammetry of complex 1 referenced to ferrocene.

Uv-Vis and Fluorescence Spectroscopy

UV-Vis was performed on an Agilent Cary 3500 UV-Vis in CH_2Cl_2 in a quartz cuvet. A peak was observed at ~375 nm wavelength (Figure 3, top) , and then fluorescence was measured with an excitation wavelength of 360 nm (Figure 3, bottom). These results matched those reported by Yao et al.[36]

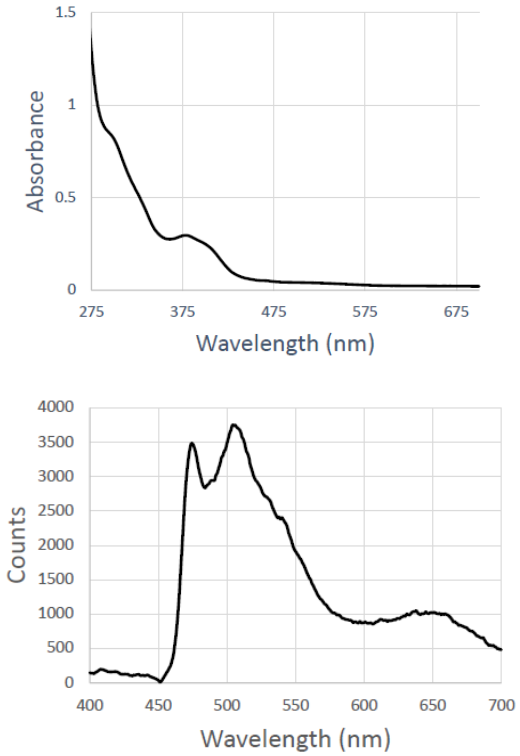


Figure 3. (Top) UV-Vis absorbance spectrum and (bottom) fluorescence spectrum of complex 1.

Conclusion

This study details the synthesis and greater characterization of $[(Ir(ppy)_2)_2dpm]Cl_2$ as a foundation for future work. Future work entails synthesizing derivatives with substituents on the ppy ligands and evaluating their electronic properties via UV-vis, fluorescence, and cyclic voltammetry. This work adds to the growing body of knowledge regarding bimetallic iridium complexes.

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References

1. Evans, R.C.; Douglas, P.; Winscom, C.J. Coordination complexes exhibiting room temperature phosphorescence: Evaluation of their suitability as triplet emitters in organic light emitting diodes. *Coord. Chem. Rev*. 2006, *250*, 15-16. DOI: 10.1016/j.ccr.2006.02.007

2. Li, T.Y.; Wu, J.; Wu, Z.G.; Zheng, Y.X.; Zuo, J.L.; & Pan, Y. Rational design of phosphorescent iridium (III) complexes for emission color tunability and their applications in OLEDs. *Coord. Chem. Rev*. 2018, *374*, 55-92. DOI: 10.1016/j.ccr. 2018.06.014

3. Li, X.; Xie, Y.; Li, Z. Diversity of luminescent metal complexes in OLEDs: beyond traditional precious metals. *Chem. Asian J*. 2021, *16*, 2871-2829. DOI: 10.1002/asia. 202100784

4. Santos, P.L.; Stachelek, P.; Takeda, Y.; Pander, P. Recent advances in highly efficient near infrared OLED emitters. *Mater. Chem. Front*. 2024. *8*, 1731-1766. DOI: 10.1039/ D3QM01067H

5. Zhou, J.; Li, J.; Zhang, K.Y.; Liu, S.; Zhao, Q. Phosphorescent iridium(III) complexes as lifetime-based biological sensors for photoluminescence lifetime imaging microscopy. *Coord. Chem. Rev*. 2022. *453*, 214-334. DOI: 10.1016/j.ccr.2021. 214334.

6. Shi, H.; Wang, Y.; Lin, S.; Lou, J.; Zhang, Q. Recent development and application of cyclometalated iridium(III) complexes as chemical and biological probes. *Dalton Trans*. 2021, *50*, 6410-6417. DOI: 10.1039/d1dt00592h.

7. Ma, D.-L.; Ng, H. P.; Wong S.-Y.; Vellaisamy, K.; Wu, K.-J.; Leung, C.-H. Iridium(III) complexes as reaction based chemosensors for medical diagnostics. *Dalton Trans*. 2018, *47*, 15278-15282. DOI: 10.1039/c8dt03492c.

8. Canisares, F.S.M.; Mutti, A.M.G.; Santana, E.F.; Oliveira, V.C.; Cavalcante, D.G.S.M.; Job, A.E.; Pires, A.M.; Lima, S.A. M. Red-emitting heteroleptic iridium(III) complexes: photophysical and cell labeling study. *Photochem. Photobiol. Sci*. 2022, *21*, 1077-1090. DOI: 10.1007/s43630-022-00200-8.

9. Li, C.; Wang, H.; Shen, J.; Tang, B. Cyclometalated iridium complex-based label free photoelectrochemical biosensor for DNA detection by hybridization chain reaction amplification. *Anal. Chem.* 2015, *87*, 4283-4291. DOI: 10.1021/ac5047032.

10. Ma, D.-L.; Wu, C.; Tang, W.; Gupta, A.-R.; Lee, F.-W.; Li, G.; Leung, C.-H. Recent advances in iridium (III) complex-assisted nanomaterials for biological applications. *J. Mat. Chem. B*, 2018, *6*, 537-544. DOI: 10.1039/C7TB02859H.

11. Kapuscinski, J. DAPI: a DNA-specific fluorescent probe. *Biotech. Histochem.* 1995, *70*, 220-233. DOI: 10.3109/ 10520299509108199.

12. Zhou, Y.; Jia, J.; Li, W.; Fei, H.; Zhou, M. Luminescent biscarbene iridium (III) complexes as living cell imaging reagents. *Chem. Comm.* 2013, *49*, 3230–3232. DOI: 10.1039/C3CC40845K.

13. Li, Y.; Liu, B.; Xu, C.- X.; He, L.; Wan, Y.- C.; Ji, L.- N.; Mao, Z.- W. Mitochondriatargeted phosphorescent cyclometalated iridium (III) complexes: synthesis, characterization, and anticancer properties. *J. Biol. Inorg. Chem.* 2020, *25*, 597-607. DOI: 10.1007/s00775-020-01783-2.

14. Flamigni, L.; Barbieri, A.; Sabatini, C.; Ventura, B.; Barigelletti, F. Photochemistry and photophysics of coordination compounds: iridium. *Top. Curr. Chem.* 2007, *281*, 143203. DOI: 10.1007/978-3-540-73349-2.

15. Lamansky, S.; Djurovich, P.; Murphy, D.; Abdel-Razzaq, F.; Kwong, R.; Tsyba, I.; Bortz, M.; Mui, B.; Bau, R.; Thompson, M.E. Synthesis and characterization of phosphorescent cyclometalated iridium complexes. *Inorg. Chem.* 2001, *40*, 1704-1711. DOI: 10.1021/ic0008969.

16. Zanoni, K.P.; Kariyazaki, B.K.; Ito, A.; Brennaman, M.K.; Meyer, T.J.; Murakami Iha, N.Y. Blue-green iridium (III) emitter and comprehensive photophysical elucidation of heteroleptic cyclometalated iridium (III) complexes. *Inorg. Chem*. 2014, *53*, 40894099. DOI: 10.1021/ic500070s

17. Mandal, S.; Poria, D.K.; Seth, D.K.; Ray, P.S.; Gupta, P. Cyclometalated rhodium and iridium complexes with imidazole containing schiff bases: synthesis, structure and cellular imaging. *Polyhedron*, 2019, *27*, 12-21. DOI: 10.1016/j.poly.2014.01.033.

18. Loganathan, D.; Morrison, H. Effect of ring methylation on the photophysical, photochemical and photobiological properties of cis-dichlorobis(1,10phenanthroline)rhodium(III) chloride. *Photochem. Photobiol.* 2006, *82*, 237-47. DOI: 10.1562/2005-01-19-RA-420.

19. Caspar, R.; Cordier, C.; Waern, J.B.; Guyard-Duhayon, C.; Gruselle, M.; Le Floch, P.; Amouri, H.; A new family of mono- and dicarboxylic ruthenium complexes [Ru(DIP)2(L2)]2+ (DIP = 4,7-diphenyl-1,10-phenanthroline): synthesis, solution behavior, and x-ray molecular structure of trans-$[Ru(DIP)_2(MeOH)_2][OTf]_2$. *Inorg. Chem*. 2006, *15*, 4071-8. DOI: 10.1021/ic0601236.

20. McKenzie, L.K.; Flamme, M.; Felder, P.S.; Karges, J.; Bonhomme, F.; Gandioso, A. Malosse, C.; Gasser, G.; Hollenstein, M. A Ruthenium-oligonucleotide Bioconjugated Photosensitizing Aptamer for Cancer Cell Specific Photodynamic Therapy. *RSC Chem. Biol*. 2021, *2*, 85-95. DOI: 10.1039/d1cb00146a.

21. Obali, A.Y.; Ucan, H.I. Preparation of different substitued polypyridine ligands, ruthenium(II)-bridged complexes and spectoscopıc studies. *J. Fluoresc.* 2016, *26*, 1685-97. DOI: 10.1007/s10895-016-1859-3.

22. Waern, J.B.; Desmarets, C.; Chamoreau, L.M.; Amouri, H.; Barbieri, A.; Sabatini, C.; Ventura, B.; Barigelletti, F. Luminescent cyclometalated Rh(III), Ir(III), and $(DIP)_2Ru(II)$ complexes with carboxylated bipyridyl ligands: synthesis, x-ray molecular structure, and photophysical properties. *Inorg. Chem*. 2008, *21*, 3340-8. DOI: 10.1021/ic702327z.

23. Serroni, S.; Juris, A.; Campagna, S.; Venturi, M.; Denti, G.; Balzani, V. Tetranuclear bimetallic complexes of ruthenium, osmium, rhodium, and iridium. synthesis, absorption spectra, luminescence, and electrochemical properties. *J. Am. Chem. Soc*. 1994, *116*, 9086-9091.

24. Iglesias, M.; Sola, E.; Oro, L.A. Binuclear iridium complexes in catalysis. *Topics Org. Chem*, 2015; 31-58.

25. Mitić, N.; Smith, S.J.; Neves, A.; Guddat, L.W.; Gahan, L.R.; Schenk, G. The catalytic mechanisms of binuclear metallohydrolases. *Chem. Rev*. 2006, *106*, 33383363. DOI: 10.1021/cr050318f.

26. Marshall, J.L.; Strobart, S.R.; Gray, H.B. Spectroscopy and photochemistry of binuclear iridium(I) complexes. *J. Am. Chem. Soc*. 1984, *106*, 3027-3029. DOI: 10.1021/ja00322a045.

27. Chou, P.-T.; Chi, Y. Phosphorescent dyes for organic light-emitting diodes. *Chem. Eur. J.* 2007, *13*, 380-395. DOI: 10.1002/chem.200601272.

28. Evans, R. C.; Douglas, P.; Winscom, C. J. Coordination complexes exhibiting room-temperature phosphorescence: evaluation of their suitability as triplet emitters in organic light emitting diodes. *Coord. Chem. Rev*. 2006. 250, 2093-2126. DOI: 10.1016/j.ccr.2006.02.007.

29. Holder, E.; Langeveld, B.M.W.; Schubert, U.S. New trends in the use of transition metal–ligand complexes for applications in electroluminescent devices. *Adv. Mater.* 2005, *17*, 1109-1121. DOI: 10.1002/adma.200400284.

30. Orselli, E.; Kottas, G.S.; Konradsson, A.E.; Coppo, P.; Frohlich, R.; Fröhlich, R.; De Cola, L.; van Dijken, A.; Buchel, M.; Borner, H. Blue-emitting iridium complexes with substituted 1,2,4-triazole ligands: synthesis, photophysics, and devices. *Inorg. Chem.* 2007, *46*, 11082-11093. DOI: 10.1021/ic701110p.

31. Baranoff, E.; Bolink, H.J.; De Angelis, F.; Fantacci, S.; Di Censo, D.; Djellab, K.; Gratzel, M.; Nazeeruddin, M.K. An inconvenient influence of iridium(III) isomer on OLED efficiency. *Dalton Trans*. 2010, *39*, 8914-8918. DOI: 10.1039/C0DT00414F.

32. Coppo, P.; Duati, M.; Kozhevnikov, V.N.; Hofstraat, J.W.; De Cola, L. White light emission from an assembly comprising luminescent iridium and europium complexes. *Chem.; Int. Ed*. 2005, *44*, 1806-1810. DOI: 10.1002/anie.200461953.

33. Adeloye, A.O. Exploration of the structural and photophysical characteristics of mono- and binuclear Ir(III) cyclometalated complexes for optoelectronic applications. *Materials*. 2019, *12*, 2734. DOI: 10.3390/ma12172734.

34. Auffrant, A.; Barbieri, A.; Barigelletti, F.; Lacour, J.; Mobian, P.; Collin, J.-P.; Sauvage, J-P.; Ventura, B. Bimetallic iridium(III) complexes consisting of $Ir(ppy)_2$ units (ppy = 2Phenylpyridine) and two laterally connected N^N chelates as bridge: synthesis, separation, and photophysical properties. *Inorg. Chem*. 2007, *46*, 6911-6919. DOI: 10.1021/ic700494e.

35. Andreiadis, E. S.; Imbert, D.; Pécaut, J.; Calborean, A.; Ciofini, I.; Adamo, C.; Demadrille, R.; and Mazzanti, M.; Phosphorescent Binuclear Iridium Complexes Based on Terpyridine–Carboxylate: An Experimental and Theoretical Study. *Inorg. Chem.* 2011, *50*, 8197-8206. DOI: 10.1021/ic200704s

36. Yao, S.-Y.; Ou, Y.-L.; Ye, B.-H. Asymmetric synthesis of enantiomerically pure mono- and binuclear bis(cyclometalated) iridium(III) complexes. *Inorg. Chem.* 2016, *55*, 6018-6026. DOI: 10.1021/acs.inorgchem.6b00527

37. Nonoyama, M. Benzo[h]quinolin-10-yl-N iridium(III) complexes, *Bull. Chem. Soc. Jpn.* 1974, *47*, 767-768, DOI: 10.1246/bcsj.47.767

38. Sprouse, S.; King, K.A.; Sepllane, P.J.; Watts, R.J. Photophysical effects of metal-carbon σ bonds in ortho-metalated complexes of iridium(III) and rhodium(III). *J. Am. Chem. Soc*. 1984, *106*, 6647–6653. DOI: 10.1021/ja00334a031.

39. Ru, J.-X.; Guan, L.-P.; Tang, X.-L.; Dou, W.; Yao, X.; Chen, W.-M.; Lui, Y.-M.; Zhang, G.-L.; Liu. S, W.; Meng, Y.; Wang, M.-C. Turn-on phosphorescent chemodosimeter for Hg2+ based on a cyclometalated Ir(III) complex and its application in time-resolved luminescence assays and live cell imaging. *Inorg. Chem*. 2014, *53*, 21, 11498-11506. DOI: 1021/ic501417s.

40. Echevarría, I.; Vaquero, M.; Manzano, B.R.; Jalón, F.R.; Quesada, R.; Espino, G. Photocatalytic aerobic dehydrogenation of N-heterocycles with Ir(III) photosensitizers bearing the 2(2′-Pyridyl)benzimidazole scaffold. *Inorg. Chem.* 2022, *61*, 6193-6208. DOI: 10.1021/acs.inorgchem.2c00358.

Planning for Growth: Towards a "Centers of Smart Growth" Future along the Wasatch Front

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ABSTRACT

Utah is growing, and quickly. In 2024, the state had approximately 3.5 million people, and estimates suggest that the state will be home to over 5 million people by 2050. Much of the current population and projected growth is happening on the urbanized Wasatch Front. For years, planners and policymakers have, to varying degrees, attempted to encourage Wasatch Front growth to adopt practices that involve mixed-use, transit-oriented developments with higher levels of walkability. This paper will begin by exploring these 'smart-growth' characteristics and then proceed by examining how these planning principles have been applied in cities along the Wasatch Front. This paper will then look forward to future mixed-use, transit-oriented, and walkable developments, specifically The Point and Utah City, and assess the potential impact of these developments. In short, this paper explores how upcoming developments along the Wasatch Front will use smart growth planning tools to address continued population growth.

Utah's population is growing. With approximately 3.5 million residents in 2024, Utah was the fastest growing state from 2010 through 2020, and it continues to be among the fastest growing states in the country. Estimates predict that 5 million people will live in Utah by 2050 and 5.5 million by 2060 (Hollingshaus et al. 2022). Most of the state's current residents, as well as most of the anticipated new residents, live along the urbanized Wasatch Front; 82% of the state's population lives in the cities from Provo in the southern Wasatch Front, to Salt Lake City in the center, and Ogden in the north (Hollingshaus et al. 2022, Banta 2023).

In addition to being a rapidly growing urban region, the Wasatch Front has a unique geographic situation, with outward expansion of the urbanized area being constrained between the Wasatch Range on the east and the Great Salt Lake and the West Desert in the west. In short, with rapid population growth and physical expansion constraints, the Wasatch Front cannot simply continue to grow outward as some other cities might. Envision Utah, a statewide planning agency that is trying to develop strategies for future growth scenarios, summarizes the challenges:

> "Communities along the Wasatch Front are facing a challenge: by the year 2050, our population will nearly double. Constrained by geographic factors and with many cities already almost built out, where will this new population live? Where will they work? Where will they be able to find services, recreation, and amenities? These questions are even more significant for people of low to moderate income. Will the cost of living in a decent neighborhood increase inequality and income segregation while limiting access to opportunity?" (Envision Utah 2021).

With a nearly built-out landscape, already strained services, continued inequality, and increasing housing affordability and availability, the urbanized Wasatch Front is forecast to have many growth challenges over the next few decades.

With its attention to the "interrelatedness of decisions and the long range consequences of present actions" (American Planning Association 2024), the field of urban planning has developed an effective set of tools for addressing these types of growth and development challenges (Duany et al. 2000, Speck 2022). In this paper, we will explore some planning solutions that can help Utah grow effectively amid the predicted population growth and the challenges that will accompany that growth. Specifically, we will explore a 'Centers of Smart Growth' strategy that

seems particularly well-positioned to meet this dynamic region's growth challenges. Then, we will briefly explore The Point and Utah City, two case studies of how centers of smart growth development can work along the Wasatch Front.

Smart Growth

At its core, the smart growth movement is about building livable communities for all. Smart Growth America, a leading organization dedicated to the creation of smart growth principles, explains: "We envision a country where no matter where you live, or who you are, you can enjoy living in a place that is healthy, prosperous, and resilient" (2024). Unlike urban sprawl, a development model where growth moves away from an urban core and reinforces separation and disconnection, smart growth seeks to connect people through effective urban planning and design.

Smart growth principles are a recent reaction to the unsustainable urban growth patterns of sprawl (Daniels 2001, Bruegmann 2019). For most of urban history, cities have by necessity been walkable communities with a lot of mixed land uses. This ensured that cities grew increasingly dense and also increasingly polluted and congested as urban residents were working, living, and shopping in the same communities. After the Industrial Revolution, the desire of urban residents to escape the density and pollution of the city center was constrained by limited transportation options. However, in the postwar United States, the emergence of affordable cars and the government-funded interstate highway system led to the separation of urban land uses so that wealthier and middle-class residents could live in one part of the city and work in another, creating the rapidly expanding urban footprint known as sprawl. By the early 1960s, writers and urban critics began to recognize that sprawl was unsustainable.

As an alternative to sprawl, by the 1980s, urban planners developed a set of closely aligned schools of thought called new urbanism, walkability, or smart growth. The Congress for New Urbanism (n.d.) describes this emerging philosophy as "a planning and development approach based on the principles of how cities and towns had been built for the last several centuries: walkable blocks and streets, housing and shopping in close proximity, and accessible public spaces. In other words," The Congress for New Urbanism argues, "New Urbanism focuses on human-scaled urban design." Jeff Speck, one of the leading figures in this planning movement, explains the flexibility in the naming conventions, recalling: "We first called this concept 'neo-traditional town planning,' but that title turned off the liberals. And then we called

it 'New Urbanism,' which turned off the conservatives… It's really just best practices in city and regional planning, but when you call it 'walkability,' people can associate it better with their own lives" (Speck, quoted in Bryson and Montague 2025, 46). Whether known as new urbanism, walkability, or smart growth, the planning movement promotes designing all cities around people's needs, rather than prioritizing automobiles as previous planning paradigms had done. Central to this movement, which we will typically refer to as smart growth moving forward, are three core principles: mixed land uses, transit-oriented development, and walkability.

Mixed Use

The term 'mixed-use development' can hold a variety of meanings, but ultimately the concept is centered around the principle of buildings, or neighborhoods, having multiple functions. This can be something as simple as a multistory building being used for housing in the upper levels with retail on the ground floor. Alternatively, mixed use can refer to the practice of eliminating exclusionary zoning practices so that housing, retail, commercial, and recreational opportunities can all exist within the same block or small area. Regardless of the form, the key idea of mixed land uses is to create a space where people can easily access work, shopping, and entertainment without having to rely solely on cars. Smart Growth America (2024) describes the value of this arrangement: "Mixed land uses bring more people to a neighborhood at a variety of times of day, which can support businesses, improve safety, and enhance the vitality of an area. Mixing land uses also makes it possible for people to live closer to where they work or run errands, and means they don't need to drive a car to get there."

Transit-Oriented Development

The practice of transit-oriented development clusters housing, employment, and retail opportunities around transit stations. These mixed-use centers cluster higher-density land uses together at strategic points, usually along a train line, so that residents can have opportunities to use a variety of transportation methods, instead of just a personal car. Envision Utah has long argued the benefits of this type of concentrated development, stating "[Transit-oriented development] allows people to use their cars less, walk, bicycle, and ride transit more, and use services within walking distances of their homes and local transit stations" (Envision Utah 2002, 10).

Walkability

Walkability works in tandem with mixed-use and transit-oriented development to promote high-quality living environments. Walkable urban design aims to counter automobile-centric design by fostering pedestrian-friendly spaces. Jeff Speck, in his book "Walkable City" (2022), outlines the essential qualities of a walkable environment. Firstly, the walk should be *useful*, offering convenient access to essential destinations like shopping centers, schools, or workplaces. Secondly, the walk should be *safe*, allowing residents to feel secure during their journey. Thirdly, the walk should be *comfortable*, providing seating areas and human-scale landscapes. Lastly, the walk should be *interesting*, engaging pedestrians with visually appealing surroundings. In practice, walkable design often includes elements such as narrow streets, eye-level signs, lots of street-level windows, clearly marked pathways, and many other design strategies that ensure communities are designed for humans on foot, rather than drivers.

Centers of Smart Growth

In Utah, as in other places around the United States, the planning principles of mixed land uses, transit-oriented development, and walkable design are most often used in concert to achieve smart growth goals. Since its founding in 1997, Envision Utah has been the leading advocate for smart growth principles throughout the state. In Envision Utah's language, the places where these three key planning principles come together are called centers. "A center," Envision Utah explains, "is a walkable, mixed-use location in a region, city, or neighborhood that provides a variety of amenities and services" (Envision Utah 2021, 3). All centers, as Envision Utah describes, have three central components: they are mixed-use, transit-oriented developments with walkable design. Envision Utah argues that by creating centers, Utah can: 1) improve the ability of lower-income residents to find affordable housing; 2) reduce the cost of living by having less money spent on transportation, housing, utility costs; and 3) promote walkability by placing residents closer to jobs, schools, etc. Centers can be a variety of scales from a neighborhood center to an urban center. Regardless of the scale, "centers improve accessibility and convenience, air quality, travel options, physical activity and health, cost of living, and other aspects of Utah's quality of life" (Envision Utah 2021, 2).

Whether referring to *smart growth* principles broadly or Envision Utah's *centers* approach, the key ideas of mixed-use, transit-oriented development, and walkability are critical elements. To fully align these already similar strategies, this paper introduces the term *centers of smart*

growth. Centers of smart growth are becoming critical to the way the Wasatch Front is developing to accommodate future population growth. Indeed, the Wasatch Front is poised to begin two unique land developments that are intended to demonstrate that Utah is ready to be a leader in smart growth planning. Both projects are being presented to the public as a new way forward in a state that is facing several challenges due to sprawl and growth. We explore the application of centers of smart growth in The Point and Utah City, two upcoming developments along the Wasatch Front.

The Point

The place where the Salt Lake Valley and Utah Valley meet, about equidistant between Salt Lake City and Provo, is locally known as the Point of the Mountain. It is near this landmark that the state of Utah and its partners are looking to build a 600-acre development to be known as The Point. Beginning in 1951, the Utah State Prison occupied the once-out-of-the-way site. But as urbanization on the Wasatch Front expanded, the once-rural site turned into a potentially valuable location at the heart of the urbanized region. Out-of-date facilities and inmate overcrowding concerns drove decisionmakers to build a new Utah State Correctional Facility further away from population centers, and by 2023, the state-owned old prison site was cleared for redevelopment by the newly created Point of the Mountain State Land Authority (Utah Department of Corrections, 2024).

Because of the state's ownership, the large parcel size, and the prime location near Interstate 15, the major north–south transportation corridor that connects the Wasatch Front, state developers recognized a once-in-a-generation opportunity to shape Utah's growth. Alan Matheson, executive director of The Point development team, discussed the importance of this project: "We feel, as a state project, that we've got an obligation to show how we can develop more thoughtfully. We're not going to stop growth; but we can develop in ways that preserve the quality of life that we have" (Sollitt 2023).

The Point's statement of guiding principles demonstrates the *centers of smart growth* approach to which Matheson is referring. The development aims for transit-oriented development by "maximiz[ing] connections to transportation assets" (The Point 2024). To reduce car dependence, The Point offers various transit alternatives, so that the development can reach the goal of being a 'one-car community' for residents. Bus rapid transit stations are strategically placed in high-density areas, and an 80-acre pedestrian priority zone balances auto access. The street network is designed so that pedestrians, bicycles, and

public transit are given priority. The goal is to encourage residents and visitors to rely less on cars, promoting a healthier environment and well-being. “The car will not be king” at The Point, argues a supportive local mayor (Semerad 2021).

The Point’s commitment to walkable design is evidenced by their goal of “emphasiz[ing] walkability” and “creat[ing] a clear project center” (The Point 2024). Specifically, The Point aims to be the first ‘15-minute city’ in the United States, a conceptual goal that aims to ensure that all daily necessities are accessible within a 15-minute walk. To achieve this goal, residences, retail/dining space, and businesses will all be arranged in distinct districts within the development.

Developers for The Point further aim to ensure mixed land uses by siting recreational trails, affordable housing, quality employment, and cultural amenities all within “sub-districts and sub-centers based on a 5-minute walking radius” (The Point 2024). These mixed-use subdistricts are all embedded in a network of interconnected open spaces. More than 142 acres of public open space, a quarter of the site, comprise linked parks and greenways for recreation, leisure, and social connectivity. The Central Park serves as the recreational and civic heart of the community, with every development parcel connected to open space along the central River to Range trail.

Although The Point is a highly anticipated development with all of the hallmarks of a quality center of smart growth, it is still in its early stages and is not likely to house residents, businesses, or customers for several years. Construction on crucial infrastructure has recently started, but vertical construction is not planned until 2026. Despite the timeline, state leaders, community figures, and developers remain optimistic about the potential of this project.

Utah City

Like The Point, Utah City is a large-scale master-planned, mixed-use, transit-oriented, walkable community. From 1944 to 2002, Geneva Steel produced steel on the shores of Utah Lake to the west of Provo. The mill was important to Utah County’s economy for several decades by providing thousands of jobs and attracting other businesses to the Orem/Provo area. Although the facility endured for more than 50 years, it was permanently closed because of bankruptcy in 2002. Twenty years later, in 2022, Vineyard City and the Utah Transit Authority held a ceremony to celebrate the grand opening of a new FrontRunner commuter rail station at the site and to announce a new land development project located on what was once the cooling pond for the steel mill. Utah City, officials noted, is “over 800 acres of master-planned new

development focusing on sustainability and walkability. It will offer places to live, work, shop, dine, worship, and more, with a promenade running through the center of it leading to Utah Lake" (Utah City 2023, August 28).

Utah City has strong credentials as a center of smart growth. Jeff Speck has been involved in the design of the project from early on and has ensured that the design is true to best planning practices. The community will feature walkable neighborhoods with dining, shopping, entertainment, employment, and housing of all types, from single family to multi-family mixed throughout the space. Utah City describes its efforts at walkability: "We have designed a mixture of uses near each other in Utah City. Mixing retail, office, parks, and residential allows people the option of walking instead of driving for some of their everyday trips" (Utah City 2023, November 30). Additional land within the development has been donated for the creation of a new Huntsman Cancer Institute and an expansion of nearby Utah Valley University. Fifty acres of green space, walking and biking paths, and a 12-acre promenade in the town center will tie the spaces together. Moreover, Utah City is transit-oriented: remember that the project was announced at a Utah Transit Authority Frontrunner commuter rail stop located at the heart of the development.

Like The Point, Utah City is still years away from completion. Construction on 450 of the multifamily dwellings began in 2023, and the cancer facility is on track to break ground in 2024. After this initial phase of building, though, timelines remain unclear, but will likely take more than a decade. The long buildout of this project ensures that the long-term goal of bringing transit-oriented, walkable, mixed-use design to the Wasatch Front requires patience and multi-generational thinking.

Conclusion

Both of these future projects use a *centers of smart growth* strategy to address the challenges associated with population growth along the rapidly growing Wasatch Front. By recognizing that outward expansion in car-dependent sprawl is not a sustainable solution, developments like these use contemporary planning principles to bring mixed land uses, transit-oriented development, and walkability to Utah's cities. Although these large developments will not solve population growth challenges on their own, they use *centers of smart growth* principles to demonstrate the value of proactively planning for growth. Ideally, over the next few years, as these two signature developments become successful, planners and developers will see the benefits of developing centers of smart growth throughout the Wasatch Front.

References

American Planning Association. (2024). Ethical principles in planning. Retrieved June 12, 2024, from https://www.planning.org/ethics/ethicalprinciples/.

Banta, M. (2023, August 4). Utah cities added hundreds of thousands of people in a decade. The Salt Lake Tribune. Retrieved May 25, 2024, from https://www.sltrib.com/news/2023/08/04/most-utahs-growth-happens-1-its/.

Bruegmann, R. (2019). Sprawl: A Compact History. University of Chicago Press, Chicago.

Bryson, J. and Montague, J. (2025). The new urbanism: reframing idea(l)s of city walkability. Weber Journal, Spring/Summer 2025, 45-53.

Congress for the New Urbanism. (2024). About the Congress. Retrieved March 17, 2024, from https://www.cnu.org/cnu28/about.

Daniels, T. (2001). Smart growth: a new American approach to regional planning. Planning Practice and Research, 16 (3-4), 271-279. doi: 10.1080/02697450120107880.

Duany, A., Plater-Zyberk, E., and Speck, J. (2000). Suburban Nation: The Rise of Sprawl and the Decline of the American Dream. North Point Press, New York.

Envision Utah. (2002). Wasatch Front transit oriented guidelines. Retrieved March 15, 2024, from https://envisionutah.org/wasatch-front-transit-oriented-guidelines.

Envision Utah. (2021). Creating communities: a guide to walkable centers. Retrieved May 10, 2024, from https://envisionutah.org/creating-communities-guide.

Hollingshaus, M., Hogue, M., Harris, E., et al. (2022). Utah long-term planning projections: a baseline scenario of population and employment change in Utah and its counties. Retrieved May 15, 2024, from https://gardner.utah.edu/wp-content/uploads/LongTermProj-Jan2022.pdf?x71849

Semerad, T. (2021, August 11). Plans for The Point would create a new 15-minute city in Draper to replace Utah's prison. The Salt Lake Tribune. Retrieved May 25, 2024, from https://www.sltrib.com/news/2021/08/11/plans-point-would-create/.

Smart Growth America. (2024). What is smart growth? Retrieved May 23, 2024, from https://smartgrowthamerica.org/what-is-smart-growth.

Sollitt, S. (2023, December 13). Housing, trails and retail: backers of The Point aim to pack a lot into 600 acres. The Salt Lake Tribune. Retrieved May 25, 2024, from https://www.sltrib.com/news/business/2023/12/13/housing-trails-retail-backers/

Speck, J. (2022). Walkable City: How Downtown Can Save America, One Step at a Time. Picador, New York.

The Point. (2024). Framework plan. Retrieved March 17, 2024, from https://thepointutah.org/framework-plan.

Utah City. (2023, August 28). Vineyard FrontRunner station open, and new mixed-use, walkable project announced. Retrieved May 14, 2024, from https://utahcity.com/2023/08/28/vineyard-frontrunner-station-open-and-new-mixed-use-walkable-project-announced/.

Utah City. (2023, November 30). Benefits of a walkable city. Retrieved May 13, 2024, from https://utahcity.com/2023/11/30/benefits-of-a-walkable-city/.

Utah Department of Corrections. (2024). Territorial and state prison history. Retrieved March 15, 2024, from https://corrections.utah.gov/history/.

“I Read the News Today, Oh Boy”: Oppositional Consciousness-Raising in British Invasion Rock

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Abstract

British Invasion rock bands emerged within a particularly unique societal context. World War II had a significant and lasting impact on a generation of British youth growing up in the economic hardship of its immediate wake. There were, in fact, quite a lot more youth to go around with a postwar baby boom of sorts, mirroring a similar boom in the U.S. These youth were, in addition, directly impacted by the change in British conscription laws that ended the draft, leaving idle a generation of working-class teenagers who would create their own unique identities. At the same time, English youth were influenced by a late 1960s zeitgeist made up of various facets, including a counterculture that questioned authority as well as antiwar demonstrations against a brutal and costly war in Southeast Asia. These elements would have a profound influence on the British Invasion rock bands caught up in such transformation and turmoil. This paper focuses on a lyrical and thematic analysis of the work of three legendary British Invasion bands as they reflected on and responded to the sociohistorical context of their times. The paper

specifically unpacks the lyrics of these British Invasion bands through a theoretical lens that evokes oppositional cultures or cultures of resistance within distinct social locations or cultural formations—a distinctive brand of oppositional consciousness-raising within a most turbulent time.

INTRODUCTION

> Whatever wind was blowing at the time moved the Beatles, too. I'm not saying we weren't flags on the top of the ship; but the whole boat was moving. Maybe the Beatles were in the crow's-nest, shouting, "Land ho," or something like that, but we were all in the same damn boat.
>
> (John Lennon quoted in Sheff 1981)

This quote from John Lennon, intrepid and legendary member of perhaps the most influential of all British Invasion bands—the Beatles, manages to encapsulate a few noteworthy themes in the era of British Invasion rock. The quote speaks to profound sociohistorical changes and movements that were happening during John Lennon's coming-of-age years. The changes were so momentous that they literally moved the entire boat, influencing everyone and everything in this metaphorical ship space, which suggests the world itself. Interestingly, John Lennon is also remarking on the place of the Beatles within this ship metaphor as harbingers of a sort—a "crow's-nest" of four young men from Liverpool, England, who are experiencing these changes so acutely that they are compelled to say something about what they are witnessing. Moreover, what they are witnessing is momentous—something akin to historic discoveries as "Land-ho" suggests. There is something else as well in this quote, something subtler but still visible—the boat is a ship of the damned. The use of the words "the same damn boat" seems to indicate some unspecified dissonance, detriment, or threat.

John Lennon, in a few words, lets us know that the Beatles are a significant voice among many "flags" who presage a change that has already come. This paper is an exploration of the lyrics of three renowned British Invasion bands whose work reveals impressive oppositional voices as they describe their particular social location. The paper contributes to our understanding of the work of British Invasion rock bands through a theoretical lens evocative of what Bonnie Mitchell and Joe Feagin (1995) introduced as "oppositional cultures" and what Raymond Williams (1989) designated as "cultural formations." Through

this analysis, we can uncover how these British Invasion bands responded to their sociohistorical moment.

OPPOSITIONAL CULTURES AND CULTURAL FORMATIONS

The theory of oppositional cultures or cultures of resistance was introduced by Mitchell and Feagin (1995) to describe how disenfranchised peoples draw on their own cultural traditions and unique knowledge bases to resist subjugation. Oppositional cultures themselves, according to Mitchell and Feagin, can come in many forms, including kinship networks and social movements, but particularly for our purposes these authors assert that expression within artistic and cultural mediums can be a significant form of oppositional culture. In this respect, Mitchell and Feagin (1995: 69) assert that oppositional cultures such as art and music can serve to "provide an alternative construction of identity" and give "members of the dominant group an insightful critique of their own culture." Although Mitchell and Feagin introduced oppositional cultures or cultures of resistance as emergent among people of color, the theory has much broader implications for analysis and understanding of other oppressed and repressed groups.

The work of Mitchell and Feagin resonates with that of Raymond Williams (1989) who focuses on the significance of the social location in which music and art work emerge. Williams (1989: 175) states that historical analyses at their very heart will consistently reveal the "remarkably extended and interpenetrating activity of artistic forms and actual or desired social relations." This overarching interrelationship between social relations and artistic forms are what Williams (1989: 175) describes as "cultural formations," which are "simultaneously artistic forms and social locations." Williams essentially argues that art is in dynamic and constant relationship to the place in which it arose and the society in which it exists, both point of origin and social location. More than that, Williams (1989: 176) describes a particular characteristic of cultural formations "where the cultural and artistic intention is shaped, from the outset, by the acceptance and the possibility of broader common relationships, in a shared search for emancipation."

It is the central argument of this paper that our selected British Invasion bands shaped messages of resistance within their music. These bands offered a bold challenge to the status quo within their sociohistorical location both in their home country as well as within the greater milieu of the 1960s—a place and an era experiencing profound and lingering societal disruption, repression, and a brutal war in Southeast Asia. The lyrics of our selected bands are oppositional cultures

in addition to cultural formations—strident voices of dissent where they lived and in their times.

ROOTS OF THE BRITISH INVASION

British Invasion rock music was deeply rooted in the profound social, political, and economic disruptions that marked England in the wake of a world war. England was, in fact, economically gutted by the Second World War, a nation still maintaining wartime rationing and austerity measures while trying to rebuild in the bare wreckage of the war's aftermath (Szatmary 2007; Jackson 2015; Feeney 2015). James E. Perone (2009) describes a direct linkage between British Invasion rock and the devastation after the war. He writes, "One aspect of the development of British Invasion rock that the reader must keep in mind is the devastation that Great Britain endured in World War II" (2009: 4). In fact, Perone asserts that "[n]early every biography or autobiography of British rock musicians who were born in the late 1930s or the first few years of the 1940s touch on—or even focus on—the results of the war" (2009:4). Perone states that this is true in the main because "[n]ot only did the war create indelible images on the psyche of the young people who were children during the German bombardment of the United Kingdom, but the destruction of factories, schools, and housing areas created harsh conditions that lasted for years" (2009: 4).

Perone additionally asserts that the British class structure also played a role in British Invasion rock, noting that for the most part "the musicians that made up the British Invasion came from working-class families—they did not come from the upper classes of British society" (2009: 5). More than this, British Invasion artists were caught up in the distinctive working-class youth subcultures prevalent at the time, namely, the Rockers and the Mods (Szatmary 2007; Feeney 2015). Rockers were essentially a motorcycle subculture, complete with greased back pompadours, black leather jackets, tight-fitting jeans, t-shirts, and either pointed boots or suede shoes (Szatmary 2007). Mods, in contrast, rode motor scooters, popped pills, and particularly focused on clothing fashions. As Szatmary suggests, reacting "against the generic simplicity necessitated by the impoverished conditions following WWII, they [the Mods] especially favored brightly colored, eye-catching styles" (2007: 105). Both Rockers and Mods preferred African American R&B music, but while Rockers focused on 1950s rock and roll, Mods favored jazz and Jamaican music (Perone 2009). Perone (2009) suggests that the British Invasion bands "that made commercial and sociological impact in the United States either leaned heavily in the Mod direction or were interesting hybrids that took their influences from the music favored in

the late 1950s and early 1960s by both the Mods and Rockers," which they "made into something that was essentially different from the source material" (2009: 4)

Beyond economic hardships and growing youth subcultures, other sociopolitical troubles marked the growing-up years of British Invasion rock artists, who were essentially members of the British version of the baby boom (Friedlander 2006; Feeney 2015; Webb 2017). Jackson (2015) describes several global stressors in post-war Britain, including "the perpetuation of global instability during the Cold War, evident in Western responses to the consolidation of Soviet power, the Korean War and the arms race, as well as the humiliation of the Suez crisis in 1956" (2015: 1). Perhaps the climax of global instability for the baby boomers of post-war Britain, spawned by the Cold War itself, was the American war in Southeast Asia. British baby boomers were deeply influenced by American baby boomers, who would create an entire countercultural ethos born of Beat poets and in opposition to their Cold warrior, nationalistic parents—an antiwar ethos that questioned all established authority and encouraged free expression and the use of mind-expanding drugs (Farber 1994; Szatmary 2007). Addison (2010: 19) remarks that antiwar student protests that had begun in earnest in Berkeley, California would fan out to become "an international phenomenon" that also included British student protests in which the "Vietnam war was condemned as an expression of the militarism and imperialism of the United States."

In all, post-war Britain serves as a sociohistorical backdrop that describes several coinciding realities. The world in which British Invasion bands grew up had experienced profound and lasting trauma and adversity. The working class youth of this era—baby boomers all—created unique identities and subcultures in response to the world they faced. More than that, these British baby boomers were deeply impacted by youth subcultures across the globe, particularly the counterculture unfolding in the U.S. that was questioning authority and using mind-expanding drugs as it reckoned with a brutal war in Southeast Asia. These threads speak to a distinct social location in which music would flourish and reflect on the very era in which it emerged.

A WORD ON THE METHOD

British Invasion rock emerged in an era of profound change both in Britain and around the globe. The present study will center on a thematic and lyrical analysis of the work of three fabled British Invasion bands—the Beatles, the Rolling Stones, and The Who (Friedlander 2006; Szatmary 2007; Perone 2009). Each band reflects on their social location

in their own inimitable way, framing oppositional messages within their specific sociohistorical context—distinctive cultural formations that are markedly resistant to the status quo. Each band was selected because of their particular relevance to their times (Friedlander 2006; Szatmary 2007; Addison 2010; McGrath 2015; Perone 2009; Feeney 2015; Graham and Luttrell 2019).

The lyrical and thematic analysis in the present study unpacks the work of these bands within an analytical rubric whereby "analysis is conceived as an emergent product of a process of gradual induction...very much a creative act" (Lofland and Lofland 1995: 181-182). More specifically, the analysis will describe common themes and tropes that emerge from examining the lyrics of selected songs by each band. As Shulamit Reinharz (1992: 159) suggests, "qualitative sociologists apply an inductive, interpretive framework to cultural artifacts. What differentiates sociologists from historians is simply the use of sociological theory as an aid in the explanation." Guided by our theoretical lens, then, we will explore the work of our British Invasion bands as they shaped oppositional messages within their unique sociohistorical context. In so doing, we will reveal cultural formations—the remarkable combination of art and social location (Williams 1989).

THE BRITISH INVASION

The British Invasion bands that were chosen for this analysis—the Beatles, the Rolling Stones, and The Who—articulate their sociohistorical context in evocative, idiosyncratic, and often biting lyricism. Drawing on our theoretical lens, we will uncover sometimes subtle and sometimes strident oppositional messages that at times "provide an alternative construction of identity" to their generational forebears" and consistently "give members of the dominant group an insightful critique of their own culture" (Mitchell and Feagin 1995: 69). Moreover, the lyrics of our British Invasion bands serve as witness to a unique social location born out of a world war and an emergent 1960s counterculture—a cultural formation attuned to harsh realities and resistance (Williams 1989).

THE WIND CRIES MARY

The Second World War left physical and emotional trauma in its wake for the British people. Jackson (2015: 1) asserts that when the war ended, the British people "were struggling to reconcile themselves to the appalling consequences of the war: over 450,000 British soldiers and civilians had been killed and many more wounded; families and communities had been destroyed; cities and homes had been reduced to

rubble." Addison (2010: 11) notes that the Emergency Powers Acts of 1939 and 1940 during the war years would have a direct effect on the British public, particularly "a general acceptance of food rationing" as well as the rationing of consumer goods. However, the end of the war, Addison suggests, did not lead to immediate relief—hastily approved American loans "gave the British a breathing-space but a further period of austerity was unavoidable" (2010:11). As Feeney (2015: 20) writes, "Times were still hard and rationing was on going," while "the idea that anybody could be privileged enough to live the dream—a job they loved and a comfortable home to return to each night—was just a fairytale to the post-war working classes." A sociohistorical moment viewed through the prism of despair, neglect, and decay is reflected in the work of our selected artists—voices of resistance within a particular social location.

"Eleanor Rigby" (1965), the song by the Beatles, presents the listener with the life of a woman of the title name. In the first verse, we observe that while the world goes on around her—a "wedding has been" held at her church—Eleanor Rigby "picks up the rice in the church" thrown in its wake. The listener can interpret this in a few ways—she is tasked with cleaning out the church or perhaps needs the rice for food or both—they seem to indicate a life of meager means and want. The next line throws Eleanor Rigby into low relief as we understand that she "lives in a dream"—she seems not fully tethered to the social world and this is also an indication of mental distress. The lyrics then note that Eleanor Rigby "waits at the window" of the church for someone who seems never to quite arrive. The mention of a wedding earlier in the verse could point to that someone being a husband perhaps lost in the war or a lover who was lost before he could become a husband. More than that, as she waits for this someone she is "wearing the face that she keeps in a jar by the door." This suggests that she puts on an appearance that she discards when no one else is watching—she keeps a face ready for that particular someone. Then the lyrical protagonist who observes Eleanor's life enters the verse by asking into the identity of that someone—"Who is it for?" The question is asked gently, almost tenderly in a gesture that seems striking in this context. No one else seems to care for or in any way pay heed to Eleanor Rigby, who walks through her circumscribed life in a dream, so the question seems almost like a sad sort of balm in this setting.

In the second verse, we are introduced to a second character involved in the church—the parish priest or "Father McKenzie." He is a second person in the song that is a signification of a life unheralded and unnoticed—he is "writing the words of a sermon that no one will hear" and "no one comes near." The stress on "no one" could suggest that the priest is disliked by his parishioners or that he has few parishioners left

because of the stresses of a post-war world. The fact that Eleanor Rigby herself, who seemingly works in the church, doesn't enter into it as someone paying heed to the sermons suggests "no one" could also mean that the church is filled with lost souls who are so far buried in their grief and stress that nothing registers with them and they are not fully functioning humans anymore. The lyrical protagonist notes that Father McKenzie is seemingly diligent in his vocation—"look at him working"—and there is also an implication of want as he is "darning his socks in the night"—he clearly cannot easily afford a new pair. Father McKenzie's relentless isolation, like that of Eleanor Rigby, is stressed as "nobody's there." The lyrical protagonist asks a question here as well—"What does he care?" Unlike the question with regard to Eleanor Rigby, this one seems to veer into a tense bleakness, questioning Father McKenzie's need to go on with unheeded sermons and his assiduous darning as if there is nothing here to care about. The third verse tells us that Eleanor Rigby "died in the church" where she picked up the wedding rice. More than that, she "was buried along with her name"—she died childless and perhaps never actually a bride or she simply faded without a trace, because "nobody came" to the funeral. Father McKenzie literally buries Eleanor Rigby, "wiping the dirt from his hands as he walks from the grave." Here the lyrical protagonist adds a further note of unremitting cheerlessness—"no one was saved"—there is no hope to be had in this story, no happy ending for Eleanor Rigby.

Finally, the chorus that runs through the tale radiates from a place of acute melancholy. First, there's the initial pre-chorus strains of "Ah, look at all the lonely people." Then, the chorus itself continues the mantra—"All the lonely people, where do they all come from?/All the lonely people, where do they all belong?" Jackson (2015: 1) suggests that post-war Britain was not a place of much-needed respite and calm but rather a place where "welfare services were struggling to cope with the burden of physical and psychological illnesses." Moreover, the stressors of the times—from the Cold War to the Korean war to the arms race—"amplified the anxieties and fears of men and women already rendered vulnerable by the cumulative stresses of separation, injury and loss" (Jackson 2015: 1).

The song "Mother's Little Helper" (1966) by the Rolling Stones is an excruciating look at a slide into drug abuse. The first verse starts out with the line "What a drag it is getting old"—a flinching comment from the lyrical protagonist on the issue of aging. This is followed by a quote from a mother—"'Kids are different today'/I hear every mother say"—which turns out to be the seed of an excuse for what comes next. The lyrical protagonist tells us that the mother in question "needs something today to calm her down." The mother is "not really ill" but "there's a

little yellow pill" that she turns to for help—"She goes running for the shelter of her mother's little helper." The pill will help "her on her way" and get "her through her busy day." The second verse starts out with the mother's quote, but this time it's "'Things are different today'/I hear every mother say." In this instance, the mother is tired of making food from scratch—"Cooking fresh food for her husband's just a drag." Her solution is to buy "an instant cake and she burns a frozen steak." This spurs her to turn back to pills for help—she again "goes running for the shelter of her mother's little helper." Only this time, she needs more—"And two help her on her way/Get her through her busy day."

The third verse begins with another quote—"'Men just aren't the same today'/I hear every mother say." In this respect, the mother feels undervalued and that her husband is too hard to please—"'They just don't appreciate that you get tired'/They're so hard to satisfy." So, she needs to "tranquilize" her mind by "running for the shelter of a mother's little helper." Only this time, she needs more again—"And four help you through the night/Help to minimize your plight." After the second and third verses, there is a chorus where we learn where mother gets her pills and that she is abusing them—"'Doctor, please, some more of these'/Outside the door, she took four more." The chorus ends with—"What a drag it is getting old"—the lyrical protagonist almost carelessly describing the issues of aging. Finally, we'll look at the last verse, which again starts with a quote from the mother—"'Life's just much too hard today'/I hear every mother say." This time the mother is so far removed from everything and everyone that she feels no more need to continue—"the pursuit of happiness just seems a bore." The lyrical protagonist seemingly warns the mother that "if you take more of those/You will get an overdose." The protagonist then seems to reach a point that was foreshadowed as they observe directly to the mother that there is "No more running for the shelter of a mother's little helper." The pills have eventually "helped you on your way/Through your busy dying day."

In post-war Britain, Jackson (2014: 8) suggests that there were a variety of responses to the war's aftermath. "Just as there were a variety of stressors, including separation, loneliness, tiredness, illness, bereavement, and repatriation, so too there were a range of adaptive strategies that individuals and families employed to cope with stress." Ali Haggett (2009: 58) suggests that women in post-war Britain who presented with psychological symptoms "recounted memories of distressing childhood events, unhappy marriages, and occasionally a familial predisposition to mental illness." The song "Mother's Little Helper" recounts a harrowing addiction journey for a mother who became more and more removed from her husband and children. The mother in the song turns to prescription drugs but eventually finds herself

unable to cope. We don't know how this particular mother found herself in this position, but we do know that she, like many other mothers in her day, were experiencing some of the most harrowing challenges known to human experience.

RIPPLE

Working class British baby boomers were coming up within a backdrop of austerity and economic hardship but also less regimentation (Jackson 2015). In 1957, young men were no longer drafted to national service in the British military because of changes to English conscription laws—"compulsory military service and reserve obligations had become unpopular for disrupting work and family life" (Vazquez 2011: 754). Within this milieu, a generation of working-class teenagers in post-war Britain were taking on their own mantles of creativity and identity, crafting their own youth subcultures (Szatmary 2007; Perone 2009). According to Szatmary (2007: 106), the Mods were straying from the old ways and "blurring the class lines in British society" as they "fostered a sense of belonging among some lower-class British youths." Dick Hebdige (1975: 93) goes further to suggest that the Mod style was, in effect, a parody of straight culture and a subversion of consumer society—the "mod dealt his blows by converting and distorting the images so cherished by his employers and parents." Pete Townshend of The Who notes that "It was the first move I have ever seen in the history of youth toward unity, toward unity of thought, unity of drive and unity of motive" (Pete Townshend quoted in Szatmary 2007: 106). Fundamental generational and class differences are reflected in the work of our selected bands, complete with youthful cynicism within a 1960s social location.

The song "My Generation" (1965) by The Who is a ferocious diatribe against the older generation, and the first verse outlines the reasoning for this divide. The lyrical protagonist in this opening verse speaks directly to their parents' generation who they perceive as scornful and belittling to their children when said children try to live their own lives—"People try to put us d-down/Just because we get around." The response in the verse is to unleash on parents who the children perceive as acting in ways that are seemingly hardened, emotionless, or even detached—"Things they do look awful c-c-cold." But the line that follows is the ultimate rejection of the older generation itself—"I hope I die before I get old." In addition, throughout the verse, there is a call and response of sorts where each line is followed with the line "Talkin' 'bout my generation"—an in-your-face, deliberately grammatically incorrect, consistent reminder of a chasm of generational difference. The second

verse holds a different derisive message for the older generation with the lines—"Why don't you all f-f-fade away/And don't try to dig what we all s-s-say." In this instance, the lyrical protagonist is scathing in tone and wishes for nothing more than the older generation to disappear, consciously snubbing and pushing them away for in any way making overtures of understanding between the generations—the scathing implication is that there is no common ground to be found. The next two verses are replications of the first two, as if to underscore the abyss between generations in a mocking repetitive chant. The chorus is two lines and winds through the verses—"My generation/This is my generation, baby"—a continuous thread that manages to sneer as it asserts independence of thought and action.

Paul Friedlander (2006: 119) suggests that of all the British Invasion bands, the Who "most directly and thoughtfully confronted the philosophical and political issues of the day." In this regard, Friedlander argues that Townshend intentionally wrote "My Generation" to drive the separation between generations home—"It repulsed those it was supposed to repulse, and it drew a thick line between the people that dug it and the people that didn't dig it" (Pete Townshend quoted in Friedlander 2006: 123). Yet, fascinatingly, Townshend also admits that the song "was very much about trying to find a place in society. I was very, very lost" (Pete Townshend quoted in Friedlander 2006: 123). In many ways, "My Generation" speaks both to the titanic rift between the British baby boom and their parents' generation and to the need for the younger generation to explore their own unique identity within their social milieu.

The song "Baba O'Riley" (1971) by The Who is yet another generational tour de force. The first verse speaks very much to social class concerns and the striving of manual laborers—"Out here in the fields/I fight for my meals/I get my back into my living." The verse also suggests that fighting to survive does not mean bowing or kowtowing to the powers that be, because the cause of working class people is just—"I don't need to fight/to prove I'm right/I don't need to be forgiven." The bridge stands out as a sort of declaration—"Don't cry/Don't raise your eyes/It's only teenage wasteland." It could be this verse is speaking to the dominant class, insisting that they need not look at working-class youth with pity, but it could also be a reminder to the youth themselves not to fall into despair but to embrace their experience as valid. The word "wasteland" has a strong negative connotation, an evocation of neglect in this context. Although placing the word "wasteland" in juxtaposition to the word "teenage" could point toward something terrible, it could also perhaps serve as a bold and uncompromising look at awful truths in a bid for independence. In the second verse, the lyrical protagonist

speaks to traveling with a young woman, seemingly roughing it by campfire and asking her to keep looking forward—"Sally, take my hand/We'll travel south 'cross land/Put out the fire and don't look past my shoulder." The verse suggests that the protagonist and his companion are part of a mass movement of youth who will be happy when they are together, and there is a cautionary reminder that they want to hold on to the days of their youth as long as they can—"The exodus is here, the happy ones are near/Let's get together before we get much older." The chorus once again embraces what is unsparingly a "teenage wasteland"—"Teenage wasteland/It's only teenage wasteland/Teenage wasteland/Oh yeah/Teenage wasteland/They're all wasted!" Using "wasteland" and "wasted" together implies drug use but also a clear understanding of what working-class youth truly face in a world that has no place for them.

Szatmary (2007) notes that Pete Townshend recognized that the members of the Mod teenage subculture he had embraced "were nothing. They were the lowest, they were England's lowest common denominators. Not only were they young, they were also lower-class young" (Pete Townshend quoted in Szatmary 2007: 106). Yet for Townshend, this group of "nobodies" meant everything—"It's like that moment, that incredible feeling of being part of something… Any kid, however ugly… he was a Mod. He was a Mod!" Just so, "Baba O'Riley" confronts the older generation with a vision of working-class youth who have faced the unkind truths, creating a world in their own way and on their own terms.

STOP CHILDREN, WHAT'S THAT SOUND

The "perpetuation of global instability" characterized the growing-up years of British baby boomers, reaching a peak with the American war in Southeast Asia—a catastrophic offspring of the Cold War that was costing so many thousands of lives (Farber 1994). Interestingly, as Farber (1994: 155) notes, "One of the first signs of a broader movement against the war appeared on university campuses across the country in the spring of 1965" and would span across the globe. Just so, a young anti-war protestor by the name of Bronwen Davies recounts a demonstration in Trafalgar Square—central London—in March of 1968 as she notes, "I was 17 years old, still at school, and outraged by British support for US foreign policy. I was young enough to be very shocked that the police were being violent towards the demonstrators, and remember crying and trying to pull a policeman off someone who was being held on the ground. The event made a very deep impression on me" (Bronwen Davies quoted in Henley 2008). These international

campus protests were born of a countercultural movement that emerged in the mid-1960s in the U.S., a movement influenced by the Beat poets that denounced the hypocrisy and the Cold warrior attitude of the status quo while embracing the consciousness-raising of mind-altering drugs (Farber 1994; Szatmary 2007). A countercultural consciousness and the horrors of war are powerfully reflected in the work of our selected bands from this era.

The song "A Day in the Life" (1967) by the Beatles is a psychedelic romp into a sort of stream of consciousness that includes two distinct voices. The first verse launches into the lyrical protagonist reading a news story—"I read the news today, oh boy." The "oh boy" at the end of the line reads as sarcastic in this context and in some way mocking the whole venture of reading news. On this particular day, the news features a story about an incident with "a lucky man who made the grade"—the man was in some way fortunate because of a success or had some prominence with others. But in this case the news about the man "was rather sad." Despite this, the lyrical protagonist finds the story in some way amusing—"Well, I just had to laugh/I saw the photograph." It turns out that the lucky man had some disaster while driving—"He blew his mind out in a car/He didn't notice that the lights had changed." The implication is that he was impaired in some way, perhaps with drugs, and this led to his failure to notice the lights, resulting in an accident that took his life. The lyrics continue by noting the gawkers at the scene—"a crowd of people stood and stared"—all trying to decide the man's identity, because "they'd seen his face before" and were wondering if he "was from the House of Lords."

In the second verse, the tenor has changed completely and is not focused on the accident. The lyrical protagonist notes that he "saw a film today, oh boy." Again, the "oh boy" has a blasé sarcastic quality. The protagonist tells us about the film—"The English army had just won the war." It seems the filmgoers don't want to watch this story—"a crowd of people turned away"—but the protagonist "just had to look, having read the book." The crowd in this verse is the reverse of the first who stop and stare—this audience has little interest in revisiting the story of the war, perhaps because they know the story too well. This is all followed by a surprising refrain from the lyrical protagonist that seems to come out nowhere—"I'd love to turn you on." The line is removed from everything that has come before it and appears like a blessing or a mantra that alludes to some sort of respite, reprieve, or even an appeal to the listener to remove themselves from this mundanity of pointless celebrity accidents and war reenactments. It could also refer to turning one on to an alternative state through a drug experience, but still the implication is of removing oneself from these mundane scenes.

Like the previous line, the bridge comes out of seemingly nowhere. A different lyrical protagonist enters the song with a tale of his very ordinary morning routine before he goes to work—"Woke up, fell out of bed/Dragged a comb across my head." This protagonist ends up catching a bus and later "had a smoke" on his arrival. But it's at this point, the lyrics again surprise us with the line "And somebody spoke and I went into a dream." This, like the earlier lyrical desire to "turn you on," removes us as listeners from the commonplace workday and lifts us into a different plane of sorts.

The final verse returns to our original lyrical protagonist who again discusses the news in that sarcastic, blasé tone. In this story, they're talking about "four thousand holes in Blackburn, Lancashire" and how the holes needed to be counted even though they are "rather small." The lyrics then whimsically note that "now they know how many holes it takes to fill the Albert Hall." But again, this is followed by that almost unnerving line, "I'd love to turn you on." What isn't readily available to the lyrical analysis of the song is the unusual instrumentation that appears twice in the song—preceding the ordinary morning ritual and following the final line. There is an explosive urgency to the instrumentation at these points, a building of sound that reverberates like something impending, perhaps memories of air raids and bombs dropping. The sound at the end of the song peaks and falls into a sustained piano chord.

The countercultural ethos that emerged in the U.S. in the mid-1960s deeply influenced the British baby boom with its outspoken critique of the establishment, including leading institutions, values, and leadership, while it embraced the use of mind-expanding drugs (May 1988; Farber 1994; Szatmary 2007). "A Day in the Life" by the Beatles, similarly suggests a level of dissatisfaction with national figures, political minutiae, and media itself—the drug- or alcohol-driven deaths of public figures and the ridiculous counting of potholes in Lancashire. Although the Second World War is mentioned, it is notable that the public has no more stomach to linger with it—"a crowd of people turned away." McGrath (2015: 16) suggests that "A Day in the Life" captures John Lennon's "reflections on leisure, media and culture" while exposing "the vacuity of contemporary (indeed, capitalist) existence." At the same time, McGrath (2015: 16) suggests that the song is "not defeatist" as it "hints at some notion of an alternative to regulated existence." This is, in some ways, captured in one line of the song repeated twice—"I'd love to turn you on." Perhaps this is the Beatles' ode to psychedelic drug usage as a means of transcending the emptiness of post-war British life and reaching a higher plane of existence.

The song "Gimme Shelter" (1969) by the Rolling Stones is an imposingly painful glimpse into the maw of war. The first verse begins with no preamble, as the lyrical protagonist dives right into the heart of a tempest that can in fact mean their death—"Ooh, a storm is threatening my very life today." The protagonist makes a plea for some sort of refuge or protection that will save their life—"If I don't get some shelter/Ooh yeah, I'm gonna fade away." The second verse moves from the storm metaphor for war to the agony of running across hot coals and the terror of confrontation with a mad bull—"Ooh, see the fire is sweepin'/Our very street today/Burns like a red coal carpet/Mad bull lost your way." The third verse, like the first, uses the natural world as a metaphor for war and reiterates the plea for shelter and the fear of dying—"A flood is threatening/My very life today/Gimme, gimme shelter/Or I'm going to fade away." There is a first chorus and an interlude in the song that are profoundly disturbing. In the first chorus, a second lyrical protagonist reminds us all that the only thing separating us from the horrors of war is one act of hatred—"War, children/It's just a shot away/It's just a shot away/War, children/It's just a shot away/It's just a shot away, yeah." The interlude in the song, again from the second lyrical protagonist, is merciless, once again reminding us that war is hideously close with horrific ramifications—"Rape! Murder!/It's just a shot away/It's just a shot away/Rape! Murder!/It's just a shot away/It's just a shot away, yeah." Only in the final chorus is there any relief or hope in this song, and this comes from the first lyrical protagonist—"I tell you, love, sister/It's just a kiss away/It's just a kiss away/It's just a kiss away…"

In an interview with *Rolling Stone* in 1995, Mick Jagger discusses his memories of the 1960s, especially the Vietnam war—"it's a very rough, very violent era. The Vietnam war. Violence on the screens, pillage, and burning" (Wenner 1995). He also underscores the war's influence on the entire album from which "Gimme Shelter" is taken, as well as the countercultural antiwar movement that came to Britain—"People objected, and people didn't want to fight it…Even though I was living in America only part time, I was influenced. All those images on television. Plus, the spill out onto campuses" (Wenner 1995). The song serves as a lasting impression of a particular sociohistorical timeframe, as well as a harbinger and ward against what was an avoidable catastrophe.

CONCLUSION

In the conclusion to his book, *Mods, Rockers, and the Music of the British Invasion* (2009), James E. Perone writes:

> The most self-evident aspect of the British Invasion of 1964-65 is that it really did resemble an invasion, in the sense of a sudden, unexpected, overwhelming revolutionary change.
>
> (Perone 2009: 161)

The present study situated itself very much within the scope of this revolutionary change as it focused on the work of three legendary British Invasion bands. Our analysis uncovered lyrical reflections on the adversity, as well as profound physical and psychic trauma of the post-war British world, clear class and generational gulfs between working-class youth and the status quo, and a marked countercultural antiwar ethos that was willing and able to question authority and all established institutions. These intrepid bands crafted oppositional messages that served to "provide an alternative construction of identity" and "give members of the dominant group an insightful critique of their own culture" (Mitchell and Feagin 1995: 69). Moreover, the artistry of our bands occurred in dynamic and constant relationship to the place in which it arose, as they expressed distinctive "cultural formations" which are "simultaneously artistic forms and social locations" (Williams 1989: 175).

The British Invasion bands themselves were revolutionaries of a sort, part of a youth culture in Britain that "had broken free of its origins in pop music, fashion, and teenage gangs, and exploded into a firework display of countercultural experiment and political protest" (Addison 2010: 214). Resonant with this, and beyond the sex-drugs-rock-and-roll mantra, these bands in many ways came early or late to demonstrate what Williams (1989: 176) describes, "where the cultural and artistic intention is shaped, from the outset, by the acceptance and the possibility of broader common relationships, in a shared search for emancipation." The Beatles, the Rolling Stones, and The Who were in the vanguard of a musical moment that reflected on the fractures apparent in post-war Britain but also shared with their countercultural brethren a distinct tendency to question authority and to advocate for peace.

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REFERENCES

Addison, Paul. 2010. No Turning Back: The Peacetime Revolutions of Post-War Britain. New York: Oxford University Press.

Farber, David. 1994. The Age of Great Dreams: America in the 1960s. New York: Hill and Wang.

Feeney, Paul. 2015. The Baby Boomer Generation: A Lifetime of Memories. Cheltenham, UK: History Press.

Friedlander, Paul. 2006. Rock and Roll: A Social History, 2nd ed. Boulder, CO: Westview Press.

Graham, Phil and Briony Luttrell. 2019. "A rhetoric of style: Eleanor Rigby and the reordering of popular music. Social Semiotics, 29 (2): 222-239.

Haggett, Ali. 2009. "'Desperate housewives' and the domestic environment in post-war Britain: individual perspectives." Oral History 37 (1): 53-60.

Hebdige, Dick. 1975. "The meaning of Mod." Working Paper in Cultural Studies, 7(8): 87-96.

Henley, Jon. 2008. "1968: I was there." The Guardian, May 21. Retrieved June 23, 2023 from https://www.theguardian.com/world/2008/may/21/1968theyearofrevolt.antiwar.

Jackson, Mark. 2015. "Stress in post-war Britain: an introduction." Pp. 1-15 in Stress in Post-War Britain, 1945-85. New York: Routledge.

Lofland, John and Lyn H. Lofland. 1995. Analyzing Social Settings: A Guide to Qualitative Observation and Analysis. 3rd ed. Belmont, CA: Wadsworth.

May, Elaine Tyler. 1988. Homeward Bound: American Families in the Cold War. New York: Basic Books.

McGrath, James. 2015. "'Where you once belonged': class, race and the Liverpool roots of Lennon and McCartney's songs." Popular Music History, 9 (1): 1-34.

Mitchell, Bonnie L. and Joe R. Feagin. 1995. “America’s racial-ethnic cultures: opposition within a mythical melting pot.” Pp. 65-86 in Toward the Multicultural University, edited by B. Bowser, T. Jones and G. A. Young. Westport, CT: Praeger.

Perone, James E. 2009. Mods, Rockers, and the Music of the British Invasion. Westport, CT: Praeger.

Reinharz, Shulamit. 1992. Feminist Methods in Social Research. New York: Oxford University Press.

Sheff, David. January 1981. “John Lennon interview, September 1980.” Playboy. Retrieved June 27, 2023, from https://www.beatlesinterviews.org/dbjypb.int2.html.

Szatmary, David P. 2007. Rockin’ in Time: A Social History of Rock-and-Roll, 6th ed. Saddle River, NJ: Pearson-Prentice Hall.

Vazquez, III, Joseph Paul. 2011. “More than meets the eye: domestic politics and the end of British conscription.” Armed Forces & Society, 37 (4): 571-756.

Webb, Simon. 2017. Post-War Childhood: Growing Up in the Not-So-Friendly “Baby Boomer” Years. South Yorkshire, UK: Pen & Sword History.

Wenner, Jann S. 1995, December 14. “Jagger remembers: Mick’s most comprehensive interview ever.” Rolling Stone. Retrieved June 29, 2023, from https://www.rollingstone.com/feature/mick-jagger-remembers-92946/.

Williams, Raymond. 1989. “The uses of cultural theory.” Pp. 163-176 in Politics of Modernism: Against the New Conformists. London: Verso.

MUSIC REFERENCES

Beatles, The. 1965. “Eleanor Rigby.” Revolver. Parlophone, Capitol.

_____. 1967. “A Day in the Life.” Sgt. Pepper’s Lonely Hearts Club Band. Parlophone, Capitol, EMI.

Rolling Stones, The. 1966. “Mother’s Little Helper.” Aftermath. Decca, London.

_____. 1969. Gimme Shelter.” Let it Bleed. Decca.

Who, The. 1965. “My Generation.” My Generation. Brunswick.

_____. 1971. “Baba O’Riley.” My Generation. Track, Decca.

College Students' and Professors' Perceptions of a Student with ADHD: Does the Gender Matter?

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Abstract

Attention-deficit/hyperactivity disorder (ADHD) is an increasingly prevalent disorder, affecting about 9% of U.S. children and between 2 and 6% of the adult U.S. population. The present study examined the perceptions of male and female college students who have ADHD. In a 2×2 between-subjects design (male/female vignette), participants (n=281 students; n=101 professors) were randomly assigned to read one of two vignettes detailing either a male or a female student with symptoms consistent with ADHD. Findings indicated that male and female college students with ADHD were perceived similarly on nearly all measures. Professors had more positive perceptions and lower stigma of the student with ADHD compared with the undergraduate participants. Findings suggest that the gender of the target did not impact perceptions of college students with ADHD, but students exhibited more negative perceptions on several measures compared with professors. Future directions and implications are discussed.

Attention-deficit/hyperactivity disorder (ADHD) is described as a pattern of inattention and/or hyperactivity that appears prior to age 12 (American Psychiatric Association [APA], 2013). Indicators of ADHD include restlessness, challenges organizing tasks, difficulty directing attention, and struggles with maintaining physical stillness (APA, 2013). These symptoms significantly impact an individual's daily life, making it challenging to focus on tasks and manage their activities.

ADHD is a condition affecting a substantial portion of the global population. Depending on the source, estimates of the prevalence of ADHD vary. Globally, about 5% to 7% of children are diagnosed with ADHD (De Rossi et al., 2022; Song et al., 2021). Other studies have found that 9% of U.S. children are diagnosed with ADHD (e.g., Lebowitz, 2016; Ohan et al., 2011). Additionally, 2-6% of U.S. adults are diagnosed with ADHD (Canu et al., 2008), and 2-8% of college students experience ADHD (Green & Rabiner, 2012). Girls are consistently underdiagnosed and are diagnosed later than boys, likely because they display fewer hyperactive symptoms and more internalized symptoms (Dakwar et al., 2014; Skogli et al., 2013).

Individuals who exhibit symptoms of mental illness are often subject to various forms of social stigma. Social stigma has been described as "an attribute that is deeply discrediting" that reduces someone "from a whole and usual person to a tainted, discounted one" (Goffman, 1963, p. 3). Stigma can include public stereotypes, marginalization, and self-stigmatization (Corrigan, 2005). When individuals fail to meet social norms, others tend to ostracize or discriminate against them, which can fuel mental health stigma (MHS) (Chew et al., 2007; Rössler, 2016).

About one in five adults in the U.S. lives with a mental illness (National Institute of Mental Health, 2022), yet MHS remains prevalent. MHS can be categorized into three types of stigma: public stigma, self-stigma, and courtesy stigma. Public stigma refers to a larger population's stigmatization of mental illness (Corrigan & Rao, 2012) and can lead to other forms of MHS (Godfrey et al., 2021; Rüsch, 2005). Stigma can also arise when a person without stigma is connected to someone who is stigmatized. This can lead to the person without stigma feeling or perceiving the effects of stigma. This is referred to as courtesy stigma (Muller et al., 2012; Rössler, 2016). Self-stigma is the internalized response to MHS or perceived MHS that stigmatized individuals experience (Corrigan & Rao, 2012; Watson et al., 2007).

MHS intensifies the challenges beyond those presented by mental illness (Rüsch et al., 2005). There are negative consequences on self-esteem and self-efficacy for stigmatized individuals and associated individuals (Rössler, 2016; Sickel et al., 2014). Diminished self-esteem

and self-efficacy often cause the stigmatized individual to have a more difficult time succeeding academically (Vance & Weyandt, 2008). MHS also causes discrimination in the workplace, which hinders their ability to maintain employment (Corrigan & Rao, 2012; Rüsch et al., 2005; Watson et al., 2007). Ostman and Kjellin (2002) found that of 162 family members who were surveyed, 40% felt that the stigmatized family members caused mental health issues in themselves. More than half of this group felt that their family members with mental health issues were better off dead.

MHS is also recognized as one of the most critical barriers to seeking professional mental health care (e.g., Godfrey et al., 2021; Masuch et al., 2019; Rössler, 2016). MHS can impact the quality of care provided to individuals with mental health concerns. Corrigan et al. (2014) found that mental health professionals who had stigmatized views of their patients believed they would not adhere to medical treatments and provide suboptimal care, such as not referring the patient to a specialist or refilling a prescription. Individuals with mental health concerns also may experience direct discriminatory actions by employers and healthcare professionals, such as the decreased likelihood of a prescription refill, earning lower wages, and maintaining their employment (Corrigan et al., 2014; Rüsch et al., 2005; Sickel et al., 2014).

Despite increased knowledge of mental illness, MHS has not decreased (Godfrey et al., 2021). Research has revealed that the level of MHS varies among different mental illnesses depending on the visibility of the illness in social settings (Canu et al., 2008). There has been an increased awareness of ADHD stigma. Teachers and parents view children's academic abilities more negatively when the child is diagnosed with ADHD (Lebowitz, 2016). Research has also shown that teachers have gendered perceptions of children diagnosed with ADHD. Olsson (2022) revealed that although there are no gender differences in the actual level of hyperactivity, teachers and parents perceived girls as more hyperactive and verbally impulsive than boys who displayed the same behaviors. Conversely, among an undergraduate sample, male college students diagnosed with ADHD faced more severe judgments than female students in both academic and social environments (Canu et al., 2008).

Although there is a substantial body of research on perceptions of children with ADHD, a notable gap exists in our understanding of how adults with ADHD are perceived. Reports indicate that over half of students who were diagnosed with ADHD in their childhood found symptoms continued into early adulthood, and up to 11% of college students in the U.S. have ADHD (Mak et al., 2021). College students are

more likely to describe their ADHD peers negatively compared with their peers without ADHD (Canu et al., 2008; Chew et al., 2009).

College students are also less likely to willingly engage with students with ADHD, such as collaborating on a group project, getting to know them, or becoming friends with them (Lebowitz, 2016). Thompson and Lefler (2016) discovered that college students tend to stigmatize their peers who exhibit behaviors associated with ADHD, regardless of whether those peers have an official diagnosis of ADHD.

The Present Study

Only a handful of studies have looked at how adults with ADHD are perceived, and just one has examined how college professors view college students with ADHD (Vance & Weyandt, 2008). The researchers found that 25.7% of college professors agreed that faculty should not accept alternative assignments or provide lecture notes to students with ADHD. Interestingly, perceptions of students with ADHD did not differ based on the professors' levels of education, experience, or prior experiences with students with ADHD (Vance & Weyandt, 2008). To our knowledge, only one study has examined whether there are gendered perceptions of college students with ADHD (Canu et al., 2008). In the present study, we expanded on this body of research and examined college students' and professors' perceptions of a student with ADHD and examined whether male and female college students with ADHD are perceived differently by professors and fellow college students.

Method

Participants and Design

This was a 2 (faculty/student)×2 (male/female vignette) between-subjects design with one manipulated variable and one quasi-independent variable. The student participants were recruited through the Psychology 1010 subject pool at Weber State University using the SONA system, a participant recruitment platform. They received course credit for participating. Professors were recruited using a combination of Facebook, emails, flyers, and snowball sampling techniques. Because of the difficulty of getting faculty members to fill out our survey, we allowed faculty members from other universities to participate in the study as well. Anyone who had taught at the undergraduate or graduate level was eligible to participate. Faculty members were entered into a raffle to win an Amazon gift card ($30). The total sample size was N=382. The demographics of the participants are shown in Table 1.

Table 1. Demographics for student (n=281) and faculty (n=101) participants		
Variables	**Student**	**Faculty**
Mean age in years (SD)	22.79 (7.21)	46.09 (11.51)
Gender		
Man	71	30
Woman	196	59
Agender	1	1
Gender queer, questioning, fluid	5	0
Transgender man	1	0
Transgender woman	1	0
Prefer not to answer	2	0
Other	2	0
Race/Ethnicity		
Arab, Middle Eastern, North African	0	0
Asian or Asian American	9	3
Black or African American	2	
Hispanic or Latino	35	1
Native American or Alaska Native		0
Native Hawaiian or other Pacific Islander	3	0
White or European American	203	82
Biracial or multiracial	19	2
Some other race, ethnicity, or origin	4	1
I prefer not to answer	4	1
Sexual Orientation		
Asexual/Aromantic	10	1
Bisexual	23	5
Demisexual	1	1
Gay	7	4
Lesbian	4	1
Pansexual	8	3
Straight or heterosexual	221	75
Other	5	0
Missing data	2	11

Student Participant Demographics

Among the 281 students recruited, the mean age was 22.79 years (*SD*=7.21). There were 71 (25%) cisgender men and 196 (70%) cisgender women, with smaller frequencies of other gender identities. In terms of ethnic/racial identity, the sample was mostly White (*n*=203;

72%), Hispanic or Latinx (*n*=35; 13%), and Biracial (n=19; 7%). Most student participants were heterosexual (*n*=221; 79%) followed by bisexual or pansexual (*n*=31; 11%) and asexual/aromantic (*n*=10; 4%).

Participants were provided with the diagnostic criteria for ADHD. They were asked whether they thought they would be diagnosed with ADHD (1=*definitely not*, 2=*probably not*, 3=*might or might not*, 4=*probably*, 5=*definitely*). There were 106 student participants (38%) who indicated they probably or definitely would be diagnosed with ADHD. There were 46 student participants (17%) with a formal diagnosis of ADHD, with the majority of those being diagnosed with the combined presentation subtype (*n*=17). Of the students with a formal diagnosis, 28 (61%) reported that they take medication for their ADHD.

Faculty Participant Demographics

There were 101 faculty participants. Their mean age was 46.09 years (*SD*=11.51). There were 59 (58%) cisgendered women, 30 (30%) cisgendered men, and one participant was agender. The majority of the faculty sample was White (n=82; 81%) and heterosexual (n=75; 74%).

When asked to self-identify as having ADHD, 27 faculty (29%) indicated that they probably or definitely would be diagnosed with ADHD. Seven faculty had been formally diagnosed with ADHD. All 7 faculty members with a formal diagnosis reported being on medication for their ADHD symptoms.

Faculty participants were asked a series of questions regarding their university teaching experience. The majority of faculty taught at a four-year university (*n*=83; 82%) and primarily taught undergraduate students (*n*=72; 71%). The faculty roles were relatively evenly split across part-time (*n*=12), lecturer/instructor (*n*=14), assistant professor (*n*=24), associate professor (*n*=19), and full professor (*n*=19). Participants averaged 13.66 years (*SD*=10.16) of college teaching experience.

Procedure

We received IRB approval at Weber State University. Participants were randomly assigned to read one of two 300-word vignettes detailing a student (Eric or Erica) with symptomology consistent with ADHD, without explicitly labeling the ADHD (see Appendix).

After reading the vignette, participants completed several measures of their perceptions of Eric[a]. Next, participants were asked questions related to their general beliefs and stigma toward ADHD (not specific to the Eric[a] vignette). The last two blocks of the survey included questions about participants' own experiences with ADHD and demographic questions.

Measures[1]

Causal Attributions

The Attributions for ADHD Questionnaire (Wiener et al., 2012) was originally designed to assess participants' attributions regarding the cause of their ADHD. However, in the present study, the scale was reworded to measure participants' perceptions of the cause of the target's ADHD. This scale comprised three items tapping into controllability, three items tapping into pervasiveness, and one locus of causality item. We did not include the stigmatization items of the AAQ because they could not be easily reworded to apply to perceptions of a target. Past research has demonstrated high internal consistency of the AAQ (α=.85; Wiener et al., 2012).

Anticipated Behaviors

The Anticipated Behavior Form (ABF) (Thompson & Lefler, 2016) is an 11-item survey assessing participants' expectations about what it would be like working with Eric[a].

Participants were asked questions such as: What is the likelihood that… "Eric[a] will do [his/her] share of the workload," and "You will enjoy working with Eric[a]." Responses were made using a 7-point scale from 1 (*very unlikely*) to 7 (*very likely*). Thus, higher scores indicate more positive impressions of working with Eric[a]. The ABF has been found to have high internal consistency (α=.85; Thompson & Lefler, 2016). In the present study, the items demonstrated high internal consistency, α=.91.

Social Distance Scale

The Adapted Social Distance Scale (SDS) (Thompson & Lefler, 2016) consists of 12 items and measures a person's willingness to engage with another person socially (such as being friends, sitting next to them in class, and being roommates with the target person). This measure was only given to student participants because several items were not appropriate for a faculty/student relationship. Responses were made on a 7-point scale from 1 (*extremely unlikely*) to 7 (*extremely likely*). The original scale went from 1 (*extremely likely*) to 7 (*extremely unlikely*), but we reversed the anchors in the present study to be consistent with the rest of the survey anchors. Prior to averaging across the 12 items to create the composite score, we reverse-coded each item so that higher scores

[1] Qualtrics survey and raw data can be found at http://osf.io/63tq4.

on this scale indicated more social distancing (i.e., reluctance to engage with the target socially). Previous research has found this scale to be internally consistent (α=.86; Thompson & Lefler, 2016). In the present study, α=.92.

ADHD Stigma Questionnaire

The ADHD Stigma Scale (Fuermaier et al., 2012) is a 37-item measure, on which responses were made using a six-point scale from 1 (*strongly disagree*) to 6 (*strongly agree*). The scale comprises six subscales: reliability and social functioning (9 items; α=.74; e.g., "Adults with ADHD are able to lead a group of people"), malingering and misuse of medication (9 items; α=.88; e.g., "Many adults with ADHD fake symptoms"), ability to take responsibility (5 items; α=.77; e.g., "I would mind if my investment advisor had ADHD"), norm-violating and externalizing behavior (5 items; α=.69; e.g., "Adults with ADHD act without thinking"), consequences of diagnostic disclosure (4 items; α=.68; e.g., "Adults with ADHD feel excluded from society"), and etiology (4 items; α=.72; e.g., "Extensive exposure to video games and TV shows can cause ADHD"). It is worth noting that two of the subscales had low reliability. The "consequences of diagnostic disclosure" subscale originally had five items but removing one of the items increased the alpha from .66 to .68. Thus, we used the four-item composite for that subscale. The "norm-violating and externalizing" subscale also had a low alpha, but removing items did not improve the reliability.

Expectations of Classroom Behaviors

Based on Akin and Huang's (2019) measure of expectations of disruptive classroom behaviors, participants were asked to consider college students with ADHD and to indicate the likelihood of nine behaviors: cheating on an exam, asking too many questions in class, slowing down lectures with questions, making distracting movements, failing to take turns in class discussions, being difficult to get along with, displaying obsessive-compulsive behaviors, disrupting class with loud noises, and becoming frustrated easily in class. Responses were made on a scale from 1 (*not at all likely*) to 7 (*extremely likely*). These items were analyzed as separate items (rather than creating a composite score).

Deserving of Academic Accommodations

Faculty participants were asked four questions regarding whether Eric[a] deserved academic accommodations: "Eric[a] deserves to receive

academic accommodations," "Without academic accommodations, it would be difficult for Eric[a] to deal with his[her] ADHD in a typical school day," "Academic accommodations give Eric[a] an unfair advantage" (reverse coded), and Eric[a] may fake his[her] condition in order to receive accommodations." Cronbach's alpha with the four items was .68. Taking out the last item increased the reliability to α=.73. Thus, the composite measure was created using only the first three items on the scale.

We also assessed academic accommodations more generally, not specifically to Eric[a]. Akin and Huang (2019) assessed participants' perceptions of the deservingness of academic accommodations for psychiatric, cognitive, and physical disabilities. In the present study, the items were adapted to be specific to ADHD. Using a 5-point scale from 1 (*strongly disagree*) to 5 (*strongly agree*), participants rated the degree to which students with ADHD should receive academic accommodations. Sample items included: "Academic accommodations give students with ADHD an unfair advantage" (reverse-coded) and "Students with ADHD deserve to receive academic accommodations." A composite score was created (α=.85). Higher scores indicate the belief that students with ADHD deserve accommodation.

Results

Causal Attributions

Three questions addressed the controllability of ADHD behaviors. First, participants were asked: "If Eric[a] tried really hard, do you think he[she] could stop his[her] ADHD behaviors? Because the responses were made on an ordinal scale (can't stop it at all, can stop it a little, can stop it a lot), we analyzed these data using a Mann-Whitney U nonparametric test. There were no significant differences between Eric and Erica on perceptions of controllability for the student participants (z=.98, p=.33), the faculty participants (z=.66, p=.51), or collapsing across students and faculty (z=.52, p=.60). The second controllability question asked: "To what extent do you think Eric[a]'s ADHD behaviors come out even when he[she] doesn't want them to?" Again, the results were not significant for the student sample (z=1.32, p=.19), the faculty sample (z=1.47, p=.14), or collapsing across samples (z=.29, p=.77). The third controllability question asked: "To what extent can Eric[a] control his[her] ADHD behaviors? When we split the file by sample, there was no significant difference among the student participants on controllability between Eric and Erica (z=.66, p=.51). However, there was a significant difference among the faculty participants (z=2.09,

p=.037). Specifically, Erica's ADHD was perceived as less controllable than Eric's ADHD (Figure 1).

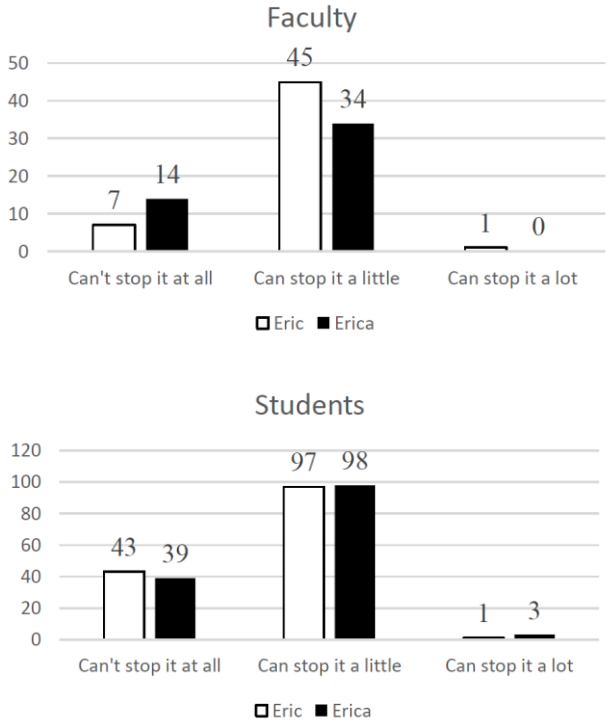

Figure 1. Faculty and student perceptions on controllability question 3 ("To what extent can Eric[a] control his/her ADHD behaviors?")

Three questions asked participants about attributions of pervasiveness. The first question asked: "How long do you think Eric[a] has had ADHD?" (only a short time, a few years, as long as he[she] can remember). The Mann-Whitney U was not significant for student participants (z=1.69, p=.09), faculty participants (z=.68, p=.50), or collapsing across samples (z=1.31, p =.19). The second question asked: "Eric[a] experiences ADHD symptoms…" (almost never, some of the time, all of the time). Again, there were no significant differences based on gender among the student participants (z=.74, p=.46), the faculty participants (z=1.25, p=.21), or collapsing across samples (z=.16, p=.87). The third pervasiveness question asked: "Do you think Eric[a]'s ADHD….(is going to disappear soon, is going to last a few years, is

going to last forever). There were no significant differences in perceptions of pervasiveness based on gender for student participants (z=.83, p=.41), faculty participants (z=.95, p=.34), or collapsing across samples (z=.68, p=.50).

There was one question that asked about the locus of causality: "What do you think causes Eric[a]'s ADHD? Is it something around him[her], (like people), or something inside of him[her] that makes him[her] have ADHD?" We conducted a Chi-Square test of independence to examine whether the target's gender was independent of locus of causality. The Chi-Square value was not significant for the student or the faculty participants, meaning that neither group was influenced by the target's gender on this question.

ABF and SDS

We conducted a two-way analysis of covariance (ANCOVA) to examine whether the target's gender (Eric/Erica) and the participant's role (student/faculty) impacted scores on the ABF, controlling for the age of the participants. There was not a main effect of target gender on ABF [F(1, 364)=1.37, p=.24, η_p^2=.004]. There was a main effect of the participant's role on ABF [F(1, 364)=7.91, p=.005, η_p^2=.02]. Professors (M=5.11, SE=.15) were more likely to indicate that working with Eric[a] would be positive compared with the student participants (M=4.57, SD=.07). There was not a significant interaction between target gender and participant's role on ABF.

Only the student participants filled out the SDS. We conducted a two-way analysis of variance (ANOVA) to examine the target's gender (Eric/Erica) and participants' self-diagnosis of ADHD symptoms on the overall SDS score. There was not a significant main effect of the target's gender on social distancing [F(1, 275)=.16, p=.69, η_p^2=.001]. There was a significant main effect of participants' self-diagnosis [F(1, 275)=5.30, p=.02, η_p^2=.02]. Participants who self-diagnosed as having ADHD had lower scores on the SDS scale (M=3.74, SE=.11) than participants who reported they likely did not have ADHD (M=4.07, SE=.09). Thus, having ADHD symptoms made participants less likely to socially distance themselves from someone else with ADHD symptoms. There was not an interaction between the target gender and the participant's ADHD on social distancing.

Deservingness of Academic Accommodations

Faculty participants were asked four questions about whether Eric[a] deserved academic accommodation. An independent samples t-test revealed no significant differences between Eric and Erica in terms

of perceived deservingness of academic accommodations on any of the four items or on the composite measure.

Later in the survey, we asked faculty and students whether students with ADHD deserve academic accommodations. These questions were not specific to the vignette in the study. Rather, these questions were simply asking about students with ADHD in general. We conducted a t-test to examine whether students and professors differed in their perceptions of academic accommodations for students with ADHD. There was a significant difference between faculty participants and student participants [$t(229.69)=8.66$, $p<.001$, $d=.94$]. Faculty participants were more likely to agree that students with ADHD deserve academic accommodation. We also conducted a two-way ANCOVA to examine the impact of the participant's role (faculty/student) and the participant's self-diagnosis of ADHD on deservingness of academic accommodations for a student with ADHD, controlling for age. There was not a main effect of the self-diagnosis of ADHD on deservingness of academic accommodations [$F(1, 364)=.60$, $p=.44$, $\eta_p^2=.002$]. There was a main effect of the participant's role on perceptions of academic accommodations (consistent with the above t-test results) [$F(1, 364)=12.19$, $p<.001$, $\eta_p^2=.03$]. There was not an interaction between ADHD self-diagnosis and participant's role.

Likely Behaviors

The participants were asked how likely a student with ADHD would be to engage in certain behaviors (e.g., cheating on an exam, asking too many questions, being difficult to get along with). We conducted a multivariate ANCOVA to examine whether the participant's role (student vs. professor) and self-diagnosing with ADHD would impact the perceived likelihood of certain behaviors, controlling for age.

There were main effects for role on several of the likely behaviors. Students were more likely to believe that a student with ADHD would ask too many questions in class [$F(1, 364)=16.58$, $p<.001$, $\eta_p^2=.04$], slow down lectures [$F(1, 364)=17.49$, $p<.001$, $\eta_p^2=.05$], make distracting movements [$F(1, 364)=30.46$, $p<.001$, $\eta_p^2=.08$), fail to take turns in discussions [$F(1, 364)=21.52$, $p<.001$, $\eta_p^2=.06$], display obsessive–compulsive behaviors [$F(1, 364)=23.44$, $p<.001$, $\eta_p^2=.06$), disrupt class with noises [$F(1, 364)=11.53$, $p<.001$, $\eta_p^2=.03$], and become frustrated in class [$F(1, 364)=14.27$, $p<.001$, $\eta_p^2=.04$].

There were main effects of self-diagnosed ADHD on three of the behaviors. Students without ADHD symptoms were more likely to think students with ADHD would cheat on an exam [$F(1, 364)=4.15$, $p=.042$,

η_p^2=.01], ask too many questions in class [F(1, 364)=10.50, p<.001, η_p^2=.03], and slow down lectures [F(1, 364)=10.55, p<.001, η_p^2=.03].

There was an interaction between the participant's role and self-diagnosed ADHD on the likelihood of a student with ADHD slowing down lectures with questions [F(1, 364)=5.73, p=.017, η_p^2=.02]. Among students, there was no difference in perceptions between those with and without ADHD. Among faculty participants, those with self-diagnosed ADHD were significantly less likely to think that a student with ADHD would slow down lectures with questions [F(1, 364)=10.15, p=.002, η_p^2=.03] (Figure 2).

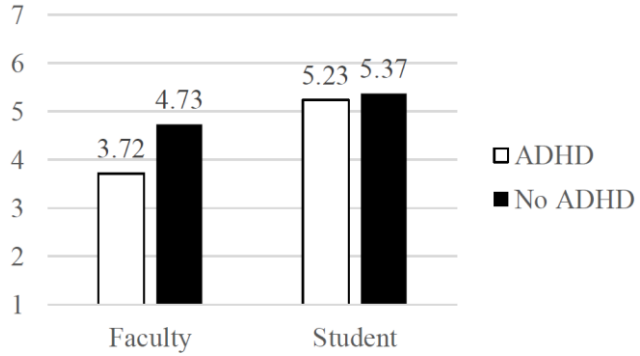

Figure 2. Interaction between self-diagnosis and participants' role on perceptions of the likelihood of a student with ADHD slowing down lectures with questions.

There was also an interaction between the participant's role and self-diagnosed ADHD on the likelihood that a student with ADHD would make distracting movements [F(1, 364)=7.24, p=.007, η_p^2=.02]. For participants with ADHD, students were significantly more likely to think a student with ADHD would make distracting movements [F(1, 364)=32.37, p<.001, η_p^2=.08]. The difference was also significant for participants without ADHD, but the effect was smaller [F(1, 364)=10.26, p=.001, η_p^2=.03] (Figure 3).

ADHD Stigma

We conducted a two-way ANCOVA with role (faculty or student) and self-diagnosed ADHD as the fixed factors, and the six subscales of the ADHD stigma scale as the dependent variables. We controlled for age.

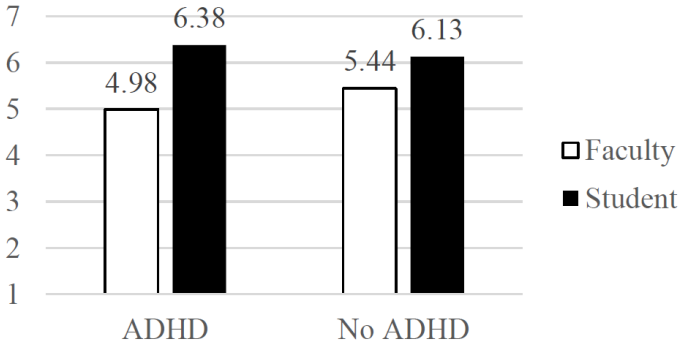

Figure 3. Interaction between self-diagnosis and participants' role on perceptions of the likelihood of a student with ADHD making distracting movements

There was a main effect of role on the reliability scale [F(1, 364)=10.17, p=.002, η_p^2=.03] ($M_{student}$=2.16, SE=.04; $M_{faculty}$=1.80, SE=.09). There was a main effect of role on the malingering [F(1, 364)=11.38, p<.001, η_p^2=.03] ($M_{student}$=1.88, SE=.05; $M_{faculty}$=1.45, SE =.10). There was a main effect of role on responsibility [F(1, 364)=9.29, p=.002, η_p^2=.03] ($M_{student}$=1.94, SE=.05; $M_{faculty}$=1.50, SE=.12). There was a main effect of role on externalizing [F(1, 364)=18.83, p<.001, η_p^2=.05] ($M_{student}$=2.88, SE=.05); $M_{faculty}$=2.24, SE=.12).

There was a main effect of ADHD self-diagnosis on reliability [F(1, 364)=9.07, p=.003, η_p^2=.02], with participants who likely have ADHD scoring lower (M=1.86, SE=.07) compared with those without ADHD (M=2.10, SE=.05). Similarly, there was a main effect of ADHD self-diagnosis on responsibility [F(1, 364)=9.06, p=.003, η_p^2=.02]. Participants who self-reported being likely having ADHD had lower scores on the responsibility subscale (M=1.57, SE=.09) than participants without ADHD (M=1.87, SE=.06).

There was a significant interaction between role and self-diagnosed ADHD on externalizing [F(1, 364)=4.21, p=.041, η_p^2=.01]. Examining simple main effects revealed that for participants with ADHD, faculty had significantly lower scores on the externalizing subscale compared with the student participants [F(1, 364)=19.70, p<.001, η_p^2=.05]. The same pattern of results occurred for participants without ADHD, but the effect was not as large [F(1, 364)=6.55, p=.001, η_p^2=.02] (Figure 4).

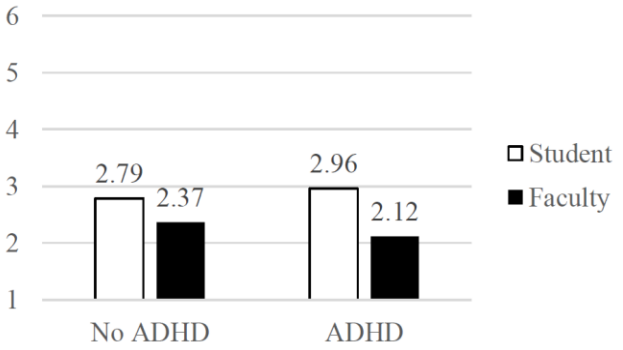

Figure 4. Interaction between self-diagnosed ADHD and role on externalizing

Discussion

It is of growing concern that few studies examine the presentation of ADHD in adults and even fewer studies that have examined gendered perceptions of ADHD. Our findings revealed no discernable pattern of gendered perceptions of ADHD. "Eric" was perceived similarly to "Erica" on all measures except for one of the controllability items. Only one previous study has examined gendered perceptions of ADHD stigma at the college level (Canu et al., 2008), and the findings of the present study fall in line with that study.

Our study was the first study to compare students and faculty members on their perceptions of ADHD. Our findings indicated that students displayed more negative attitudes than faculty towards their peers with ADHD. Faculty had more positive impressions than students of working with Eric[a], they were more supportive of academic accommodations for students with ADHD, and they had lower scores on several subscales of the ADHD stigma scale. Overall, several findings in the present study support the notion that faculty members were more empathetic and had more positive impressions of a student with ADHD compared with the undergraduate participants.

Among students and faculty, having self-diagnosed symptoms of ADHD reduced negative perceptions of a student with ADHD. This is not surprising, given the robust in-group favoritism effect in the social identity theory literature (e.g., Tajfel et al., 1971). Student participants with symptoms of ADHD were less likely to socially distance themselves from someone with ADHD and were less likely to believe that a student with ADHD would cheat or slow down lectures. Similarly, faculty with ADHD were less likely to perceive students with ADHD as distracting.

Limitations

Several limitations were faced in our study. The internal validity of two of the six ADHD stigma subscales demonstrated a notably lower internal validity. Cronbach's α values for the consequences of diagnostic disclosure and norm-violating behaviors were .68 and .69, respectively. We removed one item from the norm-violating behaviors subscale, which resulted in an alpha of .69. However, removing further items from either subscale did not improve the α values. Findings with those two subscales of the ADHD stigma scale should be viewed with caution.

Participants were required to remain on the vignette page for 30 seconds. The intention behind this stipulation was to ensure sufficient engagement and thoughtful consideration of the presented vignettes. Unfortunately, many participants exited the survey at this point. We speculate that participants either believed the survey was "broken" or grew frustrated that they could not advance to the next page of the survey. In hindsight, we should have informed participants of the fact that they would be required to stay on that page for 30 seconds.

Because of the difficulty of getting faculty participants, we opened the survey to faculty from other universities. Thus, the faculty data included participants from our university as well as some participants from other universities. Different universities (and states) have distinct academic cultures and educational priorities. We cannot be sure whether our findings are limited to our university or whether we can generalize to faculty more broadly.

Each fall semester, Weber State University hosts its annual diversity conference. Coincidentally, in 2023, the conference theme was neurodiversity. The conference was open to both faculty and students. However, student data collection for the present study began in spring 2023 (prior to the diversity conference), and faculty data began around the time of the diversity conference (fall 2023). We failed to ascertain whether our participants attended this event. The conference may have provided participants with heightened awareness and a deeper understanding of neurodiversity. By not accounting for this variable, we may have missed an important factor that could explain some variability in the data. This provides important directions for future inquiry, which are discussed below.

Future Directions

Many universities have begun to include curricula directly focusing on mental health awareness and advocacy. To our knowledge, no studies have examined the extent to which such coursework reduces MHS. If there are university-wide events, such as our university's diversity

conference on neurodiversity, that would be an excellent opportunity to provide evidence of the efficacy of such programming. Mental health awareness courses may provide an avenue to curb MHS, and ADHD stigma in particular.

We attempted to collect data on the faculty member's department at the university. However, for ethical reasons, we kept this question optional. Some departments at our university are small, and this question could make the survey less anonymous for participants in small departments. That said, it would be interesting to examine whether faculty in specific fields are more stigmatizing toward students with ADHD compared with faculty in other fields. For example, future research might compare STEM faculty members with faculty in the social sciences on their perceptions and stigma toward students with ADHD. These are essential questions to address in future research.

Conclusion

ADHD used to be regarded as a disorder that occurred in childhood. However, we now know that for many children diagnosed with ADHD, symptoms persist into adulthood. It is estimated that about 2-8% of college students experience ADHD (Green & Rabiner, 2012), yet little is known about the stigma they may face from their peers or their professors. Our study is one of the first to examine perceptions of a college student with ADHD, particularly focusing on gendered perceptions. There was no evidence of gendered perceptions of college students with ADHD. We did find that compared with undergraduate students, faculty members had less stigma and fewer negative perceptions of a student with ADHD. Finding ways to reduce MHS, and ADHD stigma in particular, is a crucial direction for future research.

ADHD stigma is detrimental to a student's academic and social well-being. Anticipating being discriminated against is associated with impaired psychosocial functioning and a lower quality of life (Masuch et al., 2019). Research shows neurodivergent individuals are reluctant to seek treatment because of concerns about MHS (e.g., Eisenberg et al., 2007; Wu et al., 2007). Alarmingly, recent data provided evidence that controlling depression and ADHD among college students predicted suicide ideation (Eddy et al., 2020). Given the overwhelming evidence that MHS negatively impacts several areas of functioning, we hope there will be more research examining stigma toward college students with ADHD.

References

Akin, D., & Huang, L.M. (2019). Perceptions of college students with disabilities. *Journal of Postsecondary Education and Disability, 32*(1), 21–33.

American Psychiatric Association (2013). *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596.

Canu, W.H., Newman, M.L., Morrow, T.L., & Pope, D.L. (2008). Social appraisal of adult ADHD: stigma and influences of the beholder's Big Five personality traits. *Journal of Attention Disorders, 11*(6), 700–710. https://doi.org/10.1177/1087054707305090.

Corrigan, P.W., Kerr, A., Knudsen, L. (2005). The stigma of mental illness: Explanatory models and methods for change. *Applied and Preventive Psychology, 11*(3), 179–190. https://doi.org/10.1016/j.appsy.2005.07.001.

Corrigan, P.W., & Rao, D. (2012). On the self-stigma of mental illness: stages, disclosure, and strategies for change. *Canadian Journal of Psychiatry, 57*(8), 464–469. https://doi.org/10.1177/070674371205700804.

Corrigan, P.W., Mittal, D., Reaves, C.M., Haynes, T.F., Han, X., Morris, S., & Sullivan, G. (2014). Mental health stigma and primary health care decisions. *Psychiatry Research, 218*(1-2), 35–38. https://doi.org/10.1016/j.psychres.2014.04.028.

Chew, B. L., Jensen, S. A., & Rosen, L. A. (2009). College students' attitudes toward their ADHD peers. *Journal of Attention Disorders, 13*(3), 271–276. https://doi.org/10.1177/1087054709333347.

Dakwar, E., Levin, F.R., Olfson, M., Wang, S., Kerridge, B., & Blanco, C. (2014). First treatment contact for ADHD: Predictors of and gender differences in treatment seeking. *Psychiatric Services, 65*(12), 1465–1473. https://doi.org/10.1176/appi.ps.201300298.

De Rossi, P., Pretelli, I., Menghini, D., D'Aiello, B., Di Vara, S., & Vicari, S. (2022). Gender-related clinical characteristics in children and adolescents with ADHD. *Journal of Clinical Medicine, 11*(2), 385. https://doi.org/10.3390/jcm11020385.

Eddy, L.D., Eadeh, H.M., Breaux, R., & Langberg, J.M. (2020). Prevalence and predictors of suicidal ideation, plan, and attempts, in first-year college students with ADHD. *Journal of American College Health, 68*(3), 313–319. https://doi.org/10.1080/07448481.2018.1549555.

Eisenberg, D., Golberstein, E., & Gollust, S.E. (2007). Help-seeking and access to mental health care in a university student population. *Medical Care, 45*(7), 594–601. https://doi.org/10.1097/MLR.0b013e31803bb4c1.

Godfrey, E., Fuermaier, A.B.M., Tucha, L., Butzbach, M., Weisbrod, M., Aschenbrenner, S., & Tucha, O. (2021). Public perceptions of adult ADHD: Indications of stigma? *Journal of Neural Transmission, 128*, 993–1008. https://doi.org/10.1007/s00702-020-02279-8.

Goffman E. (1963). *Stigma: Notes on the Management of Spoiled Identity*. Prentice-Hall.

Green, A.L., & Rabiner, D.L. (2012). What do we really know about ADHD in college students? *Neurotherapeutics, 9*(3), 559–568. https://doi.org/10.1007/s13311-012-0127-8.

Lebowitz, M.S. (2016). Stigmatization of ADHD: A developmental review. *Journal of Attention Disorders, 20*(3), 199–205. https://doi.org/10.1177/1087054712475211.

Mak, A.D.P., Lee, S., Sampson, N.A., Albor, Y., Alonso, J., Auerbach, R.P., Baumeister, H., Benjet, C., Bruffaerts, R., Cuijpers, P., Ebert, D.D., Gutierrez-Garcia, R.A., Hasking, P., Lapsley, C., Lochner, C., & Kessler, R.C. (2021). ADHD comorbidity structure and impairment: results of the WHO World Mental Health Surveys International College Student Project (WMH-ICS). *Journal of Attention Disorders, 26*(8), 1078–1096. https://doi.org/10.1177/10870547211057275.

Masuch, T.V., Bea, M., Alm, B., Deibler, P., & Sobanski, E. (2019). Internalized stigma, anticipated discrimination and perceived public stigma in adults with ADHD. *ADHD Attention Deficit and Hyperactivity Disorders, 11*(2), 211–220. https://doi.org/10.1007/s12402-018-0274-9.

Mueller, A.K., Fuermaier, A.B.M., Koerts, J., & Tucha, L. (2012). Stigma in attention deficit hyperactivity disorder. *ADHD Attention Deficit and Hyperactivity Disorders, 4*(1), 101-114. https://doi.org/10.1007/s12402-012-0085-3.

National Institute of Mental Health (2024, September). *Mental Illness*. https://www.nimh.nih.gov/health/statistics/mental-illness#part_2539.

Ohan, J.L., Visser, T.A., Strain, M.C., & Allen, L. (2011). Teachers' and education students' perceptions of and reactions to children with and without the diagnostic label "ADHD." *Journal of School Psychology*, *49*(1), 81–105. https://doi.org/10.1016/j.jsp.2010.10.001.

Olsson, Å. (2022). Teachers' gendered perceptions of attention deficit hyperactivity disorder – a literature review. *European Journal of Special Needs Education, 38*(3), 303–316. https://doi.org/10.1080/08856257.2022.2076476.

Ostman, M., & Kjellin, L. (2002). Stigma by association: Psychological factors in relatives of people with mental illness. *British Journal of Psychiatry, 181*, 494–498. https://doi.org/10.1192/bjp.181.6.494.

Rössler W. (2016). The stigma of mental disorders: A millennia-long history of social exclusion and prejudices. *EMBO Reports, 17*(9), 1250–1253. https://doi.org/10.15252/embr.201643041.

Rüsch, N., Angermeyer, M., & Corrigan, P. (2005). Mental illness stigma: Concepts, consequences, and initiatives to reduce stigma. *European Psychiatry, 20*(8), 529–539. https://doi.org/10.1016/j.eurpsy.2005.04.004.

Sickel, A.E., Seacat, J.D., & Nabors, N.A. (2014). Mental health stigma update: A review of consequences. *Advances in Mental Health, 12*(3), 202–215. https://doi.org/10.1080/18374905.2014.11081898.

Skogli, E.W., Teicher, M.H., Andersen, P.N., Hovik, K.T., & Øie, M. (2013). ADHD in girls and boys—gender differences in co-existing symptoms and executive function measures. *BMC Psychiatry, 13*, 298. https://doi.org/10.1186/1471-244x-13-298.

Song, P., Zha, M., Yang, Q., Zhang, Y., Li, X., & Rudan, I. (2021). The prevalence of adult attention- deficit hyperactivity disorder: A global systematic review and meta-analysis. *Journal of Global Health, 11*, 04009. https://doi.org/10.7189/jogh.11.04009.

Tajfel, H., Billig, M.G., & Bundy, R.P. (1971). Social categorization and intergroup behavior. *European Journal of Social Psychology, 1*, 149–178. https://doi.org/10.1002/ejsp.2420010202.

Thompson, A.C., & Lefler, E.K. (2019). ADHD stigma among college students. *ADHD Attention Deficit and Hyperactivity Disorders, 8*, 45–52. https://doi.org/10.1007/s12402-015-0179-9.

Vance, T.A., & Weyandt, L. (2008). Professor perceptions of college students with attention deficit hyperactivity disorder. *Journal of American College Health, 57*(3), 303–308. https://doi.org/10.3200/jach.57.3.303-308.

Watson, A.C., Corrigan, P., Larson, J.E., & Sells, M. (2007). Self-stigma in people with mental illness. *Schizophrenia Bulletin, 33*(6), 1312–1318. https://doi.org/10.1093/schbul/sbl076.

Wiener, J., Malone, M., Varma, A., Markel, C., Biondic, D., Tannock, R., & Humphries, T. (2012). Children's perceptions of their ADHD symptoms: Positive illusions, attributions, and stigma. *Canadian Journal of School Psychology, 27*(3), 217-242. https://doi.org/10.1177/0829573512451972.

Wu, L., Pilowsky, D.J., Schlenger, W.E., & Hasin, D. (2007). Alcohol use disorders and the use of treatment services among college-age young adults. *Psychiatric Services, 58*(2), 192–200. https://doi.org/10.1176/ps.2007.58.2.192.

Appendix

Vignette

[Eric/Erica] is 20 years old. [He/She] is very sociable and friendly with you, introducing [himself/herself] at the beginning of the semester. You notice [he/she] is always moving and fidgeting in [his/her] chair, getting up multiple times during class to get water, throwing trash away, or doodling while the professor is lecturing. [He/She] makes connections

between concepts quickly but seems to constantly change from taking notes on a laptop, notebook, or the back of other documents throughout the semester. [He/She] likes to participate in class, but often forgets to raise [his/her] hand. Instead, [he/she] constantly blurts out questions, so much so that you don't get a chance to answer. [He/She] is clearly intelligent and willing to interact in the class, although [he/she] often interjects [himself/herself] into her classmates' conversations throughout the semester. When assisting [Eric/Erica] on a writing assignment, you notice [his/her] assignment contains careless mistakes, is lacking in detail, and in the end was turned in late. [Eric/Erica] asks you the same question several times throughout the semester and appears very forgetful even though she writes everything down religiously. [He/She] also seems to come to class ill-prepared; [he/she] sometimes needs to borrow a pen or paper. [Eric/Erica] often struggles to focus during exams, looking around the room and appearing "scatterbrained." Sometimes, when the exams are passed back, [Eric/Erica] realizes that [he/she] forgot to answer a few of the questions. [Eric/Erica] seems to struggle with the motivation and focus in the class, even though [he/she] puts forth a lot of effort. At the end of class, you usually find [Eric/Erica] looking for [his/her] phone, pencil, or keys, which [he/she] "swears I just had."

Becoming Fannibals: Identity and Engagement in the *Hannibal* Fandom

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Abstract

"Hannibal," a TV crime drama based on Thomas Harris's book series of the same name, aired on NBC from 2013 to 2015 and has garnered a large following that continues to grow even ten years after the show's debut. The objective of this research was to analyze the fandom surrounding NBC's "Hannibal." This research explores the questions of why the fandom has been so prolific; how its fans interact with the show, each other, and fan-made content online; how the "Hannibal" fandom operates; and what the motivations, experiences, and identities of those within it are? To understand the experiences of fans of "Hannibal," a literature review was completed, a 39-question anonymous Google Forms survey was promoted in social media groups dedicated to the show, and a thematic analysis of the survey results was performed. The preliminary analysis of survey results indicated that a majority of participants identify as 2SLGBTQIA+, white, neurodivergent, and having a mental health condition; themes of representation, inspiration, community, appreciation, and exploration of identity emerged.

Introduction

Hannibal is a TV adaptation of Thomas Harris's tetralogy by the same name starring Mads Mikkelsen and Hugh Dancy, created by Bryan Fuller. It aired for three seasons on NBC from 2013 to 2015. It includes elements of the plots from all four books, but it does not feature Clarice Starling or the plot of *The Silence of the Lambs*. The show revolves around the relationship between renowned psychiatrist (and cannibalistic serial killer) Dr. Hannibal Lecter and neurodivergent FBI special investigator Will Graham. Unlike the books and their movie adaptations, the show begins before Dr. Lecter has been found out. Thus, the plot of Season One is about Graham's criminal investigations with the help of Dr. Lecter, and, eventually, Graham's investigation of Dr. Lecter himself. As the show progresses, we see their relationship evolve from a mutual appreciation to a never explicitly stated, but clearly defined, emotional affair. Dr. Lecter and Graham's relationship in NBC's *Hannibal* is heavily inspired by the romance between Clarice Starling and Hannibal Lecter as seen in *The Silence of the Lambs* (1988) and *Hannibal* (1999).

Fans of NBC's *Hannibal*, so-called 'fannibals,' have created and sustained a vibrant online fandom even years after the show's cancellation. The fandom is especially known for including many 2SLGBTQIA+ fans. This paper lays out preliminary research findings exploring why the fandom has been so prolific, how its fans interact with the show, each other, and fan-made content online, and what the motivations, experiences, and identities of those in it are.

Literature Review

Hannibal subverts tropes and conventions of queer media and crime procedurals by challenging stereotypes of sexuality, gender, and race. *Hannibal* acknowledges the queerphobic history of queer-coded villains, using it to humanize rather than vilify queer characters. This reclamation allows *Hannibal* to present a queer love story that is transformative and deeply humanizing, challenging the homonormative portrayals prevalent in contemporary media. Bryan Fuller's approach to his adaptation provides a complex and nuanced representation of queerness that resonates with queer audiences, positioning queerness as a signifier of humanity and belonging. In this way, *Hannibal* subverts the genre expectations for a horror show by featuring queer characters that are nuanced and complex and that exist outside of stereotypes and tropes (Crape, 2022).

Hannibal is unique not only because it features queer characters, but it is unique in its portrayals of queerness. The show's portrayal of

queerness, which incorporates elements of the monstrous and the uncanny, is more liberating and relatable for queer viewers than more normative representations. The show's extravagant visual style and its focus on artistic, grotesque murders serve to queer the crime procedural genre, distancing it from traditional narratives that uphold heteronormative justice. This contrasts with the post-marriage equality push for positive, sanitized queer representation, which might do more harm than good in its creation of an unhelpful "homonormativity." This approach creates a queer story featuring queer characters that are more relatable to and perhaps liberating for a queer audience (Donovan, 2016).

Hannibal is subversive within the crime procedural genre by using a queer love story to drive the plot with the addition of other queer characters. The series shifts the traditional detective dynamic by featuring a neurodivergent protagonist, Will Graham, whose perspective, abilities, and disabilities are central to the narrative. This subversion of expectations also extends to gender and race-bent characters that create a diverse cast that challenges crime procedural tropes. Through its portrayal of self-sufficient women, neurodivergent, and queer people, *Hannibal* breaks the norms of the crime procedural genre in a way that makes more space for marginalized viewers (Casey, 2015).

Hannibal has garnered a large, devoted fanbase that continues to grow to this day, despite the show's cancellation in 2015. Tumblr has become a central hub for the fandom, starting when the show first aired and continuing to thrive today. The platform's "rhizomatic" nature facilitates rapid growth and diversification within fandoms. Tumblr's visual and interconnected nature makes it easy for fans to participate in the online fandom space, and *Hannibal*'s fandom is no exception (Morimoto and Stein, 2018). The interaction between fans and the show's cast and crew, such as Mads Mikkelsen recognizing fans by their flower crowns, illustrates the permeable boundary between fan culture and the production team. This mutual recognition fosters a sense of shared community and ownership over the cultural product (Nielsen and Morimoto, 2023).

Media texts and fandoms provide structure and meaning to individuals' lives. For many fans, *Hannibal* contributes to their identity and sense of self, especially through seeing one's identities or experiences represented by characters in the show (Williams, 2018). The show's end threatened the "ontological security" of its fans, a concept referring to the stability provided by ongoing engagement with a beloved series. This disruption led fans to find ways to maintain their connection to the show, which manifested mostly in online fandom engagements. This passion sustained after the end of the show has continued today as new fans discover the show and join the community (Williams, 2018).

The interactive dynamic between the fans and the creators of the show, particularly through social media and events, highlights a mutual enthusiasm that blurs the lines between fans and creators. This relationship not only sustains the fandom's vitality but also reinforces the sense of community and shared identity among fannibals, demonstrating the lasting impact of *Hannibal* on its dedicated audience (Ewoldt, 2019).

The findings of this literature search present *Hannibal* and its fandom as a queer phenomenon. This research seeks to further understand the identities and experiences of members of the fandom.

Methods

A 39-question anonymous Google Forms survey was promoted in social media groups dedicated to the show. It was posted on both X (Twitter) and Tumblr but only received engagement and responses from Tumblr. The survey was published in December 2023 and has received 25 responses. The survey included 9 demographic, 24 multiple-choice, and 15 free-response questions (including both closed and open-ended questions). Informed consent was obtained before beginning the survey. Participants were informed that they could skip any question and that they did not have to provide any information they were not comfortable sharing. See the Appendix for the full survey. This research received approval from the Salt Lake Community College Institutional Review Board for November 2023 until November 2024.

In a preliminary thematic analysis, the themes identified were *Hannibal*'s unique queer representation, community engagement, and self-understanding.

Demographic Data

Participants ranged in age from 18 to 44 years, but most were between the ages of 18 and 24 years. Nearly all (96%) of the participants identified as white, and most live in North America. The majority (88%) of participants identified as 2SLGBTQIA+, with a majority identifying as queer, non-binary, and/or transgender. A majority identified as having a mental health condition, and a majority also reported identifying as neurodivergent. Twelve respondents (48%) identified as autistic, having autism spectrum disorder (ASD), or otherwise being on the autism spectrum.

Engagement Data

Most participants have watched *Hannibal* three times or less, with most having watched it three times. Most people found the show through Tumblr, although this is likely due to selection bias, whereas 32% heard about the show through friends, family, or others they know in real life. Despite the show airing from 2013 to 2015, most participants first watched it within the last two years (between 2022 and 2023). The year participants joined the fandom mostly correlates with the year they first watched the show. Most participants identify as a 'fannibal,' the fan-coined name for those who participate in the *Hannibal* fandom.

In addition to Tumblr, most participants engage in the *Hannibal* fandom on fanfiction sites like Archive Of Our Own (AO3) and Wattpad. Other social media sites were also represented, with YouTube, TikTok, Instagram, Facebook, Reddit, and Discord all used by some participants. Most participants primarily engage with the *Hannibal* fandom on Tumblr, although 20% said they primarily engage with the fandom on fanfiction sites.

Participants consume a variety of fan-made content, with no category left untouched. Memes, fanart, fanfiction, GIFs and screenshots from the show, and meta-analysis/critique are the most popular categories, with 100% of participants saying they consume fanart. Most participants also make their own fan content, with most making memes, analysis/critique, and fanart, with fanfiction being the most popular medium.

Results

The selected quotes from the survey responses highlight recurring patterns and themes that emerged across many participants' answers, as identified through coding. Because of the open-ended nature of the questions, these quotes are not a one-to-one correspondence between survey questions and answers and are instead thematically organized. See the Appendix for full survey questions.

Community Engagement

From the preliminary thematic analysis, one of three main themes that emerged was community engagement. Despite the show ending in 2015, having only run for three seasons of the planned four, the *Hannibal* fandom has remained active and passionate and continued to grow, long after the show's original run. Participants noted several factors that contribute to this sustained and growing community.

Participants said the show's narrative and characters are compelling and layered, offering new insights with each rewatch. This complexity keeps fans engaged over time. Also mentioned was the quality of the show, with some saying there is always more to find on a rewatch and that its artistic quality keeps it intriguing even years later.

> "*Hannibal* is complex, as it requires a lot of knowledge, media literacy, and comprehension to understand. I've found that media such as this tends to "stick," or is not easily forgotten as it allows the viewer to reflect more than other media does. That said, I think that what contributes most to the fandom's longevity is the uniqueness of the show's premise and, thus, the uniqueness of the members of its fandom. It's not something you can easily find elsewhere, and, thus, it begins to feel like home."

Participants said that *Hannibal*'s appeal to a queer and neurodivergent audience has contributed greatly to sustained community engagement. The unique and nuanced portrayal of queer characters has created a loyal fanbase that feels a deep connection to the show. Many explained that *Hannibal* helped them feel seen when they usually feel othered and that when a show can have such a positive impact on one's sense of self and community, people are not quick to abandon it.

> "I think … the show truly is one of a kind and there's always more about the elements of the show to discover. Also the show really resonates with a lot of us who have felt othered and different from society and shows that we can actually be loved in a way that doesn't involve us [being] toned down or a love that's inauthentic. That we can embrace ourselves as we are. That we don't have to be changed to be loved. The story is very potent and powerful."

Participants report participating in the fandom not only for the content of the show but for the other people present in the online spaces. They say they have seen and met queer people and that encourages them to keep engaging with the community.

> "I really feel like it's a niche space that I belong in. I also found that a lot of people in the fanbase were also trans or queer in some way and at the end of the day that's why I keep coming back. It was just for the show to start, but it eventually was because of like-minded people and a welcoming atmosphere."

According to the thematic analysis of survey responses, the *Hannibal* fandom seems to be very positive and an easy space to exist online where discussion is encouraged and harassment is uncommon.

> "There's no fandom that I've found quite as accepting as Fannibals. I love it here, we love eachother [sic] and don't see any point in being rude."

Participants say the show attracts a community of viewers who enjoy analyzing and discussing its intricate details. This intellectual engagement fosters a strong sense of community. Meta-analyses (referred to as "metas" in the fandom) and critiques were reported to be one of the most commonly made and consumed types of *Hannibal* fan content, this further emphasizes the culture of discussion.

> "The show itself is a masterpiece, artistically speaking, and the type of thing that can't be fully understood by most people by themselves, so it sparks discussions and community. The characters also go through a lot of shit, which makes people root for them and empathize. There are so many minor details and lots of care put into the show. everyone [sic] has a different interpretation so it really has endless content to consume."

Participants say the show's visual and narrative artistry continues to draw new viewers and retain existing fans.

> "Thomas Harris created a legacy and Bryan Fuller elevated it. We as humans are intrigued by darkness. We love the shock value of true crime and murder mystery. While being aesthetically pleasing, this show lets us explore those unspeakable qualities we all can't pull our thoughts away from. There's not much material exploring cannibalcore so when it's done this well, there will always be a specific group of people who won't let it die."

It was also mentioned that the fact that the show was canceled prematurely may make for a more loyal and passionate fandom. Persistent hope for a potential season 4 keeps the fanbase active and engaged. Participants remarked that the involvement of the creators and cast of the show in the fandom, and their hints and hopes for a renewal keep the fandom's interest piqued.

> "The show just keeps giving, at a base line. Second, the hope for another season continues to be stoked by cast and crew. Third, it's a show that goes on a little shelf once you watch it. Even if everyone isn't actively part of the fandom year round, fans of the show will rewatch it and fall back into the fandom time and time again."

The proliferation of the Hannibal fandom can be summarized by a participant who said, "I love it. The show is done, but the fandom isn't."

Participants report feeling inspired by Hannibal to make fan content, that the aesthetic of the show, the cliffhanger ending, and the relationships between the characters inspire their creativity.

> "I think the show is, first of all, visually beautiful, which inspires me to draw. I think the writing is poetic which then makes me want to write better. It's [sic] literary allusions/references are very widespread and well thought out meaning many other books end up reminding me of it and drawing me back. Hannibal and Will's relationship is so unique and interwoven with so much imagery it's hard to forget. Most of all, the ending was 'inconclusive' (if you'd like) and I love an ending that lets you think about all the what ifs. … That's what makes it such a fun base media to play with and expand on."

Some participants said that being neurodivergent contributes to their desire to create Hannibal fan content.

> "I love the show, and like many neurodivergent individuals, when I love something deeply I am driven to create and engage with that thing as much as possible, it makes me feel happy and fulfilled."

By posting fan content they make and sharing fan content they appreciate, participants feel a part of a community and seek to make other fans of the show happy.

> "[I post my fan content] for the sense of community! I love analyzing episodes all as a group and bouncing ideas off of each other, or sharing my specific wishes and takes for and on the characters for others to see, or making a niche joke only to see it gain traction."

Posting fan content online also provides a platform to showcase participants' hard work, receive feedback, and feel a sense of accomplishment and pride.

> "I'm proud of the work/thought I put into *Hannibal* content. If I put work into a character analysis or dissecting a monologue or in a cosplay, I want to share it with others. I want to hear their feedback."

By sharing their fan content participants said they can connect with people who understand their interests and taste.

> "It helps me express my creativity and I find 'cannibal core' beautiful. It's nice to be able to express and explore my darkness while someone else is finding it beautiful, relatable, and or funny."

One participant summed up fan creation by saying, "Why do we create? Because it would be unbearable not to."

Unique Queer Representation

The second theme that emerged from the analysis was *Hannibal's* distinct portrayal of 2SLGBTQIA+ characters, deviating significantly from other TV shows in its representation. The participant responses highlight several unique aspects that contribute to this distinction, which include the natural evolution of queer relationships, the complex and messy nature of character identities, and the central yet nuanced focus on queerness within the narrative.

Participants commented on all the characters being multi-dimensional and complex, noting that, unlike many queer shows that sanitize characters into clear categories, *Hannibal* thrives in the ambiguity and complexity of its characters' identities. Their queerness is not the central focus of their identity, nor is it their only attribute. This approach seems to have allowed for a richer, more nuanced portrayal of queer characters who are multifaceted and morally ambiguous: they are not merely defined by their queerness but are deeply complex individuals with diverse motivations and behaviors. Participants appreciated this complexity, feeling that it reflects real-life experiences more accurately.

> "Of all the queer shows I've watched, never, ever ever has a show held my identity in its hands and given it a kiss the way *Hannibal* has. The thing about *Hannibal*, I think, is that it lets

> itself be messy. Most queer media is sanitized into clear categories of identity, but in *Hannibal*, all the lines blur together. It's a show about accepting yourself but it's not a show about Categorizing yourself. It's about finding your footing in the gaps outside of social norms. It's about love. It's about murder. It's about slipping into grey areas and finding yourself alive for the first time in a thousand years."

Participants pointed out that the show avoids the pitfalls of queerbaiting and tokenism, instead presenting queer relationships in the same way it does straight ones—naturally and without undue emphasis. The queerness simply exists within a larger story, it does not serve a purpose outside the story of the show. The show's portrayal of queer relationships is significant yet subtle. It does not prioritize the characters' sexual identities over their development and actions within the story. This subtlety makes the representation feel more integrated and less performative. "Hannibal has fully revolutionized how I view love and violence and has opened my mind to stuff like that."

Participants addressed the reclamation of problematic source material, noting that Hannibal's exceptional queer reclamation of its source media transforms a story with anti-queerness at its heart and queer-coding as a rhetorical staple into an entirely by-queers-for-queers retelling.

> "Bryan Fuller took a masterpiece and made it better and modernized it for today's political climate."

Participants acknowledged the complicated history that the horror genre has with queerness, but most said that Hannibal does not fall into the "queer villain" stereotype both because the characters' villainy is not tied to their queerness, and because all types of characters—evil or not—are all allowed to be queer. Participants also said that Hannibal's queerness in its horror avoids villainizing because it portrays the queer relationships in ways that straight relationships have been portrayed in horror before—as complex and intricate, not simply existing for the sake of "representation." They say Hannibal's elements of horror are something new in a queer love story, refreshing, exciting, not overdone.

> "To me, it's never felt like it was a show overly concerned with portraying itself as positive queer representation. Instead, it is deeply devoted to its storytelling and its characters. Will, Hannibal, Alana, and Margot are all queer, but this does not preclude them from being very complicated characters who all

> engage in all sorts of morally dubious behavior, sometimes relating to their sexualities, sometimes not. Sometimes I feel as though shows which advertise themselves as queer are too worried about their queer protagonists coming across as pure, good, and relatable, and this can get in the way of storytelling. Other times, queer characters are shown as doing morally reprehensible things, and this leaves an implication that the two are somehow linked. *Hannibal* manages to avoid this entirely, by having characters who are gay and do gay things, and also frequently are horrible and do horrible things, without it ever feeling like this is borne out of any stereotypes or negative impression of the queer community."

Participants described *Hannibal* as uniquely blending its horror elements with its queer themes, creating a distinct narrative experience, noting that the element of horror is integral to the queerness and vice versa, as the love plot wouldn't exist without the elements of horror. They say the horror genre allows for a more raw and intense exploration of themes like love, obsession, and identity. This blending of horror and queerness challenges traditional representations and provides a fresh perspective that seems to resonate with participants.

> "I think *Hannibal* was great in showing how lost a person can be and also people always think they're too smart to be manipulated or they'd never end up in a cult, etc... but anyone can be. They did also show that when you accept who you are, you can truly be free and find understanding."

Participants expressed the value of *Hannibal* not being a love story about teens or young adults, homophobia/discrimination, or internalized homophobia. It establishes a world where queerness is incredibly normal and not worth commenting on, which participants found to be a more liberatory representation.

> "This isn't a cute love-story between teenagers. Sometimes you can realise that you are not entirely straight when you are almost 40 years old and it's fine. Love is connected with violence, homosexual urges are struggled against as much as the dark nature for so long."

Self-Understanding

The last theme that the analysis revealed was *Hannibal*'s influence on fan's self-understanding. The participant responses discuss the experiences of finding and understanding their gender, sexuality, and neurotype, as well as being inspired to pick up new hobbies and form new habits.

Some participants report a better understanding of their mental health after watching *Hannibal*. They say they have improved their introspection, self-acceptance, confidence, and mental health coping strategies.

> "It has helped me accept parts of myself and feel less ashamed about intrusive or unusual thoughts."

Participants said the show has had an impact on their understanding of their own identities, particularly among queer and neurodivergent individuals. They appreciate that the characters they see themselves in, being queer or neurodivergent, are given agency and are portrayed as competent individuals.

> "I definitely think that *Hannibal* helped me realize I was trans and gay. Definitely not all at once, and it was a gradual realization, but I really connected to Will's character personally and that just sparked something in me. I also just really connected to him being neurodivergent in some way which I had not really seen so specifically before."

Some participants report *Hannibal* sparking their interest in related areas. Newfound interests in cooking, forensics, criminology, psychology, horror, poetry, and fine art were commonly mentioned.

> "Oh boy it definitely inspired me to cook more! I already enjoyed cooking before watching the show, but I definitely think it's made me more committed to developing specific skills. It also compelled me to write more, which is by all means a good thing. The show makes me think and then I write about it."

Participants expressed appreciation for finding a group of like-minded people in which they can feel accepted, seen, and not isolated/strange for their experiences.

> *"Hannibal* has helped me to embrace myself more. I have struggled with a lot of shame and partly because of *Hannibal*, I've been deconstructing my shame and learning how to be more indulgent. It has helped me to be myself more online and helped me learn to put myself out there more. I think *Hannibal* has also helped with my gender and sexuality too. I finally embraced being a trans guy over the course of being into *Hannibal* and I know it's not the sole reason, but it's definitely contributed."

Some also said the show is cathartic for them, that by watching the characters struggle with mental health issues and other complicated dynamics they feel less alone in their own struggles.

> "*Hannibal* has helped me a lot with my perception of self. It's one of those things where, like, yeah you aren't supposed to relate to the self-isolation and quiet loathing of a character designed to embody the actual Devil, but I do anyway. It's easier to work through my own hells when I can externalize them."

Conclusion

These initial findings point to *Hannibal* appealing to a young adult, white, queer, and neurodivergent audience. Participants say it makes them feel seen as people who are frequently othered. The show's elements of horror are directly related to its queer representation; it portrays a messier, more relatable version of queerness that has not been sanitized for a cisgender/ heterosexual audience. People report finding a sense of community, inspiration, and happiness from participating in the online fandom.

These preliminary results raise additional research questions, such as why does *Hannibal* appeal to so many transgender men? and does the lack of explicit intimacy in the show contribute to any appeal the show might have for asexual or aromantic viewers?

This survey found that participants were mostly white; does this reflect the broader viewership and fandom, or is it due to a bias from Tumblr being the sole source of participants?

These initial findings may be best encapsulated by this participant quote,

> "*Hannibal* is horror that rarely intends to frighten its audience. Rather, it beckons them in, holds them close, and whispers that what you're seeing is beautiful. It drags you down alongside Will into its world where every death is an art exhibit and every

> person has a beast inside them waiting to wake. It is upsetting and comforting and completely unlike [anything] I have ever seen."

References

Casey, Jeff. "Queer cannibals and deviant detectives: subversion and homosocial desire in NBC's *Hannibal*." *Quarterly Review of Film and Video*, vol. 32, no. 6, July 2015, pp. 550–67. doi: 10.1080/10509208.2015.1035617.

Crape, Drumlin. "The horror of our love: hannibal lecter and the reclaiming of queer villains." Master's thesis, University of Saskatchewan. May 2022. harvest.usask.ca/handle/10388/13972.

Donovan, Sean. "Becoming unknown: Hannibal and queer epistemology." *Gender Forum: An Internet Journal for Gender Studies: Queer Film and Television*, issue 59, 2016, pp. 41-65.

Ewoldt, Amanda. "Fannibals are still hungry: feeding Hannibal and other series companion cookbooks as immersive fan experience." In *Becoming: Genre, Queerness, and Transformation in NBC's Hannibal*, edited by Kavita Mudan Finn and EJ Nielsen, Syracuse University Press, 2019, pp. 239-57.

Morimoto, Lori, and Louisa Stein. "View of Tumblr and fandom." *Transformative Works and Cultures*, vol. 27, June 2018, doi: 10.3983/twc.2018.1580

Nielsen, EJ, and Lori Morimoto. "This is my (floral) design: flower crowns, fannibals, and fan/producer permeability." *Sartorial Fandom: Fashion, Beauty Culture, and Identity*, edited by Elizabeth Affuso and Suzanne Scott, University of Michigan Press, 2023, pp. 163–75.

Williams, Rebecca. "Fate has a habit of not letting us choose our own endings: postobject fandom, social media and material culture at the end of Hannibal" *A Companion to Media Fandom and Fan Studies*, edited by Paul Booth, Wiley Blackwell, 2018, pp. 572-88.

Appendix

Survey

This research project with Salt Lake Community College's sociology department aims to better understand the fandom surrounding NBC's *Hannibal* (2013-2015), why it has been so prolific, and how fannibals interact with the show, each other, and fan content.

Link to this survey: https://forms.gle/3tah3kXTP5aWVCRd6

Are you over the age of 18?*

- Yes
- No

* A "yes" response was required to continue with the survey.

Have you watched "Hannibal" (NBC, 2013-2015)? (If you have watched it but have not finished the show, please select "yes." This survey is spoiler-free.)*

- Yes
- No

* A "yes" response was required to continue with the survey.

1. How many times have you watched "Hannibal"?
    a. I haven't finished it yet
    b. Once
    c. Twice
    d. 3 times
    e. 4 times
    f. 5 or more
2. How did you hear about "Hannibal"? (select all that apply)
    a. Friends, family, or other people I know in real life
    b. Tumblr
    c. Other social media (such as Instagram, Twitter, Reddit, TikTok, etc.)
    d. Advertising
    e. I saw it on TV
    f. I found it through a streaming service
    g. I don't know/don't remember
    h. Other:

3. When did you first watch “Hannibal” (NBC, 2013-2015)? (Best guess is ok)
    a. 2013
    b. 2014
    c. 2015
    d. 2016
    e. 2017
    f. 2018
    g. 2019
    h. 2020
    i. 2021
    j. 2022
    k. 2023
    l. 2024
4. When did you join or start participating in the “Hannibal” fandom? (Best guess is ok)
    a. 2013
    b. 2014
    c. 2015
    d. 2016
    e. 2017
    f. 2018
    g. 2019
    h. 2020
    i. 2021
    j. 2022
    k. 2023
    l. 2024
5. Do you identify as a “fannibal”?
    a. Yes
    b. No
    c. Not sure

Demographic Questions

You are encouraged to answer as many questions as you feel comfortable. You may skip any question or leave the survey at any time.

1. Do you identify as 2SLGBTQIA+?
    a. Yes
    b. No
    c. Not sure or questioning

2. Please select all that apply to your romantic and/or sexual orientation
    a. Lesbian
    b. Woman-loving-woman
    c. Gay
    d. Man-loving-man
    e. Bisexual
    f. Biromantic
    g. Pansexual
    h. Panromantic
    i. Asexual
    j. Aromantic
    k. Demisexual
    l. Demiromantic
    m. Queer
    n. Two-Spirit or other Indigenous identity
    o. Straight
    p. Heterosexual
    q. Heteroromantic
    r. Other:
3. Please select all that apply to your gender identity
    a. Cisgender (identifying with the gender assigned at your birth)
    b. Transgender
    c. Intersex
    d. Woman
    e. Man
    f. Non-Binary
    g. Agender/I don't identify with any gender
    h. Genderqueer
    i. Gender non-conforming or gender-divergent
    j. Two-Spirit or other Indigenous identity
    k. Other:
4. What race and/or ethnicity best describes you? (select all that apply)
    a. Asian
    b. Black or African American
    c. Hispanic or Latino
    d. Native American
    e. Native Hawaiian or Other Pacific Islander
    f. White
    g. Other:

5. How old are you?
    a. 18-24
    b. 25-34
    c. 35-44
    d. 45-54
    e. 55-64
    f. 65+
6. Do you identify as someone with a mental health condition?
    a. Yes
    b. No
    c. Not sure
7. Do you identify as neurodivergent? Dictionary.com definition
    a. Yes
    b. No
    c. Not sure
8. Do you identify as autistic, someone with autism spectrum disorder (ASD), or otherwise on the autism spectrum?
    a. Yes
    b. No
    c. Not sure
9. Do you live in North America?
    a. Yes
    b. No

Fandom Interaction

1. Where do you engage with the "Hannibal" fandom? (select all that apply)
    a. Tumblr
    b. TikTok
    c. Twitter
    d. Reddit
    e. Instagram
    f. YouTube
    g. Fanfiction sites like Archive Of Our Own (AO3), Wattpad, etc.
    h. Discord or other group chats or forums
    i. Other:

2. Where do you *primarily* engage with the "Hannibal" fandom?
    a. Tumblr
    b. TikTok
    c. Twitter
    d. Reddit
    e. Instagram
    f. YouTube
    g. Fanfiction sites like Archive Of Our Own (AO3), Wattpad, etc.
    h. Discord or other group chats or forums
    i. Other:
3. What fan-made "Hannibal" content do you consume? (select all that apply)
    a. Fanart
    b. Memes
    c. Fanfiction
    d. Video edits
    e. Analysis/"metas" or critique
    f. GIFs, clips, or screenshots from the show
    g. Roleplay (including "character-run" accounts)
    h. Cosplay
    i. Other:
4. How does engaging with this fan-made content make you feel? Example: "Inspired" or "Upset."
5. What fan-made "Hannibal" content do you create? (Please select everything you create even if you don't share or post it)
    a. Fanart
    b. Memes
    c. Fanfiction
    d. Video edits
    e. Analysis/"metas" or critique
    f. GIFs, clips, or screenshots from the show
    g. Roleplay (including "character-run" accounts)
    h. Cosplay
    i. I don't create any fan content for *Hannibal*
    j. Other:
6. Please describe why you make "Hannibal" fan content.

7. What fan-made “Hannibal” content do you share online? (select all that apply)
    a. Fanart
    b. Memes
    c. Fanfiction
    d. Video edits
    e. Analysis/“metas” or critique
    f. GIFs, clips, or screenshots from the show
    g. Roleplay (including “character-run” accounts)
    h. Cosplay
    i. I don’t create any fan content for Hannibal
    j. I don’t share/post any of my Hannibal fan content
    k. Other:
8. Where do you share or post your “Hannibal” fan-made content? (select all that apply)
    a. Tumblr
    b. Twitter
    c. Instagram
    d. Reddit
    e. TikTok
    f. YouTube
    g. Fanfiction sites like Archive Of Our Own (AO3), Wattpad, etc.
    h. Discord or other group chats or forums
    i. I don’t share/post any of my Hannibal fan content
    j. I don’t make Hannibal fan content
    k. Other:
9. Why do you share or post your “Hannibal” fan content?
10. Have you ever bought “Hannibal” merchandise? (Official or otherwise)
    a. Yes
    b. No
11. Have you ever attended a “Hannibal” event such as a panel or a meet-and-greet?
    a. Yes
    b. No
12. Have you ever been harassed or witnessed harassment in the “Hannibal” fandom? (You may provide as much detail as you are comfortable with. Otherwise, you may answer simply “Yes,” “No,” or “Not sure.”)

13. Why do you participate in the "Hannibal" fandom? (select all that apply)
    a. For community
    b. To see or read art or other fan content
    c. To share art or other fan content
    d. To feel validated in my identity
    e. To discuss, analyze, or critique the show
    f. Other:
14. Please describe your relationship to the "Hannibal" fandom. Example: "I feel like I'm a part of a community," or "It's a platform for my art," or "I just like the memes."

"Hannibal" and Identity

1. Has "Hannibal" influenced your identity or sense of self? If so, how? Example: "'Hannibal' helped me understand my identity as a gay man," or "'Hannibal' inspired me to study psychology."
2. Has "Hannibal" influenced your daily routine or habits? If so, how? Example: "'Hannibal' inspired me to cook more." or "I spend time looking at fanart every day."
3. Do you see yourself represented in "Hannibal"? If so, how? How do you feel about the representation? Example: "I see myself represented in 'Hannibal' as a neurodivergent person, and I feel good/neutral/negative about it."
4. Is "Hannibal" different from other TV shows with 2SLGBTQIA+ representation? If so, how?
5. Does the show's elements of horror influence its 2SLGBTQIA+ representation? If so, how?
6. Do you have any other thoughts on "Hannibal" and identity? (How it represents different identities, how it appeals to different demographics, how it influences identity, etc.)

Your Opinions

1. Why do you think this fandom has been sustained for so long?
2. Do you enjoy "Hannibal"? If so, why does it appeal to you?
3. Is there anything else you would like to add?

Abstracts

ARTS

The Power of Art: Increasing Multi-cultural Consciousness through an Online Global Art Workshop

Ran Qi
Southern Utah University

This research delved into the impact of two interactive virtual art workshops developed for college students in the United States and China. Students from the two countries participated in interactive learning activities to create an art project that reflects specific global issues and multiple cultures. The workshops were conducted using the internet and asynchronous video conferencing. An essential component of the project was a virtually collaborative art-making activity designed to promote students' multicultural consciousness and global awareness while developing their artistic abilities. Students from two countries participated in interactive learning activities with peers for two weeks to create an art project. Upon completion, most students reported that they enjoyed learning the different viewpoints and art-making techniques from other countries and pointed out that this interactive global art workshop enlivened cross-cultural interaction, broke cultural stereotypes, promoted a higher level of understanding and critical thinking about global issues, and enhanced multicultural awareness and tolerance.

ARTS

From East to West with Ruth. St. Denis

Alyssa Arnold
Utah Valley University

On the brink of the twentieth century, the Progressive era was a time of change and innovation in all areas of culture. Women were coming to the forefront as new leaders in modernization, not only in the home but

at work as well. New modern dance forms were emerging to match the scale of change. Therefore, dance reflects culture. Traditionally, the Western had anxiety over the body refusing to use it in ritual, an idea adopted from the GrecoRoman ancients. Westerners had a yearning for a display of expressivity and the exotic Art Nouveau after being saturated with an "empty" European ballet. Enter Ruth St. Denis and her incorrigible creativity to transform from an Egyptian goddess, to a peacock, to a Japanese courtesan, to a flowering tree before vast audiences. New Historicism is the frame of analysis that explains how dance reflects culture by looking at the time and context dance took place. A qualitative examination of Ruth St. Denis's choreography in various video clips and still photographs in the early 1900s against the backdrop of the West's new view of the body, Orientalism or anything having to do with the exotic locales of the Far East, and spirituality will provide new knowledge of how one woman single-handedly brought exoticism to America through specific movement, dress, and expression. If dance reflects culture, then Western values were superimposed on an Eastern dance form. A critical analysis of Ruth St. Denis's Eastern-inspired dances, Nautch, Radha, Cobra, Incense, from the New Historicism perspective will demonstrate the imposition of Western Christian values on an Indian dance form.

ARTS

Ballet, Film, and Mythology: A Focus on Persephone

Samantha Marx
Utah Valley University

Goddess of Spring and Death (2023) is a dance for film co-created by three Utah Valley University undergraduates focused on a retelling of the Ancient Greek myth of Persephone and Hades through a new perspective. Throughout time, stories are often retold; however, this myth has rarely been told from Persephone's point of view. With a collaboration between the two disciplines of ballet and film, there was opportunity for a more intimate viewing of narrative-based choreography with creative camerawork and post-production editing. The purpose of this presentation is to disseminate research from the dance for camera: Goddess of Spring and Death (2023), in addition to how this collaboration affected both disciplines. The traditional myth tells the story of Hades kidnapping Persephone to the Underworld and marrying her, typically focusing on the actions of Hades and Demeter.

However, the researchers' collective focus of this narrative was to include Persephone's agency. The narrative still follows a similar plot to the original myth; however, Persephone's character was more developed as she was given the agency to go into the Underworld and eat the pomegranate of her own free will. An unlikely format for this narrative, the respective areas of ballet and film have become a popular collaboration, especially post-COVID. Stereotypically, narrative ballets are commonly performed on a proscenium stage while film works with verbal narratives. Both disciplines were challenged to explore and collaborate together in a field that is not yet standard. The experience for all on the project, including the dancers and crew, was that of gaining new learning that can be applied in the post-graduate fields.

ARTS

Frederic Balazs and Ernst von Dohnányi: From Budapest to the American Southwest

Jackie Bodily Biggs
Brigham Young University

Hungarian American musician Frederic Balazs (1920–2018) enjoyed early success, receiving the prestigious Reményi prize and becoming the youngest concertmaster in the history of the Budapest Symphony at age seventeen. He graduated from the Franz Liszt Academy with honors and later worked as a concert violinist, composer, conductor, and professor in the United States. Despite these achievements, however, Balazs's life and work have yet to attract scholarly attention. This paper represents perhaps the first attempt to bring such attention by examining Balazs's interactions with legendary Hungarian musician Ernst von Dohnányi (1877–1960). Their associations not only paint an introductory picture of Balazs but also provide insights into Doh's far-reaching influence and the emigration experiences of Hungarian musicians. Balazs studied with Dohnányi in Budapest, observed his conducting of the Budapest Symphony, and felt that he possessed a spiritual kinship with Liszt. Dohnányi later helped Balazs emigrate to the United States at the advent of World War II. Once there, Balazs heard about Doh's courageous defense of Jewish musicians during the war and followed suit by collaborating with African American musicians during the Civil Rights Movement. Balazs also defended Doh's romantic compositional style. When Dohnányi left Europe at the war's end, Balazs extended both empathy and a concert invitation to Texas, where they performed

together. Despite the challenges of emigration, both musicians employed optimism and humor in their music and daily life.

ARTS

Notation for Fighting Arts: The Integration of Propositional Logic and Boxing

Brody Mikesell
Southern Utah University

This research explores the integration of propositional logic, communication, linguistics, dance, and boxing, providing a systematic approach to symbolize various fighting techniques. The study draws parallels between traditional Laban dance notation and the proposed fight notation system, emphasizing the reduction of complex human motion into symbols and propositions. The alphanumeric representation of boxing movements allows for the construction of logical equations, providing a foundation for exploring the application, tendencies, and habits of boxers. The paper also discusses future research directions, including the incorporation of additional fighting arts and potential for natural deduction and proofs within the proposed system. The ultimate goal is to enhance the fighting community's understanding and provide objective insights into fighting techniques.

ARTS

Researching Sound Deprivation with Classical Music

Chastalynn Chamberlain Martin
Utah Tech University

Many in the Deaf community have several ways to enjoy music, including lyrics. But what happens when lyrics are taken away? Lack of hearing does not necessarily mean that one is less able than someone else. Facial cues are not only a big part of American Sign Language communication but also classical music. Both are described as a way to feel and express emotion. Additionally, music can be enjoyed by knowing its functions and how to adequately compose a piece. Taking disability in mind, music is also a way to surpass limits and increase potential. This paper explores a sound-deprived performance of

Dohnanyi's Serenade in C Major and how the musicians involved had to work together with cues and emotion to create a worthy performance piece for the musicians themselves as well as a hearing audience.

ARTS

Seeing is Not Always Believing: An Analysis of the Score Errors in the Adagio from Louis Vierne's 3rd Organ Symphony

Connor Larsen
Brigham Young University

One of the most prominent organ composers is a 20th-century composer named Louis Vierne. Vierne's works are written in the dramatic French tradition, with a lot of focus given to articulation, registration, and interpretation. Unfortunately, in all these notes are many errors left behind due to Vierne's poor eyesight. This paper focuses on three types of score errors within Vierne's works— inaccurate editorial additions, misplaced score markings, and inconsistencies in phrasing marks—and probable solutions to each. These three types of errors are especially prominent in the lyrical fourth movement Adagio of Vierne's Third Symphony. Vierne always sought for clarity, so in identifying and navigating errors, that consideration should be paramount as one prepares and studies his music. Despite being removed by over 100 years from the original composition of the piece, there are pieces of information left that, when pieced together, provide a clearer picture of Vierne and his works. This list includes interviews with some of his students, performances by those who have been trained within the French tradition in the 20th century, logical assessments of markings in the score, and tendencies of Vierne that can be found in his other compositions. Undeterred by these challenges, Vierne continued to compose, and his compositions are widely accepted as 'canon' in the organ repertoire. As one equips and educates themself not only in reading music and markings from the score, but truly understanding the true intentions of Vierne, a performer can unlock a performance that reflects the composer's true artistic vision despite any of the disabilities or challenges he faced in his life.

BIOLOGICAL SCIENCES

Bioprospecting of Antibiotics from Soil Bacteria

Cori Bailie and Olga Kopp
Utah Valley University

Antibiotic resistance is a growing global crisis. Nosocomial infections are concerning because of the increase in antibiotic resistance, making it essential to focus our efforts on discovering new antibiotics. Soil is teeming with a rich microbial life, and many of those microorganisms produce antibiotic compounds as a defense mechanism against other soil bacteria. In the 1940s, streptomycin was discovered in a sample of New Jersey soil. Malacidins were discovered in 2018 by researchers studying gene clusters from DNA extracted from environmental samples. These malacidins are active against methicillin-resistant *Staphylococcus aureus* (MRSA). The number of new antibiotics is about 60% lower than in the mid-1980s hence the potential of bioprospecting soil bacteria for antibiotic production. In this research, we test soil for the presence of bacteria with antibiotic properties against relatives of ESKAPE pathogens. Three promising colonies were isolated. Colony 7 showed antibiotic activity against *Bacillus subtilis*. Colonies 6 and 13 inhibited *Mycobacterium smegmatis* and *Staphylococcus aureus*. PCR analysis is being conducted for the identification of these bacteria. In addition, chemical analysis will also help us characterize these microorganisms. These findings have the potential to help us identify new antibiotics to treat common infections.

BIOLOGICAL SCIENCES

Using Transfection as an Annotation-free Ground Truth for Training Noninvasive Metastatic Cancer Mapping Methods

Drew Allred and Vern Hart
Utah Valley University

Surgery remains one of the most common and effective treatments for a variety of cancers, especially those that form solid, localized tumors such as breast and colorectal cancers. During these treatments, the palpable lesion is surgically resected with the assumption that cancerous cells have metastasized to nearby tissues. As such, surgeons will excise a

tissue margin surrounding the tumor in hopes of removing any additional cancer, thus preventing further spread of the disease. However, this process is time-consuming and requires specialized expertise from a trained pathologist to verify that all cancer has been removed. Furthermore, if the pathology report indicates that not all cancerous cells have been extracted, additional follow-up visits and surgeries are typically required. In recent years, a number of noninvasive technologies have been developed that seek to map cancerous cells in whole tissues. Training and validating these methods still requires a reliable ground truth, typically provided by an annotated pathology report. We propose a simpler model in which two cell species were co-cultured to provide a heterogeneous training sample. One of these species (PANC-1) was transfected with a vector coding for a fluorescent marker to represent healthy tissue, while the other species (COS-7) remained untreated, representing cancerous cells. An experiment was then conducted using a coherent diffraction imaging (CDI) system, in which laser light incident on the cells was used to quantify phase shifts produced by each cell type. Fluorescent microscopy was then used to create a map of transfected and nontransfected cells for comparison. Results will be presented demonstrating a correlation between the phase shifts produced by the two cell types and the corresponding fluorescent images, potentially facilitating optical cell identification without the need for pathology.

BIOLOGICAL SCIENCES

Equisetum bogotense: Still Phylogenetically Labile after all these Years

William D. Speer
Salt Lake Community College

The genus *Equisetum* is recognized as having 15–18 species in 2–3 subgenera. Previous phylogenetic studies have found strong support for both subg. *Equisetum* (minus the previously included *E. bogotense*) and subg. *Hippochaete*. Some of these examinations have also discussed the lability of *E. bogotense* in terms of its phylogenetic relationships. More recently, the monotypic subg. *Paramochaete* (*E. bogotense*) has been proposed. The present study reexamines rps4 gene and rps4-trnS spacer data for this genus in general and *E. bogotense* specifically using downloaded sequences from GenBank. Data matrices representing rps4 gene plus rps4-trnS spacer, rps4 only, and rps4-trnS spacer only sequence data were evaluated using maximum parsimony (MP) and

maximum likelihood (ML) optimality criteria. Because the sequence data employed here consist of two partitions (the rps4 gene and the rps4-trnS spacer), partition homogeneity tests were conducted to evaluate possible incongruence between them. However, significant incongruence was not found ($p > 0.05$). Consistent with earlier studies, midpoint rooting (except for one ambiguous result) placed the root to separate both subg. *Equisetum* and subg. *Hippochaete*, although placement of *E. bogotense* was variable. Comparable with some previous examinations, MP results tended to placed *E. bogotense* in either a sister relationship with subg. *Hippochaete* or in a sister relationship with the rest of the genus. ML results differed noticeably, with *E. bogotense* in a sister relationship with the rest of subg. *Equisetum* or clearly embedded in that subgenus. Neither ML result was obtained in previous studies. A smaller set of downloaded rps4 protein sequences were evaluated also, which generated results mostly comparable to the nucleotide data with respect to optimality criteria. Genetic distance analyses for nucleotide vs. protein produced slightly differing results. These phylogenetic results, although sometimes differing with previous studies, continue to confirm the lability of *E. bogotense*.

BIOLOGICAL SCIENCES

Circulation Tumor Cell Detection in Flowing Samples

Vern Hart, Ellie Evans, Tyler O'Loughlin, Caroline Torgersen, and Clint Flinders

Utah Valley University

Circulating tumor clusters/cells (CTCs) are cancer cells that are carried through the circulatory system that can be an indicator for early cancer detection. Current detection methods for CTCs involve drawing blood and lab work involving various technologies (Vidlarova et al. *Int J Molec Sci* 2023;24(4):3902). Center for Imaging and Biophotonics Experiments Advancing Medicine (CIBEAM) laboratory research aims to improve CTCs detection methods to be even less invasive and more effective in standard screening. Using convolutional neural networks (CNN) and coherent diffraction imaging (CDI), this research is aimed at detecting CTCs without drawing blood, thus reducing the time and means needed for initial CTC screening. Ideally, this technology will help with making cancer screening a feasible part of annual or routine physicals. Previous and recent work in the CIBEAM laboratory has led to the creation of a CNN that can differentiate diffraction patterns.

Diffraction patterns are created by directing light, often a laser, toward an object and collecting the light data that results with a sensor. A CNN and imaging system has been developed that can differentiate microbeads of varied sizes in water (representing intravenous fluid containing CTCs) pumped through an intravenous tube (representing a vein or artery). Current research is moving towards further testing and improving this system using sheep's blood and PANC-1 cancer cells. The CNN obtained 97.7% accuracy in detection between diffraction images of fluid pumped through a glass tube from a solution of 50,000 CTCs in 50 mL of water with 20 of uL defibrinated sheep's blood and images using the same solution without the CTCs. We hope to share continued advances.

BIOLOGICAL SCIENCES

BioArt Scholars in Microbiology and Visual Arts

Jude Agboada, Megan Capener, Natalie Pollock, Alex Robles, and Lisa Wiltbank

Weber State University

The BioArt Scholars program has a mission to join enthusiastic visual arts students and microbiology students in producing agar art. Here, we report our findings in four areas: 1. Microbiology students' works of agar art for the annual American Society for Microbiology agar art competition; 2. Art students' documentation and collaborating of agar art; 3. Microbiology growing "palette" of environmental samples that can be used for art; 4. Efforts towards timelapse documentation of the growth of agar art. In the future, we hope to improve the documentation of timelapse videos of microbial growth, with improved environmental parameters such as humidity and temperature control to ensure better growth of microorganisms. We will also assess student outcomes from participation in the BioArt Scholars program in changing science identity and interest in art and science. This is a great opportunity for students from both fields to experience collaboration and the importance of group work and learning.

BUSINESS

Moonlighting Madness: Mixing Student Learning with Paid Consulting

Kristy Grayson, Kathryn Davis, and Phillip Garner
Utah Tech University

In today's competitive marketplace, higher education institutions face the challenge of attracting and retaining students while equipping them with marketable, career-ready skills. To address this issue, this study investigates the use of innovative pedagogy through applied learning activities facilitated by faculty members who integrate paid consulting work into their curriculum. Additionally, it examines student perceptions regarding incentives for their involvement in such activities. Further, it challenges the conventional notion that faculty engagement in paid consulting, commonly referred to as "moonlighting," should not include student participation. The study reveals that students display motivation to participate in applied learning activities when incentives are provided to enhance their career-ready skills in their respective fields. Notably, the study uncovers a surprising finding: faculty members perceive the incorporation of applied learning from externally compensated consulting engagements as an ethical practice. In addition, the findings reveal more nuanced insight into incentives that motivate students to participate. This research contributes to the field of applied learning pedagogy and offers insights into the perspectives of both faculty and students, ultimately imparting effective strategies for fostering career readiness in higher education.

BUSINESS

Measuring the Efficacy of AI-Enabled Communication: Advancing Websites Beyond Traditional Interfaces

Chong Oh and Matthew Pecsok
University of Utah

In an era defined by the rapid digitalization of communication, evaluating the efficacy of artificial intelligence (AI)-enabled chat systems in advancing web interfaces is crucial. This study investigates the transformative impact of generative AI on the communicative functions of the business school's website. With the integration of

advanced natural language processing and machine learning technologies, this study seeks to evolve beyond conventional static, menu-driven interfaces to offer a dynamic, conversation-based user experience. The research meticulously measures the performance and outcomes of these AI systems, using both quantitative and qualitative methods to assess their potential to enhance engagement, increase operational efficiency, and elevate overall satisfaction for a diverse array of users. This inquiry not only contributes to the field of educational technology but also informs the wider debate on the role of AI in the modernization of web communication across multiple sectors. We scrutinize the efficacy of AI-enabled communication systems in enriching the user experience and satisfaction across university websites, with particular emphasis on the Business School at the University of Utah. Acknowledging the imperative for efficient and intuitive interfaces in academia, the research broadens its scope to include considerations of technological sustainability and the capacity for these systems to support cross-cultural connections. A mixed-methods approach underpins the study, encompassing usability testing for a hands-on assessment of AI chat systems' functionality and cross-cultural analysis to discern their global implications. Further, we evaluate the environmental footprint of AI deployment and utilize sociocultural research methods to dissect the intricate interactions between users and this emergent technology. Community engagement strategies also come under scrutiny to determine AI's role in fostering inclusive educational environments. The expected outcomes of this rigorous inquiry aim to refine the digital interfaces of websites and add to the substantive dialogue regarding technology's place in governance.

BUSINESS

Revamping Organizational Hierarchy to Foster Innovation

Jonathan H. Westover and Rachel Bi
Utah ValleyUniversity

In today's rapidly evolving business landscape, the convergence of technological advancements and the exponential growth of data has fundamentally reshaped the way organizations operate. These transformative forces have emerged as critical drivers of innovation, enabling companies to gain a competitive edge and thrive in an increasingly dynamic marketplace. However, despite the immense

potential that technology and data offer, many organizations find themselves shackled by traditional hierarchical structures that impede their ability to adapt and innovate. This developmental conceptual paper will explore the concept of RenDanHeYi, a relatively new management model that seeks to break down the silos created by traditional hierarchies and foster a culture of innovation and collaboration. Furthermore, we will examine the four key elements of RenDanHeYi and discuss the benefits and challenges of implementing this model in organizations. Additionally, we will delve into the challenges posed by these organizational hierarchies and explores strategies to overcome them, empowering companies to embrace change, foster a culture of innovation, and seize new opportunities in the face of evolving market conditions.

BUSINESS

Tabletop Gamification in Leadership Education

Scott Hammond and Parker White
Utah State University

We hear it and ignore it. Once again, a study shows that lecture, the most common format of university classes, is a poor way to teach (Mulryan-Kyne. *Teaching Higher Ed* 2010;15(2):175-185). Research shows Gen Z and Millennials, who are conditioned by screens, games, apps, and personal devices, learn differently. Very differently. This paper shows how a Utah State University online undergraduate leadership course has incorporated tabletop elements and virtual reality to teach leadership. Driven by research and student feedback, this class immerses students in a life-or-death survival scenario where they must collaborate with others and practice the principles of leadership they are learning. The authors developed a "Leadership Quest" that tests students' ability to strategize, make decisions, think critically, and solve complex problems in an Icelandic wilderness setting. To survive, teams must strengthen skills and adapt to the changing environment. We hypothesized that students would 1) prefer the interactive gamification course over a traditional course and 2) perform better on the final evaluation. A post-course instrument polled students' opinions on course delivery methods and effectiveness. The results show that, on average, both types of students would gladly take another class of a similar type. A two-sided independent T-test was performed on the responses from regional and Logan campus students, and it found students from regional campuses

were even more in favor of a tabletop style of learning. From these responses and improved performance on the final evaluation, it can be concluded that the Leadership Quest helps to address the aforementioned problems present in many university classes. If further research is done on gamification in learning, a good place to start could be to find out if classes that are not led by an instructor provide the same benefits to students.

EDUCATION

Workbook Style Learning Integrated into the Classroom

Willow Park, Jayden Peacock, Caysen Crum, Karissa Stalder, and Caleb Hiller
Southern Utah University

Work-book style learning has been a popular approach in primary and secondary schooling. It is well known that the transition between high-school and college may be a difficult transition. The intended purpose of this study is to directly access work-book learning in a professional classroom. Throughout our analysis we aim to quantify our data by determining if it is more effective providing them a) before class, b) in class, or c) after class. After coming to a conclusion, we aim to provide a better learning experience in the classroom, along with a retention of the information. We want students to feel secure in their education and take their knowledge beyond the classroom.

EDUCATION

Picturing Disability; Access: Artifacts of Inclusion and Exclusion in Higher Education

Rachel Bryson
University of Utah

From prominent symbols to commonplace practices, material and cultural landscapes are saturated with messaging about access and ability. In higher education, both overt and implicit structures and policies serve both to include students, faculty, and staff with disabilities—and to notably prevent or limit their access. In this

presentation, I use the highly familiar symbol of the International Symbol of Access (ISA) as a framework for understanding how texts, policies, and the built environment both enable and constrain access for people with disabilities in higher education. The ISA—or the symbol of a wheelchair user found on accessible parking spots, building entrances, and more—communicates accessibility through its presence, but its absence can also communicate a lack of access. I use the ISA to interrogate other points of access (or lack thereof) in higher education, including practices such as classroom policies, syllabus statements, and letters of accommodation. I conclude by using Jenny Davis's Conditions of Affordance model to argue for more focused attention on how we can improve and expand meaningful access for people with disabilities in higher education.

EDUCATION

Collaborative Practices Between Utah Teachers and Social Workers in Schools

Kristina Moleni, Andrea Garavito Martinez, and Fangaafa Tu'ifua
Weber State University

There is limited empirical research in the United States on collaborative activities between teachers and social workers, despite the numerous calls to increase the number of mental health professionals in schools. Collaboration between teachers and social workers is crucial to maximize students' academic achievement and success. Participants will share preliminary findings of qualitative interviews with classroom teachers and social workers in Utah schools on their collaborative practices for student success. Findings revealed that the perception of the types of collaborative activities expressed by the teachers can be characterized as communication-oriented collaboration and by social workers as task-oriented collaboration. The research indicates that the nature of cooperation between teachers and social workers is influenced by their comprehension of their duties and obligations, the procedure of how to work together, and the position they hold in the Multi-Tiered System of Support (MTSS) of the school. This is a segment of a broader interdisciplinary project.

EDUCATION

Exploring Student Outcomes in STEM Education

Jeff Clements
Weber State University

Technology-focused STEM education is a rapidly changing field of study. Educators need a clear understanding of the forces shaping it and how to respond to those changes. Our aim through this research is to explore student-related outcomes in STEM higher education. We do this by examining data from colleges and universities in 21 different states in the U.S. This research shows that universities with more STEM degrees will increase students' starting salaries, which will lead to higher overall career salaries. However, this research also shows that better teaching may not lead to higher student starting salaries. In fact, choosing to attend an expensive university and major in a STEM field may be the key to increasing future career earnings.

EDUCATION

Replacing White Noise through Seeing, Sustaining and Resisting: Listening to Hear the Voices of 2nd Generation Latino/a/x Immigrants in a Digital Storytelling Workshop

Elizabeth Healey Mainoo
Utah Valley University

This research examines the potential uses of personal storytelling, sharing, and multimedia videomaking through a communal digital storytelling workshop. The Digital Storytelling Workshop format is considered for its use as an asset-based pedagogical tool that can seek to sustain cultural identity and community heritage and practices among immigrant communities. Through incorporating Django Paris and H. Samy Alim's *Culturally Sustaining Pedagogy* (2017) and a LatCrit lens, the researcher examines how Digital Storytelling in a group setting acts as a pedagogical tool and through the process of sharing creates individual and collective testimonios of Latino/a/x experiences. The testimonios shared highlight the varied and nuanced experiences of 2nd-generation Latino/a/x people living in Utah and reinforce the significance their perspectives bring and should have within educational

theory and pedagogy as well as classroom practice. The testimonios touch on the participants borderland experiences and examples of how they are developing their own mestiza consciousness. The researcher uses a lens of Critical Whiteness as she sees and resists her own Whiteness in the workshop space and during the analysis and writing process. She seeks to build off the research of Cheryl Matias and Tanetha Grosland (2016) with the intention of improving teacher education programs for pre-service White educators to better prepare them for recognizing their own Whiteness and developing a culturally sustaining pedagogy in their classroom.

EDUCATION

Panel Discussion: Reimagining Management Pedagogy: Innovative Approaches to Engaging Learners

Angela Schill, LynnAnn Erickson, Silvia Clark, Ruthann Cunningham, Maureen Andrade, Jill Jasperson, Yang Huo, Jacque P. Westover, and Jonathan Westover
Utah Valley University

Management education is at a crossroads. Traditional teaching methods are no longer sufficient to meet the needs of today's learners. Students are seeking more engaging, interactive, and personalized learning experiences that prepare them for the complex challenges of the 21st century. In response, innovative management educators are experimenting with new pedagogies that emphasize active learning, collaboration, and real-world applications. This panel brings together a diverse group of management educators and practitioners to share their experiences and insights on effective, engaging, and provocative teaching methods. The objectives of this discussion are to showcase innovative and engaging management pedagogies that foster critical thinking, creativity, and collaboration; to explore the challenges and opportunities of implementing novel teaching methods in management education; and to provide a platform for dialogue and exchange among educators, practitioners, and students about best practices in management pedagogy. This panel submission promises to be an engaging and thought-provoking session that showcases innovative management pedagogies and encourages dialogue among educators, practitioners, and students. The diverse expertise of the panelists, combined with the interactive format, will make for a lively and informative discussion that appeals to a broad audience.

ENGINEERING

Two-Dimensional Heat Conduction in a Short Cylinder

Logan Nicholass, Daniel Hofeling, and Evan Percival
Southern Utah University

The transient temperature charts and analytical solutions for one-dimensional (1D) conduction heat transfer for plane walls and long cylinders may be used to determine the temperature distribution and heat transfer in two-dimensional (2D) heat conduction circumstances. Using a superposition approach (also known as the product solution), the 1D solutions may be multiplied to produce the 2D solution. This concept was tested using a short cylinder, where the solution is assumed to be valid when all surfaces of the cylinder are subjected to convection heat transfer with the same heat transfer coefficient and no internal heat generation. To study this concept, a short steel cylinder was cooled and heated to -1°C and 45°C, respectively. Thermocouples were placed at both ends, the center of gravity, and the outer surface of the cylinder. As the set temperature was reached, the cylinder was suspended such that the only mode of heat transfer was natural convection at the ambient temperature. The cylinder then was allowed to return to the ambient temperature as temperature data were recorded. The analytical results, as expected, showed exponential tendencies in both heating and cooling, while the experimental data did not follow true exponential curves. This resulted in discrepancy between the analytical solution and the experimental data. The analytical solution is based on the approximation method, and the discrepancies due to the approximation are discussed in the paper.

ENGINEERING

Analysis Of Air Subjected To A constant Heat Flux Within A Tube Under Forced Convection

Jacob Vinson, Joshua Brinkerhoff, Evan Percival, and Manfredi Aloisio
Southern Utah University

This analysis aimed to verify known theoretical prediction for the convection heat transfer coefficient (h) by subjecting air to a constant heat flux while undergoing forced convection in a thin-walled copper tube. The linear relationship between the surface temperature of the tube

and the temperature of airflow along the tube was also investigated. A pitot probe was used with a manometer to determine the velocity of air flowing through the tube. A constant heat flux was applied to the outer surface of the copper tube using heating tape. The temperatures of air at the inlet and outlet of the copper tube were recorded and compared with the temperatures of the outer surface of the tube. The testing was performed, first with the tube at room temperature, and second with the tube preheated to achieve steady state in a shorter time. The temperature and velocity measurements were used to experimentally determine the convection heat transfer coefficient. This value was then compared with a theoretical value. The percent difference for these values was under 2% for both methods.

ENGINEERING

Solar Heating of Water and Air

Larry Webster, Savanah Higley, Capri Franzen, and Gage Van Dyke
Southern Utah University

Solar water and air heaters are a renewable and sustainable method to collect solar energy especially in developing countries where water and air heating techniques are inefficient or scarce. Solar heaters utilize thermal radiation to heat water or air through a closed system in a relatively short time. The purpose of this paper is to design a low-cost, multifunctional solar heater, which can be used for heating both air and water. Testing with water was performed by pumping water at a continuous rate through a small, insulated water container used as the water reservoir. The water experiments were performed in Cedar City, Utah, under ambient weather conditions in October 2023. Two tests were performed using the clear plastic bottles to minimize the convection heat transfer and two tests without the bottles. During the tests using the bottles and water, the average temperature change of the water in the container was 27.5°C, while the average temperature change in the container without the plastic bottles was 18°C. The average efficiency of the system when plastic bottles were used as glazing was 59.8%. The air experiments were performed in late January 2024 with a similar setup as the water experiments, but without the small container. During these tests, the average temperature increase of the air was 35.8°C and the efficiency was 5.1%.

ENGINEERING

Analysis Of A Spray-Type Passive Downdraft Evaporative Cooler

Ayline Vega, Matt Lovell, and Jayden Payne
Southern Utah University

This paper analyzes the cooling performance of a spray-type passive downdraft evaporative cooler (PDEC) and explores the relevant literature. The aim of this research is to determine the optimal water flow rate and spray nozzle arrangement for a small, low-cost PDEC system. The evaporative cooler considered in this undergraduate research uses a fan and heater at the inlet to simulate various ambient windspeeds and temperatures. Relative humidity and dry-bulb temperature at the inlet are used to predict the outlet temperature using psychrometric equations and charts. The effectiveness ratio of the system is calculated by comparing performance to the ambient wet-bulb depression and is used to predict the outlet air temperature and airflow rates.

ENGINEERING

One-Dimensional Heat Conduction Through Composite Walls

Savanah L. Higley and Ali S. Siahpush
Southern Utah University

One-dimensional (1D) heat transfer analysis is the most fundamental assumption to make when the thermal behavior of a system is considered. This assumption states that if the thickness of a material is much smaller than the height and length, heat conduction can be assumed to be 1D. This assumption can be used to simplify the conduction heat transfer analyses, including that of a composite wall. In this experiment, a simple composite wall was designed with oak wood, PLA, and acrylic in both parallel and series, and the temperature at various points were measured to verify the validity of 1D heat transfer. The experimental temperature values were compared with transient analytical values obtained through an explicit finite difference method code executed in MATLAB and steady-state analytical values obtained by applying the thermal resistance concept. This experiment proved to be a success in validating 1D heat transfer, as the experimental temperature values were

similar to both the transient and steady-state analytical values. Minimal error was present in the experiment. Further uses of this experiment include a heat transfer lab demonstrating the 1D heat transfer concept.

ENGINEERING

Scale Analysis Of Natural Convection Over A Heated Vertical Plate

Braeden Brown and Ali S. Siahpush
Southern Utah University

Scale analysis is used to estimate the order of magnitude of desired quantities when analytical or numerical solution is difficult to achieve. This paper presents a derivation of the governing equations of convection heat transfer, specifically natural convection, along with two methods of scale analysis, one derived by Bejan and the other by Capobianchi and Aziz. Both methods of scale analysis were used to verify, support, and compare the results of a previous experiment conducted at Southern Utah University. This previous experiment investigated the thickness of the laminar thermal boundary layer caused by natural convection over a heated vertical plate with constant heat flux. Scale analysis was used to estimate the thickness of the thermal boundary layer under these same conditions. Both methods of scale analysis predicted the same order of magnitude for the thickness of the thermal boundary layer as was evaluated in the previous experiment.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

Hildolf, Son of Odin

Leif Ravnsen
Utah Valley University

Most of our knowledge about Medieval Norse myth is filtered through post-conversion Christian scholars who had little interest in maintaining pagan belief structures. Odin, god of kingship and poetry, takes center stage in poet–politician Snorri Sturluson's Edda; Tyr and Ullr were just as prominent in their own regional worship centers, yet are scarcely attested themselves. In that great gap between what once was known and what remains, we can reclaim some measure of lost knowledge by

contextualizing and reinterpreting the surviving material. Hildolf, Battle-wolf, is rarely examined and even dismissed by one prominent scholar as simply another aspect of Odin. Their bias assumes that being listed among the names of Odin's sons equates to being Odin, which has no logical basis upon examination. Free of this intellectual dead end, Hildolf can be put in his proper cosmological place. He governs the crossing of the river boundary between Asgard and Jotunheim, protects the lands of gods and men from bandits and thieves, his home is called "Counsel-island," and a disguised Odin describes him as "wise in counsel." Asgard has invested a warrior–mediator at the boundary of the realm, and in this position Hildolf shifts the commonly perceived relationship between gods and giants, civilization and wilderness, and man and animal toward something more holistic. Hildolf is also placed between Odin and Thor, representing a middle path between their respective warrior types of raider and protector. In this fractured time of partisanship and othering, we now have another symbol to help guide us toward collaboration, with those outside of us and within ourselves.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

The Benevolent Relationship between Humans and Trees: The Power of Storytelling

Jolee Robinson
Southern Utah University

The presentation addresses how Emily Esfahani Smith's pillar of storytelling provides a way for others to find belonging and connection beyond their traumas and fears through the value of benevolence and the symbolic meaning of trees as they pertain to the human condition. According to Dr. Nalini Nadkarni's book *Between Earth and Sky*, trees symbolize humans' physical and psychological state as they endure life's traumas. Both humans and trees follow the same approach to storytelling described in Smith's book, *The Power of Meaning: Finding Fulfillment in a World Obsessed with Happiness*, and utilize the value of benevolence derived from Shalom H. Schwartz's theory of basic human values to make sense of the emotional scars their traumas have left behind. In the present society, we see this utilized in Dr. Laurel Braitman's work with various groups dealing with the journey of loss and grief, bridging the gap in our understanding of the importance of storytelling on a far-reaching level rather than a singular one.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

From Story to History to Ritual: Anne Washburn's Mr. Burns: A Post-Electric Play

David A. Hatch and Anne Washburn
Southern Utah University

This presentation explores how story hardens into ritual by examining the function and implications of the multilayered references in *Mr. Burns: A Post-Electric Play*, by Anne Washburn. With the modernist aesthetic of "the plain reader be damned" challenging our egos, the audience is put to work tracing layers of reference back through the rituals developed by post-apocalyptic worshipers of "Burns" in reference to the "Cape Feare" episode of The Simpsons, then back through the two film adaptations of John D. MacDonald's 1957 novel The Executioners. Anne Washburn's use of the legendary referentiality of The Simpsons as a rhetorical tool inspires a critique of how reference and repetition raise common events or entertainment to the level of ritual after cultural trauma and long periods of time.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

Trauma Reporting Behind Barbed Wire: Japanese American Internment Camp Newspapers and Violence, 1942-1945

Glen Feighery
University of Utah

Japanese American internment was an extraordinary chapter in American history. After the attack on Pearl Harbor, 120,000 people of Japanese ancestry—two-thirds of them U.S. citizens—were forcibly removed from the West Coast and incarcerated in "relocation" camps in remote locations, including Topaz, Utah. Torn from their homes and lives by prejudice, people occupied makeshift barracks surrounded by barbed wire. Each camp became a de facto small city, and each was served by a newspaper produced by residents. These newspapers kept residents informed and, despite government control, reflected the voices and feelings of each community. Violence was rare in the camps, but on three occasions, including one at Topaz, residents were fatally shot by military guards. This research in progress lies at the intersection of U.S.

history and journalism history. It explores how camp newspapers helped traumatized communities cope with the violation of their civil rights and loss of life from the shootings. Primary sources for this study are internment camp newspapers published at the time of the shootings in 1942, 1943, and 1944, as well as government records documenting government policy toward the newspapers. These sources indicate that incarcerated Japanese American journalists exercised a high degree of agency despite government control. After two of the three fatal shootings, camp newspapers not only provided factual coverage but also expressed solidarity with mourning residents. Amid crisis, these journalists helped sustain communities at the margins of a nation that had shunned them. This work has contemporary relevance in two ways. First, it offers historical context amid an upsurge of hate crimes and discrimination against Asian Americans in the wake of the coronavirus pandemic. Second, as the United States grapples with ongoing gun violence, present-day journalists could consider ways to help communities cope with trauma and, through compassionate engagement, take steps toward healing.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

Well Stated, Half Solved: The Most Important Problem(s) Facing the State of Utah and Its National Echoes

Thomas C. Terry
Utah State University

Gallup Polling's Most Important Problem (M.I.P.) question is, arguably, the most valuable longitudinal public opinion research tool available to scholars with results extending back into the mid-1930s. Between 1,000 and 1,600 Americans over 18 years of age are asked essentially the same question almost every year (and usually multiple times as at present): "What do you think is the most important problem facing this country today." A mix of 70% cellphone and 30% landline respondents are surveyed across U.S. regions and time zones. The M.I.P.'s most salient feature—and its power and advantage—is that it is open-ended, requiring respondents to independently provide and identify their personal evaluation of what the most important issue is facing the nation without probes, prompts, or a preselected list of multiple-choice answers. In June 2023, faculty members and undergraduate and graduate students in the Department of Environment and Society at Utah State University,

Logan, decided to test the M.I.P. question in Utah and included it as the lead question in an environmental survey. Overall, the researchers found that nearly 80% of those polled identified the M.I.P. facing the State of Utah as either the environment and climate change (40%) or population growth and development (39.5%). An additional 3.8% thought homelessness was the M.I.P., that logically could have been added to the population growth category. Air quality issues were picked by 11.4% of Utahns as the M.I.P.—including pollution and its negative impacts—and this was the single largest component of the environment and climate change category. Water scarcity due to population growth was a relatively distant second, selected by 6.3% of those surveyed, not quite half of the top concern. The purpose of this study is to examine the findings of the Utah M.I.P. poll.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

Barking Up the Right Tree: Granting Moral Standing to Animals and Ecosystems

Atira Schulte and Michael Popich
Westminster University

We live in an environmental crisis caused by the mass overconsumption and nonsustainable practices of humans. These issues are rooted in anthropocentric beliefs that humans may use all other life to our benefit with no regard for consequences. Animals and ecosystems have the right to exist and flourish. Animals and ecosystems strive to have flourishing existences just like us. They have meaningful capabilities that are no less valuable than those humans possess, so they ought to have moral standing equal to that of humans. This research aimed to build a new ethical theory that would extend the same rights humans are widely considered to have to other animals and ecosystems, especially citing Martha Nussbaum, James Sterba, and Peter Singer. The age-old desire to dominate nature must be replaced with a newfound respect and wonder for nonhuman life and the environment. We must reframe our methods of thinking and move towards more sustainable methods of living. Only by changing the mindset of humans, from one of domination and exploitation to stewardship and coexistence—even friendship, can we resolve this environmental crisis.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

Reframing Empathy

Emily Richael
Brigham Young University

There are reasons to be skeptical that empathy understood as perspective taking can afford us knowledge about the mental states of others or generate care and motivate moral action. This paper will outline how self-oriented perspective taking and other-oriented perspective taking fall short of providing us with knowledge of others' mental states. In self-oriented perspective taking, the simulation ends up excluding crucial differences between the mental constitution of the empathizer and the target. Other-oriented perspective taking attempts to account for these differences, but ultimately fails because the unconscious dispositions of a target are impossible to simulate. I will then address simulation's moral limitations by arguing that neither form of perspective taking is morally motivational. Self-oriented simulation leads to personal distress, which causes us to care about ourselves rather than the target, and other-oriented simulation leads to misdirected care. Finally, I suggest that we should move towards a new picture of empathy informed by Kate Abramson and Adam Leite's idea of empathic responsiveness. This new picture will recast empathy as a mode of interaction that requires epistemic humility.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

The Magic of Familial Trauma

Ariel Longoria and Adena Rivera-Dundas
Utah State University

Trauma, the emotional response to a distressing or upsetting event, is a plot device used in a variety of contemporary Young Adult literature. Typically, it assists in character development, motivates a character's wants and beliefs, and creates a sense of change in a story. However, the use of trauma as a literalistic trope has evolved, just as our scientific and cultural understanding of trauma has evolved. One such development is the study of how families and generations impact current demographics, otherwise known as familial or generational trauma. Familial or generational trauma is rooted in cultural, racial, economic, and social factors, spanning from one generation to the next. It impacts nearly 70%

of the population according to the World Health Organization and has become a recurring theme in a variety of popular media. In literature, it is present in many notable texts, but not in the way many would expect. Whereas movies and TV shows may outright identify the trauma their family has inflicted upon them, young adult literature approaches familial trauma through themes of magic or fantasy. Examples range from characters inheriting magical destinies from their all-powerful-deceased, distant, or neglectful parents; an emerging hero, who uncovers a world hidden by their family, and a destiny they cannot escape; or characters poised by their family to defeat an all-powerful villain or perish. These tropes are not uncommon, and while intentionally or unintentionally, authors have made the themes and emotional nuance of familial trauma a common thread between their texts. However, in many of these stories, the concept of familial trauma is never addressed. It seems as though the very nature of familial trauma is replaced by magic and explained through the concept of a character's destiny. The question is, how and why are stories directed at younger audiences, using magic.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

Transcendence and Benevolence: Navigating Human Values through the insights of Emily Esfahani-Smith and Viktor Frank

Lacretia Mills
Southern Utah University

Drawing from Emily Esfahani-Smith's lecture on "Building Cultures of Meaning" and Viktor Frankl's experiences in Man's Search for Meaning, this presentation dives into the Pillar of Transcendence and the Value of Benevolence. Although seen as a journey beyond one's self, transcendence intertwines with acts of benevolence, shaping a meaningful life. Smith emphasizes expanding identity and connecting through benevolence, while Frankl's experiences highlight the essential link between personal well-being and contributing to the greater good. This presentation illuminates the transformative power of benevolence and transcendence on individual and societal levels, emphasizing acts of kindness as bridges connecting individuals to shared humanity in the pursuit of a meaningful existence.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

Navigating Intercultural Competence

Alexia Orbezua Black and Ko-Yin Sung
Utah State University

Intercultural competence is the ability to navigate effectively across cultures, whether locally or internationally. Intercultural competence encompasses three main attributes: knowledge, skills, and attitudes; effective communication in intercultural contexts requires linguistic proficiency coupled with a keen understanding of cultural norms and practices. Cultivating respect for diverse cultures and mastering effective communication skills are pivotal in fostering unity and strengthening relationships amidst cultural diversity. This study embarks on a transformative study-abroad journey in Taiwan for two months, which explores the intricate development of intercultural competence, specifically focusing on our study of how students gain this competence while studying Chinese as a second language (CSL). Of the 12 participants, we were split between freshman and sophomores, our language levels were considered elementary and intermediate. With our unique foundations, we navigated preconceptions and expectations, anticipating potential language barriers while adjusting to the rhythm of Taiwanese life. These participants all started at different language levels— there were those who had been studying for over a decade as well as those for whom this was only their first year—but it was everyone's first experience of being completely immersed in the culture. Participants engaged in a multitude of after-school activities alongside their daily language course, which led to the unearthing, practicing, and acquiring of pivotal information for the student's growth in their knowledge, skills, and attitudes. The study results show that by the end of the program, participants experienced a drastic change, as all felt they had a better grasp of functioning effectively with a variety of people across different backgrounds. Not only were participants immersed in Taiwanese culture, they were also surrounded by students from all around the world inside their classes. This culmination contributes to the discourse on intercultural competence, offering a practical template for designing immersive experiences.

HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

High-Context Instruction: Boosting Academic Success in Online Composition Courses

Jeshua Enriquez and Roberto Rojas-Alfaro
Salt Lake Community College

With the rapid growth of online education, ensuring a robust, positive learning experience in composition courses is more important than ever. This session presents methods by which faculty can amplify their support for students during coursework and promote college-wide resources. By focusing on online Beginning Composition and Intermediate Composition (English 1010 and English 2010) courses during Fall 2023, our exploratory study involved an innovative approach to data collection: check-in assignments every three weeks and dual surveys at the middle and end of the semester. The assignments and surveys, designed for convenience with a 5-minute completion time, provided a continuous stream of feedback and support. Our findings reveal that adopting a high-context approach–where rich, detailed information that takes into account students' unique backgrounds, cultures, and personal situations supports learning–significantly enhances instruction quality. This method, coupled with clear communication about student resources, can create an environment conducive to academic success, particularly for students from diverse backgrounds, including Latinx students who traditionally face an achievement gap. The session delves into these results, providing actionable strategies to optimize attendees' own instructional techniques. The emphasis will be on English instruction, but the implications are broad-reaching, suggesting a shift in pedagogical practices to cater to an increasingly diverse student body.

LANGUAGE AND LITERATURE

from "Bare My Breast"

Megan McComber
Brigham Young University

"Bare My Breast" is a lyrical essay that explores how female identity, motherhood, and inheritance are tied to the intimacy of mother and daughter. Through imagery of breasts and breastfeeding, and interwoven with biblical references and personal anecdotes, the essay focuses on the mother–daughter relationship to assess anxieties and fears surrounding

hereditary breast cancer. As she grapples with the implications of carrying the BRCA1 mutation, the narrator simultaneously interrogates cultural sexualization of female bodies and breasts, worrying that her infant daughter may not only bear the burdens of a woman in a sexualized world, but do so as a carrier of the BRCA1 gene. "Bare My Breast" is the first in a collection of lyrical essays that examine through lenses of nature and the human body such themes as motherhood, loss, and the systemic oppression of women in the face of self-discovery.

LANGUAGE AND LITERATURE

from "The Imaginary Child"

Jessica Mohsen-Crellin
Brigham Young University

"The Imaginary Child" is part of a short story cycle that explores the state of mind of a woman yearning for and struggling to have children. As she imagines her future children, the line between her dreams and her reality blurs and her anxieties about infertility, loss, and the unknowable future are played out in dream narratives that quickly dissolve into nightmare. Inspired by real-life events, the collection walks the line between fiction and nonfiction as it questions how individual reality is shaped, especially by loss and grief. In the story "The Imaginary Child," the main character, known only as "Ruth's mother," is battling the chaotic dreamscape of her own mind to find the child she believes she has lost. The story tries to make sense of the very real grief potentially tied to imagined loss.

LANGUAGE AND LITERATURE

from "Befores and Afters"

Rose-Marie Morgan
Utah Valley University

This creative work is an excerpt from my nontraditional childhood memoir, in which I reconstruct my experience of my parents' explosive divorce. The manuscript begins and ends in court, where at age twelve I testified I no longer wanted to continue my relationship with my father. It is a moment that exists outside of linear time for me. To mimic the

experience of trauma, I loop back to this scene throughout the book, each time getting closer to the moment I speak my truth. Between courtroom sections, I flash backward (and forward) to examine my relationships with each of my parents as I explore their relationship with each other, trying to make sense of how and why things fell apart. Written from the perspective of my younger self, I elevate the child's voice because, during the long experience as it unfolded, that voice did not count. At its heart, my memoir shows that, while lacking the language or experience to fully articulate trauma, a child is a full person whose experience of intense situations is no less complex or human than the experiences of the adults around her.

PHYSICAL SCIENCES

A Device to Measure Ionic Strength in a High School Lab Setting

Abigail G. Petersen and Christopher F. Monson
Southern Utah University

We are building a conductivity tester that can be used in a laboratory setting to measure the ionic strength of a solution. This device is designed to be student friendly, relatively simple to build, safe, and inexpensive. It is simple enough that students can build this conductivity tester. We are incorporating this device into a lab based on SEEd standard CHEM.3.1. We hope to have tested this lab in a classroom setting and will report the results.

PHYSICAL SCIENCES

A Microfluidic Device for the Quantitation of Dissolved Oxygen

Jedd Kjar, Mariah Clayson, Lohra Miller, Samantha Mckay, Madison J. Evans, Cameron Stokes, K. Brayden Bailey, and Christopher F. Monson
Southern Utah University

Dissolved oxygen concentration in aqueous environments is relevant to biological and chemical processes. Variations in oxygen levels may critically change metabolic and other chemical pathways. We developed

a microfluidic device modeled after the STOx electrode to measure dissolved oxygen. The STOx electrode is the most sensitive electrochemical device currently available for the quantitation of dissolved oxygen. With our device, we sought to improve the ruggedness and reduce the cost of the STOx electrode. Using an initial prototype, we have gathered data from three locations: a lake, an irrigation reservoir, and the Great Salt Lake. Based on the initial prototype's performance, we developed a new prototype with the aim of improving response time and device precision. We are currently in the testing phases of the new device.

PHYSICAL SCIENCES

Analysis of Gravitational Fields Inside of a Cavity throughout Different Dimensions

Tate Thomas and Alexander M. Panin
Utah Valley University

We mathematically derived equations describing the gravitational field in a symmetric cavity located asymmetrically inside 1-D, 2-D, and 3-D spheres for a gravitation that itself may have 1, 2, or 3 degrees of freedom (thus may diminish with distance not necessarily as inverse square). We found that if the number of dimensions and the number of degrees of freedom of gravitation match, then the gravitational field inside the cavity must be constant and uniform throughout all space inside the cavity. Discussing the details of our calculations for matching and nonmatching cases, along with their implications, is the goal of this presentation.

PHYSICAL SCIENCES

Can a Planetary System Survive a Host Star Supernova Explosion?

Benjamin Miera and Alexander Panin
Utah Valley University

Recent searches for extrasolar planets have brought a surprising discovery—almost any star seems to have a planetary system around it. We know that massive stars end their lives in a violent supernova

explosion, during which an extremely large amount of energy ($\sim 3\times10^{46}$ J) is released from the star in a very short time. Can a planetary system survive such a violent event? In this presentation, we analyze, based on known physics, the sequence of events of a type II supernova explosion—primarily the neutrino flash, gamma ray flash, and expanding plasma shell—and the effects they would have on an orbiting planet. Our calculations show that a planet is not kicked out of its orbit because of star's radiation pressure, but the momentum of exploding star shell can significantly disrupt the orbit of the planet (depending on planet's mass and proximity to the host star). We also find that the planet does not experience significant heating due to the neutrino and gamma ray flashes. Finally, we show that all stable planetary orbits around a star become escape trajectories when the star loses more than half of its mass.

PHYSICAL SCIENCES

Artificial Black Holes: Are They a Threat to Humanity?

Tate Thomas and Alexander M. Panin
Utah Valley University

We wanted to see whether accidentally creating mini black holes in high-energy particle collisions posed a real threat to humanity. To do this, we calculated some properties of such a black hole, such as its life span, radius, density, and minimum energy required. We found that it is unlikely to exist, let alone destroy the planet. Furthermore, we calculated what would happen if it were to exist, finding that it would move through the Earth with little resistance and with a small amount of Earth matter absorbed. Depending on initial velocity, the black hole either quickly escapes Earth or would settle orbiting it with the orbit part of which passes via Earth. It is interesting that in a simplified model of Earth as of a sphere of uniform density, the inner part of the orbit of black hole is also elliptical (as the outer is) but not Keplerian—with Earth center not at the focus but at the center of another ellipse. In the case of small initial velocity when entire orbit is inside Earth, the period of such inner orbit is constant regardless of birth location and initial velocity of black hole. The goal of this presentation is to discuss the results of our calculations and to explore potential applications to our understanding of interaction of mini black holes with ordinary atomic matter.

PHYSICAL SCIENCES

Can Primordial Black Holes Constitute Dark Matter?

Alexander M. Panin, Tate Thomas, Tensor Elmikawy, and Enrique Mendoza
Utah Valley University

In some scenarios of the Big Bang, the fluctuations of density in the early universe result in the formation of various-sized primordial black holes (BHs). The BHs of mass range 1010–1022 kg are good candidates for a dark matter. How many of such BHs (say, per cubic light year) are needed to constitute dark matter? Are those BHs observable? How would they move? How much gravitational waves would they radiate? Would they evaporate, or would they grow consuming interstellar matter or galactic dust? How frequent are collisions of such BHs with stars or planets and with each other? Would they consume stars—and if so, then how quickly? In our presentation, we will give quantitative answers to these questions based on known physics. We will show that due to the low number density, extremely small "cross-section" of interaction of such BHs with the visible matter, and very low "visibility" of such BHs (ecause of the low intensity of Hawkins radiation they emit), they indeed are very suitable candidates for a dark matter, or at least for a part of it.

PHYSICAL SCIENCES

2D Fluorescence of Phycocyanin Bioconjugation and Its Impact on Light Harvesting

Colton Koch, Brecken Shakespeare, Tyler Holmes, and Jacob Dean
Southern Utah University

Spirulina is a genus of photosynthetic cyanobacteria containing phycocyanin, a light-capturing pigment–protein complex. This cyanobacteria has evolved to optimize effective energy transfer in the red region (550–650 nm), which is then used to help these cyanobacteria initiate photosynthesis and provide the needed energy to sustain life. Secondary pigments can be introduced to these light-capturing pigments to potentially alter their light-harvesting capabilities. This can be through the addition of another light harvester that aids in energy transfer and shifts the range of absorption or by modifying the native protein folding that impacts the function of the pigment network as a whole. These alterations can be either beneficial, detrimental, or not affect the

protein's light-harvesting abilities. The secondary pigment diluted rhodamine-B was chosen because of its complimentary fluorescent properties and absorption in the visible light spectrum, which when introduced, can also bind nonselectively to the phycocyanin. To test the light-harvesting properties of the modified solution, we took dilute solutions with similar absorbance of phycocyanin, rhodamine-B, and a mixture of both, and collected UV-vis and fluorescence spectra of each solution. The mixture was then centrifuged to isolate bound "bioconjugate" structures and then new spectra were then taken of the solution. 2D-fluorescence spectra were then taken and analyzed to study how the secondary pigment of rhodamine-B affected the light-harvesting phycocyanin and its energy transfer. We were able to see how the mixture of rhodamine-B to the phycocyanin affected the light-harvesting properties of the phycocyanin by comparing the 2D-spectrum of each solution with that of the mixture.

PHYSICAL SCIENCES

Investigation of the Electronic Properties of Homobinuclear Iridium Complexes

Matthew B. Prater
Southern Utah University

Binuclear metal complexes have garnered interest in recent decades, yet numerous details remain unexplored. Although many enzymes leverage binuclear catalysis in their processes, progress in applying this phenomenon outside of enzymatic contexts has been limited. Means of improvement over mononuclear complexes generally remains unexplored. Homobinuclear complexes, featuring two identical metal centers within a single complex, pose intriguing challenges, particularly in elucidating exact mechanisms governing traditional organometallic steps such as oxidative addition, migratory insertion, transmetallation, and reductive elimination. Recent advances in the synthesis of Ir complexes offer a promising avenue for construction of novel homobinuclear complexes tailored to investigate electron transfer mechanisms, which we propose will offer insight into organometallic steps. The synthesis of a variety of bisiridium complexes is already underway. These complexes will undergo extensive photo- and electrochemical experiments to initially decipher the impact of electron-donating and withdrawing groups on the system. This presentation will detail the background of the research, as well as ongoing efforts.

PHYSICAL SCIENCES

Analysis of Thermospheric Neutral Densities Using GOCE Satellite Observations

Agustina Peck, Ivana Molina, and Ludger Scheirless
Utah State University

The thermosphere is a layer of the atmosphere that extends from about 90 to 500 km. Thermospheric neutral densities are critical in planning of low earth orbit satellite missions, as the neutrals produce perturbations in the orbits due to drag. Because the ionosphere is embedded in the thermosphere, gaining insight into the variability of thermospheric densities improves our understanding of how the thermosphere, ionosphere, and lower atmosphere are coupled. The ionosphere, in turn, affects technologies such as high-frequency communications and global navigation satellite systems positioning.

PHYSICAL SCIENCES

Manganese Desert Rose Nanoparticles Formation using FusionRed

Nakelle Goldie, Taytum Stratton, Simon Langlois, and Christopher Monson
Southern Utah University

In comparison to other nanoparticle types, manganese nanoparticles have been the subject of relatively few investigations. In our research project, we utilize a microfluidic device to synthesize manganese nanoparticles. Manganese acetate is the metal ion source and sodium dithionite is the source of oxide. Various proteins have been used to yield particles of different size and shape, including FusionRed, GFP, BSA, and casein and mutated variants. The use of these proteins has resulted in different sizes and shapes of the nanoparticles. We primarily use FusionRed for the formation of our desert rose nanoparticles. These nanoflowers have relatively large surface area and could therefore be useful for electrocatalysis. Making the nanoparticles without a microfluidic device gave us a broader size distribution and shorter time for nanoflower formation and led us to come up with a plausible mechanism. We propose that these nanoflowers are formed by the association between the manganese ions and a cluster of negatively charged residues on

FusionRed, leading to the formation of sheets. These sheets then interact with each other in various ways to form the petals of the desert rose nanoflowers that we see.

PHYSICAL SCIENCES

Hydrophobicity of Micropatterned PDMS

J. Fielding Hokanson, Russell M. Bodily, Kylee Stoddard, and Chris Monson
Southern Utah University

We have developed a method to make highly hydrophobic layers of polydimethylsiloxane (PDMS) by dilution in alkane solvent and addition of sacrificial magnesium particles, followed by sonication in hydrochloric acid. Dissolution of magnesium leaves behind pillar-like PDMS structures on the surface of our substrate that exhibit hydrophobic characteristics. Hydrophobicity and layer clarity can be manipulated by changing solvent type, PDMS-to-solvent ratio, and percent magnesium. Aging PDMS slurry can improve hydrophobicity.

PHYSICAL SCIENCES

Organic Chemistry Students' Perceived Costs and Goal Orientations

Seunghwan Shin
Southern Utah University

Organic chemistry is one of the most feared and failed courses in the undergraduate curriculum. Consequently, studying what makes this course "too difficult" as perceived by students is worthwhile because these perceptions result in many students not considering STEM majors because they require chemistry courses. Our research group has investigated perceived costs in general chemistry, and this study expands our understanding of these constructs in organic chemistry. Students' perceived costs of a chemistry class can be many, such as task effort, loss of valued alternatives, emotional, and others. These costs might be overcome by students' interests and goals, yet the level of perceived costs might have a lasting impact on the students' overall perception of chemistry and their desire to pursue chemistry and other STEM careers

in the future. In this study, we investigated the mentioned subclasses of perceived costs, other salient perceived costs, and mastery or performance goal orientations and the impact these constructs may have on students' experiences in organic chemistry classrooms. Expanding on a previous study in general chemistry, we present the results of interviews we conducted with students in this class. Our results reveal that students struggle with the content, pace, and overall difficulty of the material. These results are not surprising; however, we also uncovered the students' deep desire to learn and understand the material, the motivating effect of having a good relationship with their professor, and many other themes that emerged from our conversations.

PHYSICAL SCIENCES

MSR Research

Isabella Gonzalez and Angie Ordoñez
Snow College

The next phase of nuclear reactors is poised to revolutionize the world. These are the molten salt reactors (MSR). However, before these reactors can become operational, the thermodynamic properties of the molten salts must be studied. The eutectic salt mixtures necessary for MSRs are difficult and expensive to study experimentally. The most economical method for studying these mixtures is through computational methods. Historically, these methods have been limited to extrapolating from experimentally derived values. However, in this presentation, we will present a novel way to use computational methods to fully predict thermodynamic values that have never been studied experimentally. We will also report the heat capacity, coefficient of thermal expansion, and aggregation effects in a promising new eutectic mixture of LiF and UF4.

PHYSICAL SCIENCES

Photo-induced Reactivity of a Model Dipyrrole

Samuel Archer, Jaren Meikle, and Jacob Dean
Southern Utah University

Dipyrroles are a class of bicyclic and heterocyclic compounds ubiquitous in nature as subunits to biological photo-sensors. As such, these

molecules have gained significant attention in the field of photochemistry because of their ability to undergo photoisomerization and photooxidation. Because of these properties and the large absorptivity in the blue region of the electromagnetic spectrum, we are able to initiate these reactions upon irradiation of blue laser light. In this study, the photochemical behavior of a model dipyrrole representative of the central pyrrole pair in natural tetrapyrrole sensors was investigated to model and quantify the mechanism and conditions of its photoreactivity. When UV-vis spectroscopy readings were taken of the dipyrrole compound to observe the progress of the reaction over hours, transformation of the visible light absorbing feature decayed into a near-UV feature representative of a change of conjugation. Further, this transformation was found to be pH dependent and therefore protonation state dependent. Further research is currently being done to isolate the cause of formation of this unknown product and to determine the rate of conversion to this new product.

PHYSICAL SCIENCES

Numerical Analysis of Stable Steady-state Solutions in a Gray-Scott Model

Samuel Andersen
Southern Utah University

We study a Gray-Scott model arising from chemistry. Using nondimensionalization, we reduce the number of parameters, we also analyze the stability of the steady-state solutions of the system using numerical analysis. This shows us the final concentrations of two different species in an autocatalytic reaction.

PHYSICAL SCIENCES

Quantum Game Theory and Genuine Quantum Advantage

Noah Hebdon and Jean-Francois Van Huele
Brigham Young University

In recent decades, the principles of quantum physics have been applied to game theory, or the study of strategic interactions between rational

actors. As a result, classical games such as the penny flip and the prisoner's dilemma have been modeled with quantum systems. In such models, players may employ principles such as superposition or entanglement as they attempt to maximize their payoff. Meyer (*Phys Rev Lett* 1999;82:1052), among others, claims that the use of quantum strategies rewards a player with a 100% chance of victory against a classical player within the penny flip game. I investigate the following question: Can we attribute this quantum advantage to the use of quantum strategies, or is it more appropriately attributed to the arbitrary design of the penny flip game? As it stands, the quantum player enjoys a greater number of plays than the classical player. Utilizing Qiskit and IBM quantum simulators to model the penny flip game, I will show that a classical player possesses a far lesser chance of victory than the quantum player when given the same advantage of multiple plays, thereby proving that quantum advantage is genuine within the penny flip game.

PHYSICAL SCIENCES

Spatial Visualization versus Memorization Differences among Sexes in Organic Chemistry

Lauren Jensen
Southern Utah University

Differences in sexes have long been speculated, yet their application in chemistry learning environments has not been well researched. Literature shows that males have larger cerebral volumes for visual capacities more often associated with hands-on projects and courses than female brains, whereas female brains have larger cerebral volumes for areas associated with memorization and socialization, which more highly correlate with lecture-based learning. Given the high attrition of women in chemistry courses, we investigated this phenomenon in organic chemistry topics that are highly visual (e.g., chirality, Newman projections, chair conformations, bond rotations) and topics that require more memorization (e.g., functional groups, energy values associated with sterics, nomenclature, definitions). We conducted an anonymous survey with students who are currently enrolled in organic chemistry or have taken organic chemistry in the past. The questions varied in difficulty as well as levels of visualization or memorization required. The results show correlation with the literature that males score better in the visual-based questions, and females score better in the memorization-based questions. In addition, we conducted interviews with male and

female students in organic chemistry and found that the female students self-generated various techniques to visualize 3D rotations (e.g., use their hands, draw arrows), whereas most male students did not adopt these techniques because they were able to do the 3D rotations in their head. With these results, we plan to design course interventions to bridge the gaps between the extremes of visualization vs. memorization-based concepts for the students.

PHYSICAL SCIENCES

The Impact of Winter Deicing Materials on Water Quality in Weber County, Utah

Cody Ellsworth, Merick Durtschi, and Caitlin Tems
Weber State University

In winter 2022-23, Utah measured a record-breaking 30 inches of snow water equivalent, which is 216% of the average, according to the Utah Department of Natural Resources. The Utah Department of Transportation reported that over 370,000 gallons of deicing material were subsequently used on Utah roads to improve transportation safety. In this study, we investigated whether deicing materials applied to roadways impact the water quality of Ogden Valley and Ogden Canyon in Weber County, Utah. The primary water source for Ogden is Pineview Reservoir, which is located in the less-populated Ogden Valley. We collected in-situ measurements and water samples from the South Fork and Middle Fork of the Ogden River that flow into Pineview Reservoir and along a transect of Ogden River, which flows out of the Pineview Reservoir through the heavily trafficked Ogden Canyon, to assess the impact of deicing materials on water quality between October 2022 and September 2023. Water samples were analyzed on inductively coupled plasma mass spectrometry for Na, Mg, Ca, K (major components of deicing materials) and additional trace elements. All elements met the U.S. Environmental Protection Agency drinking standard limits; however, Na, Mg, Ca, and K were two to three times higher in Ogden River in Fall 2022 and Spring 2023 compared with Pineview Reservoir and its inflow streams. This suggests that the deicing material impacts water quality. The concentrations of deicing materials decreased in Fall 2023, which we suggest is due to a substantial input of water to the watershed due to spring snowmelt and is supported by water discharge recorded at the Ogden River USGS Gauge Site. We hypothesize that extreme snowfall plays an important role in flushing the watershed of

contaminants and improving water quality. As climate changes and if snowfall in Northern Utah is reduced as projected, this could result in deteriorating water quality in the region.

PHYSICAL SCIENCES

UVU VASIMR Group: Instrumenting Plasma Diagnostics

Connor Stong, Tessa Miller, Ben Miera, Josh Gibbons, and Phil Matheson
Utah Valley University

In this study, we present the design and construction of a Langmuir probe diagnostic system for characterizing our plasma source. Langmuir probes are widely used in plasma physics to measure essential plasma parameters such as electron density, electron temperature, and plasma potential. Our probe system has been specifically designed to operate within the specific environment of our small VASIMR engine. To enhance the plasma density and improve diagnostic capabilities, a mesh reflector has been implemented to redirect the radiofrequency energy back into the plasma, effectively increasing the energy and temperature in the system. This modification aims to create a denser and more uniform plasma, facilitating more accurate and reliable measurements. The presentation will provide an overview of the Langmuir probe theory and its operating principles, emphasizing the importance of proper probe design and data analysis techniques. Additionally, a brief overview of the plasma system and VASIMR engine will be given. The successful implementation of the Langmuir probe diagnostic system will enable comprehensive characterization of the plasma source, contributing to a better understanding of the plasma dynamics and paving the way for potential applications in various areas of plasma physics and electric propulsion.

POSTER: ARTS

What Is the Impact of Dramaturgy?

Amanda Dawson, Robert Mac Minshew, and Jordan Lockwood
Utah State University

A dramaturg is a person who contextualizes the world of the play via historical research, contemporary knowledge of script structure, and other elements and shares the research with the cast and crew to further the production experience. We wanted to know the impact of dramaturgy on undergraduate theatre productions. We had the opportunity to serve as researchers and participated as dramaturgs for the first two productions of the year at Utah State University: "We are Pussy Riot or Everything is P.R." and "Waiting for Lefty." We interviewed three dramaturgy faculty members at three U.S. universities and inquired about their programs and if/how dramaturgy is incorporated into their programs. We created our own dramaturgy resources for our respective shows and sent a survey to collect feedback on our work.

POSTER: ARTS

Designing for Well-being: An Investigation of Architectural Composition on Physical Health

Jared K. Bradshaw and Brandon Ro
Utah Valley University

Architecture uniquely distinguishes itself from other forms of art by its ability to create inhabitable spaces through the design of spans, supports, and openings. From the earliest structures, such as those at Göbekli Tepe, builders incorporated aesthetic designs to structural forms to resonate with the people of that era. Over time and across diverse locations and cultures, the methods of openings have been influenced by available material, laborers, technology, and cultural priorities. This research aims to understand the key factors influencing the engagement and aesthetic appeal of architectural openings as it relates to physical well-being. Research by Esther Sternberg demonstrates a connection between the built environment and physical health; thus, this research will provide architects with the knowledge to design both beautiful and healthy buildings. This study performed a comparative analysis of stone, brick, wood, concrete, steel, and plaster wall opening systems at multiple opening ratios with various applied aesthetics. A total of 72 openings

were examined with the aid of artificial intelligence eye-tracking software. This digital tool eliminated the requirement of large groups of human participants, reducing variability in results. The study's images were digitally composed and analyzed yielding graphic results of heat maps and visual interest charts, reflecting the probability of human engagement in the initial 3–5 seconds of viewership. Building upon previous research performed by Benjamin Varnell and coauthors, which hinted to the significance of opening width-to-height ratios, this study employs a broader database anticipating the conclusion of opening proportion and the use of supporting ornamentation as the primary factors contributing to engaging aesthetic openings. This study creates avenues for further investigations on the impact an architect's adoption of the findings have on physical health and well-being. These factors display the importance of design choices when seeking to design beautiful and healthy architectural spaces.

POSTER: ARTS

Psychitecture: How Light, Life, and Water in Our Built Environment Affects Mental Well-Being

Sean Donner, Nathaniel Stucki, and Brandon Ro
Utah Valley University

Human beings are drawn to nature, but we spend the majority of our lives in buildings. Through the implementation of 3M Visual Attention Software and peer-reviewed studies, this study illuminates the critical role of light, life, and water as design features in fostering healing environments and improving the overall human experience. As mental health challenges grow within our world population, designers and architects must strive to understand neuroscience and the human psyche to learn how building elements, or the lack thereof, affect mental health. We studied how bringing light, life, and water into a space can have a calming effect on our minds. We began by utilizing Building Information Modeling software to model a room with white walls and plain furniture. We then added plants, natural views, water features, and artificial and natural light all separately to the room and ran each iteration through eye-tracking simulation software to understand how the eye reacts to the changes in the environment. The final image of the room included all the aforementioned elements together and analyzed it with eye-tracking software. Through this process, we expect to find that people's ability to concentrate and their mental well-being will increase with the

introduction of natural light, living plants, and water. This research will show that although architecture is not likely the main cause of the growth in depression and anxiety disorders in our society, building design and urban planning focused on including living elements and natural materials can and should play a role in healing our minds and psyche.

POSTER: ARTS

Contextual Synergy: Exploring Architectural Compatibility within Context

Kevin Hart and Brandon Ro
Utah Valley University

The main goal of this study is to explore the intricate relationship between a target building and its surrounding context. Building upon prior research in which individuals were presented with a set of images and asked to rate their feelings toward buildings in various contexts, this study takes a more analytical approach. Instead of relying on subjective assessments, visual analysis software will be employed to objectively analyze the images and identify what captures people's attention the most. The software will produce a heat map, showcasing the areas of highest visual engagement, along with the sequence in which viewers focus on different elements. We will be able to see what draws people's attention when looking at these buildings in various contexts. The focal point of my research involves running images from the previous semester through 3M's Visual Attention Software (VAS). I will present this program with one of several images, and it will produce visual analysis diagrams. By juxtaposing these data with findings from last semester, I suspect that the out-of-context buildings will pull focus away from the buildings as a whole, which will show the correlation between where people look and their enjoyment of a space. The VAS will be key in pinpointing aspects of these images that affect user enjoyment. These data are crucial for architects and designers to understand, to create a more enjoyable experience for the users. Some architects have neglected the context around their structures, as exemplified by some of Frank Gehry's buildings, such as his Dancing House. This building disregards its neighbors and context. This research aims to shed light on how such oversights can impact the overall aesthetic and experiential aspects of a space and to identify key aspects of a building to be aware of when designing within context.

POSTER: ARTS

Turning Towards the Lord: Latter-Day Saint Temple Astro-Architectural Orientation

Desiree Ritchie, Jake Wendt, and Brandon Ro
Utah Valley University

This research analyzes the astronomical orientation of temples following the teachings of the Church of Jesus Christ of Latter-Day Saints. The objective is to document and analyze the orientation of each temple based on its architectural features to determine orientation angles. A specific pattern in connection to the ancient Jewish tabernacle alignment of carnal directions of West and East will be carefully noted and analyzed in comparison to the more temporary Christian alignments. As both religions influence the Latter-Day Saint tradition, we will determine which religious orientation is observed more. Only temples that have been fully constructed and dedicated by ecclesiastical leadership will be studied. The orientation will be analyzed using archeoastronomy research methods and means. Both interior and exterior elements will be examined, such as ornament, sacred room location, tower number and placement, and inscriptions. We expect a variety of orientations as each temple's site and location range from around the world, with most orientations facing East or West. The multiplicity of temple analyses will help establish an overall average pattern in orientation, allowing for a more generalized conclusion. Analyzing the specific architectural elements will also add increased evidence to intentions for alignment. The ongoing data collection and analysis of this research project will inform overall patterns of orientation and insight into the ever-expanding church and its connection with astro-architectural alignments.

POSTER: ARTS

Discovering Ancient Sacredness: Exploring the Astro-Architectural Orientation of Christian Churches in Israel and Palestine

Kent Miller, Yan-ho Ng, and Brandon Ro
Utah Valley University

Churches have played a major role in society and are very specific to their religion. The very direction one faces during worship is significant.

So, is it safe to assume that the orientation of a church would also be significant? Is it possible that early architects understood astronomy, which allowed them to specifically pinpoint an orientation for their ancient buildings? Also, are there astronomical inferences that can be derived from said orientations? Determining and surmising first whether the practice of actively orienting religious buildings took place can be a significant and interesting research starting point. Our project will incorporate archeoastronomy techniques to analyze the orientation of ancient archeology. The orientation and alignment will be determined based on the azimuth, horizon altitude, and solar declination. The scope of the buildings will be limited to churches with a prothesis chapel in the Holy Land. Existing archaeological plans and coordinate systems will be compiled and analyzed to determine commonalities between the different religious structures. Both churches and monasteries will be considered in this analysis. The angle of each church will be measured, and the degree of orientation will be determined by measuring coordinates from Google Earth imagery. The churches will then be analyzed based on their type, time, and location to determine whether their orientation was intentional or considered during the time of construction. It can be assumed that the orientation of the church was significant and considered during construction. Religion is often very rigid and specific in practice. It can be inferred that the orientation which greatly affected construction would be considered. The orientation would affect the location of each of the rooms within the floor plan, which would place significant importance on the orientation of each church or monastery.

POSTER: ARTS

Exploring the Impact of the Divine—A Case Study on Sagrada Familia

Eric Burton and Brandon Ro
Utah Valley University

Sacred architecture is created to leave an impression. To create a space that helps amplify and elevate one's experience into the spiritual. Sagrada Familia is an example of one of the most complex and unique sacred spaces on the planet, offering a massive space to connect with one's spirituality. In this project, we are examining the experiences of people who responded to various survey questions to explore the impact that this sacred space had on them. Sacred spaces are meant to be

appreciated by people of any faith or belief. They are spaces to embrace spirituality whatever that looks like for the person. Because our survey data were gathered at random, we believe they present an appropriate array of viewpoints on the subject. The research methodology for this case study involves analyzing survey responses from Julio Bermudez's database on Extraordinary Architectural Experiences (EAE). We will be comparing and contrasting the responses from the 24 candidates who had an EAE at Sagrada Familia. The survey responses will be compared against Lindsey Jones's three ritual contexts: theater, contemplation, and sanctuary. This will help us categorize our data into a simple and applicable format. We expect to find that the data shows that this sacred space does leave an impression, that it is important for these types of spaces to exist, and that in learning about them and taking the time to visit them and study them, one can gain a greater understanding and appreciation for sacred and meditative spaces. Although we are focusing solely on Sagrada Familia, the data we analyze will be useful for many sacred spaces. Our study will help demonstrate the significance of sacred architecture and the role it plays in helping us connect with our spirituality.

POSTER: ARTS

Exploring and Mapping Ritual onto the Byzantine Church Complex at Horvat Beit Loya

Hailey Packard and Brandon Ro
Utah Valley University

The Beit Lehi Basilica, a sacred site steeped in history, has captivated the attention of numerous researchers and archaeologists. This study delves into the ritual history of the site, focusing specifically on the ritual of baptism. The aim of this research is to paint a vivid picture of the historical and ritualistic dimensions of this sacred space, particularly the transformative experience of baptism for early Christian converts. At the heart of this study is exploring the sensory and circulatory elements involved in the baptismal rite. We seek to reconstruct, through meticulous analysis, the immersive journey undertaken by early Christians as they embraced their faith within the walls of the basilica. The rituals enacted within the Beit Lehi Basilica offer a fascinating glimpse into the religious lives of the early Christian saints. Far from being a mere religious practice, this ritual represented a profound spiritual encounter with the divine. By synthesizing existing

archaeological records and textual sources, this research endeavors to piece together the intricate mosaic of the ritual practiced within the basilica's hallowed walls. Through this approach, we aspire to uncover the possible sequence of events comprising the baptismal ritual and shed light on its broader significance within the early Christian tradition. Ultimately, this investigation seeks to unravel the experience of early Christian saints within the Beit Lehi Basilica, illuminating not only the intricacies of the ritual practice of baptism, but also the enduring legacy of faith and devotion that permeated its sacred walls. In doing so, we hope to contribute to a deeper understanding of the formative experiences that shaped the early Christian community and continue to resonate through history to today.

POSTER: ARTS

Healing by Design: Unraveling the Relationship Between Physical Spaces and Emotional Restoration

Samuel Weisler, Colton Korpi, and Brandon Ro
Utah Valley University

Understanding the connection between physical environments and human well-being has prompted a growing interest in the creation of 'healing spaces.' This is particularly relevant in educational settings. The demands of modern education, coupled with the stressors inherent in academic environments, underscore the critical need for intentionally designed healing spaces within educational institutions. Such spaces have the potential to significantly impact the physical, mental, and emotional health of individuals, creating an ideal environment for learning and creativity. This research will contribute to the integration of wellness-focused environments in educational institutions by pinpointing the principles of healing spaces identified through the research of articles, books, and previous studies. Next, we will choose a range of local outdoor educational space case studies to measure their effectiveness as healing spaces based on the principles previously identified and outline areas of improvement. The principles will then be applied through a design proposal improving an outdoor healing space at Utah Valley University's Computer Science building. We hypothesize that the principles identified through research and analysis to be readily applicable to transform existing and future outdoor spaces into healing environments. This will not only increase their utilization but will also positively impact the health and well-being of students, staff, and faculty.

The potential implications of this research extend beyond the Computer Science building at Utah Valley University. Ultimately, this project contributes to the growing body of knowledge on healing spaces and serves as a practical guide for architects, designers, and educators seeking to integrate well-being-centric design principles into our spaces.

POSTER: ARTS

Contemplating Islamic Geometric Patterns: Using Eye-Tracking Tools to Facilitate a Higher Worship Experience

Barrett Blake and Brandon Ro
Utah Valley University

In Islamic art and architecture, geometric patterns often represent the infinite characteristics of God and the unity among believers. This study aims to analyze various patterns to determine their influence on worship experience within mosques. Because of the rich mathematical, artistic, and religious significance of geometry in the Islamic tradition, recent studies of these geometric patterns seek to understand their construction, simplification, and applications. This research aims to understand better how the built environment influences spirituality using geometric patterns. This study utilizes 3M's Visual Attention Software (VAS) to analyze images of different geometric patterns used in Islamic art and architecture. VAS uses artificial intelligence algorithms based on human eye movement patterns to simulate how people objectively view images before bias influences vision with up to 92% accuracy. Using comparative analysis, this research can identify how patterns allow for a rich and contemplative worship experience based on whether they attract focused versus general attention. By utilizing "heat maps" generated by VAS, this study is designed to determine which patterns attract general attention and which act as distractions. It is hypothesized that the patterns that capture the most general attention are repetitive or non-irregular, whereas patterns centered on a single focal point likely detract from the ritual experience. This research aims to uncover how Islamic geometric patterns impact the worship experience by analyzing how unbiased visual attention algorithms respond visually to architectural ornamentation and artistic representations. Through comparison and interpretation of results, this study is expected to increase understanding of how art and ornamentation in architecture can influence the spiritual experiences of worshippers in the context of Islam.

POSTER: BIOLOGICAL SCIENCES

Isolation and Characterization of Bovine Milk-Derived Extracellular Vesicles

Logan Whitney, Elley Colledge, Jaren Wilson, Jonah Pena-Ekker, and Kolbe Mason
Southern Utah University

Extracellular vesicles (EVs) are small membrane-bound nanoparticles that are secreted from almost all cells and play a vital role in intracellular communication. They are commonly found in many organism excretions including urine, milk, and blood. Because of their stability and non-immunogenic properties, EVs may provide a new approach to target drug delivery. Our research aims to develop an isolation protocol for extracellular vesicles from raw bovine milk. Upon isolation, we characterized the extracellular vesicles through several methods. To determine the morphology of the extracellular vesicles, we used scanning electron microscopy to determine the size and shape of the EVs. The current standards set by the International Society of Extracellular Vesicles (ISEV) center on three categories: proteins, lipids, and nucleic acids, and more specifically, the protein-to-lipid ratio. To determine the surface protein concentration for the isolated EVs, we used a Rose Bengal assay as well as bicinchoninic acid assay. The concentration of lipids is characterized through the use of a sulphophosphovanillin assay. Lastly, the EVs were characterized with an RNA assay involving the use of TRIzol-protocol. The combination of these assays and characterizations aid in meeting the standards set by ISEV. This work will aid in developing a low-cost, high-yield protocol in the isolation and characterization of EVs that may be used in future research.

POSTER: BIOLOGICAL SCIENCES

Encoding and Processing of Visual Information in the Leech

Belle Brown and Krista Todd
Westminster University

The medicinal leech, *Hirudo verbana*, possesses a dual visual system consisting of five pairs of cephalic eyes and numerous photoreceptors

located in segmental sensilla along its body. In this study, we employed microdissection, extracellular electrophysiology recordings, iontophoretic dye injections, and intracellular recordings to explore the visual processing mechanisms in the leech, focusing on cellular responses to ultraviolet (UV) light stimuli. Our investigations revealed that the leech exhibits robust behavioral motor responses when its head eyes are exposed to UV light, consistent with previous findings of reactions observed with sensilla exposed to UV light. In addition, the behavioral response from the nerve cord showed significantly more activity than the simple encoding of the sensory information of the light from the eye nerve. A novel technique was also developed for dual recording of sensory and behavioral information, allowing action potentials from the eye to be matched with resulting action potentials from the nerve cord. This research significantly enhances our comprehension of the leech's visual system and sensory processing, while also providing valuable insights into broader visual neuroscience. The leech's visual capabilities represent a valuable model for investigating the visual mechanisms in simpler organisms, and it may also inspire innovative approaches in the development of artificial vision systems.

POSTER: BIOLOGICAL SCIENCES

CRISPR Deletion of Viral Receptor Genes in Human Cells

Rylan Schmanski, Mason Masters, Emilee Snow, Alexandria Offringa, Paola Robles, Joshua Mackley, Alexander Bagley, Rainey Hughes, and Daniel Clark

Weber State University

Enterovirus 71 (EV71) and herpes simplex 1 (HSV-1) are viruses that cause skin lesions in humans. EV71 causes hand, foot, and mouth disease (HFMD) and primarily affects young children. HSV-1 is a lifelong infection, causing genital herpes and cold sores, which affects 50 to 80% of US adults. We used CRISPR to edit the human genome in cultured cells (HEK293 and HeLa) to decrease the infectivity of these two viruses by deleting their receptors. To delete these virus receptors, a guide RNA (gRNA) was designed for each receptor using the Broad Institute gRNA design tool (ANXA2, SCARB2, and SELPLG for EV71; Nectin-1 and HVEM for HSV-1). Plasmids that express each gRNA and the CRISPR cutting enzyme, Cas9, were transfected into human cells using the base plasmid All_in_one_CRISPR. This plasmid contains a dsRed

fluorescent protein and a G418-selectable marker for the selection of transfected cells, which were then confirmed as knockouts by Sanger sequencing. Cells were then infected and compared for viral-induced apoptosis. Because viruses use combinations of receptors, the end goal is to determine which receptors are most critical for attachment and entry into human cells. This will lead to targeted antiviral drugs to block interactions with those receptors.

POSTER: BIOLOGICAL SCIENCES

Closely Related Enterobacteriaceae Species with Antibiotic Class and Subclass Resistance

Coleman Judd and Alexander Beagle
Weber State University

Because of the overuse of antibiotics in industrial, agricultural, and medical settings, antibiotic-resistant bacteria are becoming more prevalent in various unique settings. We set out with the goal of identifying antibiotic-resistant bacteria from the Great Salt Lake waterfront. After isolating colonies on agar containing the antibiotic tetracycline, we performed 16S rRNA gene sequencing and identified three separate Enterobacteriaceae species all exhibiting varying levels of antibiotic resistance. We performed an array of biochemical and physiological tests to further distinguish the Enterobacteriaceae species. Full spectrum biochemical tests indicate two near identical species followed by a third, novel species as both a phenotypic and biochemical outlier. Antibiotic-resistant bacteria within the Great Salt Lake region present an ever-growing dilemma of clinical and environmental danger that accompanies antibiotic-resistant microbes.

POSTER: BIOLOGICAL SCIENCES

Elucidation of an Operon(s) for a Group 3 Capsule in *Escherichia coli* Strain M12

Elise M. Ihnen, Wade A. Stanford, and Michael A. Olson
Snow College

The Enterobacteriaceae family of bacteria includes several medically relevant pathogens, including *Salmonella* spp., *Shigella* spp., and

Escherichia coli (*E. coli*). The World Health Organization lists Enterobacteriaceae as critical for researching and developing new antibiotics. *E. coli* causes various infections in the gastrointestinal tract and extraintestinal sites. The *E. coli* strain M12 can colonize several mucosal sites in a mouse model, including the mammary gland and urinary tract, and M12 can also evade outside these sites, causing sepsis. An important virulence factor for M12 to cause sepsis is a Group 3 polysaccharide capsule. Group 3 polysaccharide capsules and closely related group 2 capsules are important virulence factors for other *E. coli* that cause extraintestinal infections. However, the exact role in the pathogenesis and genetic regulation of group 3 capsules is still poorly understood. The cluster of genes needed for the biosynthesis and export of the group 3 capsule in M12 is found on a 23-kb island and consists of 3 regions with 17 genes. Our project investigated whether the capsule genes are transcribed into a single polycistronic messenger RNA (mRNA) transcript controlled by a single promoter or transcribed into shorter polycistronic mRNA segments controlled by multiple promoters. We isolated total RNA in conditions where M12 expresses the polysaccharide capsule. We identified cotranscribed genes using RT-PCR and gene-specific primers, suggesting these genes are located on a single polycistronic mRNA transcript. Our future direction is to explore the regulation of the operon(s) once we identify how the group 3 capsules are arranged in a single or in multiple operons.

POSTER: BIOLOGICAL SCIENCES

Isolation of Multidrug-Resistant *Serratia* from Soil

Kaeson Severe, Landon Severe, and Bryson Baggs
Weber State University

Antibiotics are commonly used to prevent and treat bacterial infections, but because of overprescription and misuse of antibiotics, bacteria may change in response to the use of these medicines, creating antibiotic resistance. Furthermore, bacteria are able to share that new antibiotic resistance with neighboring organisms through horizontal gene transfer. This project started as a part of our Microbial Ecology laboratory class in the spring 2022 to identify tetracyline-resistant bacteria from local soils. We collected our soil sample from a leach field outside of Eden City, Utah, from which we isolated and analyzed three antibiotic-resistant bacteria through serial dilution, growth on tetracycline-containing media, DNA extraction, DNA sequencing, and

bioinformatics. These analyses suggested that all three of our tetracycline-resistant bacteria belonged to the same genus of bacteria, *Serratia*. We performed analyses for resistance to additional antibiotics with a Kirby Bauer plate. A through literature review of the genus has suggested that *Serratia* spp. are generally not known to be antibiotic resistant, let alone multidrug resistant. Further genetic testing and research is needed to understand the variables contributing to the alarming rise of antibiotic resistance in soil samples.

POSTER: BIOLOGICAL SCIENCES

Microbial Communities in PCB-Contaminated Soils and Potential for PCB Degradation

Hali Hutchinson, Jerzee Findlay, Gina Fuller, Akir Rowe, and Kingdom Wanjoku
Weber State University

Polychlorinated biphenyls (PCBs) are toxic chemicals popularly used in electrical manufacturing companies from the 1930s through the 1970s. PCBs, colloquially known as 'forever chemicals," are known to cause significant health concerns and are notoriously difficult to remove from an environment. PCBs are currently banned in the United States; however, they can still be found in the environment because of improper disposal methods. This research aims to better understand ecological networks, genomic novelties, and potential bioremediation of microbes from PCB-contaminated environments. Microcosm cultures were developed to resemble the original conditions of the environmental samples, containing PCB-contaminated mud from Wood's Pond, Lenox, Massachusetts, and filtered pond water with three different treatments: aerobic, anaerobic, and anaerobic with the addition of sulfate. These cultures have been growing for 5 months, showing signs of active microbial metabolism (e.g., rust patches in sediment, gas production). The microcosms were used as inoculum for agar containing PCBs, and 30 PCB-tolerant colonies were isolated. In addition, we performed DNA extractions, PCR amplification, and 16S rRNA amplicon sequencing on an Oxford Nanopore MinION DNA Sequencer. Preliminary data suggest that the samples contain genera known to be associated with PCB degradation, such as *Paenibacillus*, *Clostridium*, *Rhizobium*, and *Sphingobacteria*. These data will aid further research to determine if and how these microbes metabolize PCB compounds.

POSTER: BIOLOGICAL SCIENCES

Repeatability of Fecal Egg Counts in Wild Horses

Jaron Dixon, Laura Redfield, and Graham Goodman
Utah State University Eastern

Having been used for over a century, fecal egg count (FEC) analysis is one of the most commonly used techniques for diagnosing and quantifying parasitic infections in domestic animals. Despite its long-standing use, the FEC efficacy is contingent upon the technique employed, each with its unique advantages and disadvantages. In this study, we investigated the precision of centrifugal fecal flotation using Sheather's sucrose solution. This method is commonly used by veterinarians but has not been validated in wild horses. To determine the precision of this method, we homogenized fecal samples collected from 12 wild horses and performed quadruplicate centrifugal flotation analyses in each. Our results indicate that the centrifugal flotation method is precise, with similar egg counts found across samples. This underscores its applicability in both research and clinical settings, offering a dependable tool for evaluating parasitic burdens in wild equine populations. This study not only reinforces the validity of the centrifugal flotation technique but also paves the way for its broader adoption in parasitological surveillance and management programs.

POSTER: BIOLOGICAL SCIENCES

Vegetative Cover Measurements Using Unmanned Aerial Systems in Wildfire-affected Areas

McKenzie Jordan, Jenny Thomas, and Ryan Thalman
Snow College

UAS (unmanned aerial systems, or drones) allow for the repetitive sampling using cameras of vegetation. Photographs were acquired in 2016–2023 in the areas affected by the Sandledges and Willow Patch fires in central Utah. A method is presented for analyzing vegetative cover using image analysis in Samplepoint (samplepoint.org) with UAS-captured photographs.

POSTER: EDUCATION

Benefits of Midterm Quizzes in the Classroom

Willow Park and Caleb Hiller
Southern Utah University

Chemistry is a difficult subject for many students. Often students do not perform as well on the exams as they would like, despite thinking they are prepared for the exam. They do not realize that they might not yet have mastery on a topic, even though they have completed the required homework. In an effort to help students gauge their preparedness before an exam, we have created midterm quizzes and implemented them into a general chemistry course. Midterm quizzes are designed to help students gain proficiency for troubling/difficult topics. Questions are pulled from a pool, so with each attempt students are presented a slightly different quiz. Students are allowed to retake a quiz as many times as they would like and receive the best score from all their attempts. To further incentivize students to enter the exam better prepared for success, we have also made the first 10% of their exam score dependent on their midterm quiz performance. The desired outcomes for the midterm quizzes is to help students recognize when they do not understand a topic, encourage them to work at it until they do, to help them understand the type of effort that is required to succeed with difficult material, and ultimately learn how to better prepare for exams. We are performing this study to determine whether students find the midterm quizzes to be beneficial and to identify their intrinsic motivation for taking them.

POSTER: EDUCATION

Writing with Artificial Intelligence Across Disciplines

Demetrios Pagonis
Weber State University

Generative large language models such as ChatGPT have the potential to impact nearly every academic field. We conducted a study in upper-division Literature and Chemistry courses to assess student comfort using large language models, the efficacy of the models in each field, and students perceptions of the future impacts of these models. We found that a semester of exposure to large language models increased student comfort using those models in both courses. The perceived future impacts of generative artificial intelligence varied across the courses,

with chemistry students anticipating greater impact within their field than literature students. Student feedback on the use of large language models also varied across disciplines, with literature students identifying a greater number and more significant drawbacks to using a large language model, including the ethical implications of generative artificial intelligence.

POSTER: ENGINEERING

Manufacturing of CBAM/CCP Rocket Nozzles

Samuel Buit, Steven DiPani, Alize Juarez, Tyler Putnam, and Spencer Petersen
Weber State University

Space flight is expensive. Recent advancements of reusable rockets have contributed to the reduction of overall space-flight expenses. However, a notable area where cost reduction has proven elusive is the design of the nozzle throat. The nozzle throat plays a crucial role in space flight by regulating combustion flow and generating the necessary thrust to achieve orbit. Despite the benefits of reusable rockets, the design constraints of the nozzle throat persist as a substantial cost factor. This critical component not only chokes combustion flow but also experiences the highest degree of wear during the rocket's operational lifespan. As a result, the nozzle throat demands a high level of durability, leading to increased weight and subsequent costs associated with the launch. The primary focus of this research is to spearhead a solution associated with nozzle-throat design by introducing carbon composite materials and manufacturing techniques. By utilizing the lightweight properties of carbon composites, the aim is to substantially reduce the weight of the nozzle throat while maintaining or even improving its durability and cost. The use of carbon-composite materials offers a potential solution for achieving a more efficient and cost-effective approach to space flight. Carbon composites are known for their strength-to-weight ratio, corrosion resistance, and heat capacity properties, making them an ideal candidate for applications in space flight.

POSTER: HUMANITIES PHILOSOPHY AND FOREIGN LANGUAGE

The State of Student Media at HBCUs and HSIs

Marianna Lopez, Mckinna Baird, and Jean Norman
Weber State University

This research explores the state of student media at Historically Black Colleges and Universities (HBCUs) and Hispanic Serving Institutions (HSIs) given the decline of student media outlets in the past decade due both to the challenges of newspapers in general and the pandemic. It is an attempt to document the presence of student media at these non-White institutions, an effort that does not appear to have been completed before now. Despite ample research on student media, there is a void of data specific to HBCUs and HSIs. Research also has been conducted on journalism programs at HBCUs but not addressing student media at these unique institutions. At least journalism at HBCUs has been researched. HSIs, with a much newer federal designation, have been the subject of some work in the academy, but little if any research has been done on journalism, let alone student media, in these bilingual institutions. The most current lists available show a total of 666 HBCUs and HSIs in the United States, including Puerto Rico (The Hundred Seven, 2018; Hispanic Association of Colleges and Universities, 2021). This study started by gathering information from the institutions' websites and social media and by making phone calls to the newsrooms when no information was available on websites or social media. Through this initial step, we identified 220 HBCUs and HSIs with student media, including newspapers, radio stations, broadcasts, and podcasts. This team deployed a questionnaire to learn more about these outlets to help us shed light on their production operations, publishing styles, diversity inside of the newsrooms, and work methodology. We also have created a unique dataset for future research on student media. We expect to have results from that survey in time for the conferences.

POSTER: KINESIOLOGY AND HEALTH SCIENCES

Addressing the Long-standing Health Inequities Marginalized Populations Are Facing

Julyssa Lopez
Westminster University

Although the COVID-19 pandemic was declared over, the devastating effects it had on individuals and families all over the world are everlasting. Importantly, research shows these data and outcomes go under- and/or unreported. The pandemic highlighted the fact that marginalized populations face several health disparities COVID-19 related and not and that these health disparities are long-standing and need to be addressed in affordable, equitable, and sustainable ways. There is an amplified need to advance health equity for all. This research conducts a systematic review framed by a case study to better understand the health inequities marginalized populations are experiencing and inform best practices to address preventable health conditions.

POSTER: KINESIOLOGY AND HEALTH SCIENCES

Examining Elevation Adjustments and Altitude Impact on the Number of Athletes Qualifying for NCAA Regionals and Nationals

Jeffery Kurt Ward, Kelton Gagnon, Jessica Hill, and Kevin Kirk
Weber State University

This poster presents the findings of a study aimed at evaluating the impact of elevation adjustments on the qualification rates of athletes from high-altitude institutions for the NCAA regionals and nationals. Spanning from 2010 to 2023, the study analyzed athlete performance data from NCAA track and field championships and seasonal rankings within the East and West regions, which include 215 and 125 universities, respectively. The study's results indicate a significant difference in the qualification rates for distance events among athletes training at elevated schools. The data revealed that these athletes had a higher incidence of qualifying for the NCAA national track meet compared with their counterparts training at lower altitudes. This suggests that elevation adjustments may play a crucial role in leveling the playing field, especially in endurance-based track events where

altitude acclimatization can enhance performance. In conclusion, the elevation adjustments implemented by the NCAA appear to offer a tangible benefit to smaller programs with limited budgets that preclude extensive travel for altitude training. These adjustments provide an equitable opportunity for their athletes to qualify for national competitions. By compensating for the physiological disadvantages faced at sea level, the adjustments help maintain competitive fairness across the collegiate athletic spectrum. The study's insights emphasize the necessity of such regulatory measures to foster inclusivity and fair competition, enabling athletes from various geographical and economic backgrounds to compete on an equal footing at the highest levels of collegiate track and field.

POSTER: KINESIOLOGY AND HEALTH SCIENCES

Perceived Motivators and Barriers to Facilitate Exercise Among Primary Care Clinic Patients

Kelsey Hansen and Saori Hanaki
Weber State University

PURPOSE: To determine what patients' needs are to facilitate regular exercise, including what they look for from their healthcare providers as well as their barriers and motivators to exercise. These are essential in implementing an effective intervention. METHODS: A total of 371 patients (>18 years) at four local primary care outpatient clinics completed an online anonymous survey consisting of 24 questions including demographics, medical conditions, IPAQ-short form, questions about exercise education by healthcare providers, and barriers and motivators to regular exercise. The 268 complete responses were categorized into those with chronic disease conditions (CCs) and without chronic disease conditions (NCCs) to compare how the needs and barriers to exercise differ. RESULTS: Survey respondents were mostly female (65%) and Caucasian (92%) and had postsecondary education (86%). The most common perceived barriers to exercise were low motivation, low energy, and that it takes too long. The most common perceived motivators to exercise were having a support system, planning and preparing for exercising in advance, having a partner to exercise with, tracking progress, and positive verbal affirmations. Most patients in both groups (98%) agreed exercise will improve their health. Although the amount of physical activity and sitting hours were similar between groups, fewer with CCs (53%) believed they participated in a healthy

amount of exercise than those with NCCs (67%, p=.007). Those with CCs also believed their medical conditions made it hard to exercise (40% CC vs. 15% of NCC, p<.001). More patients in the CC group (82%) , than in the NCC group (71%, p=.017) reported that exercise education provided by the healthcare providers was helpful. Most (92%) who received exercise education from their providers considered that the information was helpful, particularly when it was given verbally. CONCLUSION: Findings suggest the implementation of social support is sought out in both groups. Particularly among patients with CCs, they value the involvement of their healthcare provider in the planning and engagement in exercise.

POSTER: KINESIOLOGY AND HEALTH SCIENCES

Physiological Effects of Pickleball Based on Skill Level

Jasmine Bennett, Chelsea Cavitt, Belal Glab, Zachary Holt, Emma Lapp, Krystal Serrano, Kaitlyn Standifird, James Zagrodnik, and Ryan Zimmerman

Weber State University

Background: The Sports and Fitness Industry Association announced that pickleball is the fastest growing sport in the U.S. the last 3 years, with an 185% increase over this timespan. To date, only 2 studies have been conducted on the game and its impact on peoples' health and physiological changes. Purpose: To identify the physiological effects of pickleball based on skill level. Methodology: Participants wore Hexoskin vests that measured heart rate, breathing rate, and step count while they played pickleball. Participants performed a 5-minute rest, 30-45 minutes of recreational pickleball play with matched skill level players, a Borg Perceived Exertion Scale, and a 5-point enjoyment Likert Scale. Results: A total of 132 participants were successfully tested. Playing pickleball increased breathing rate 39.70% and heart rate 28.46% from resting across all groups. Preliminary analysis indicated that the number of games played (average: 3.2), Borg Perceived Exertion Scale (average: 13.22), and Enjoyment Rating (average: 4.72) remained consistent across skill groups. Age appears to be correlated with skill level as older players had lower skill levels and age decreased as skill level increased. The highest skill level players demonstrated the highest playing breathing rate (35.56/minute), heart rate (132.87 BPM), and cadence (71.63 steps/minute) across all skill levels. Averages indicate that as skill level increases so too does playing heart rate and cadence

while breathing rate remains relatively consistent, but statistical analysis needs to be conducted to confirm. Conclusion: Pickleball is a highly enjoyable game across many ages in which any age and skill level can have positive health-enhancing benefits from participation in game-play pickleball. Skill level may have an impact on the physiological effects of playing pickleball but statistical analysis needs to be performed to confirm, partly to account for known age-related responses to physical activity.

POSTER: PHYSICAL SCIENCES

Direct One-pot Grignard Formation and Addition to Imine Electrophiles

Kaden Jensen, Audrey So, Charles Tate, Austin Flynn, Timothy P. McFadden, Matthew B. Prater, and Shelley D. Minteer
Southern Utah University

Alkylamines are ubiquitous among biological and synthetic compounds. 1,2-Grignard reagent additions to imines remains an important method to afford alkylamines. In this poster, a one-pot strategy to generate the Grignard reagent in the presence of a target electrophile is employed. It was hypothesized that this approach may minimize the likelihood of Wurtz coupling and the need for titration. Our one-pot method displays promising results, with yields as high as 78%.

POSTER: PHYSICAL SCIENCES

Co-culture PANC-1 and COS-7: Find Methods to Effectively Grow Two Distinct Cell Lines Together

Valeria Rivera
Utah Valley University

Although stem cells are found in adult organs to preserve function and structure by remodeling differentiated cells to promote growth and re-generation. Stem cells are target to oncogenic conditions and progenies of tumor progression. Cell lines studies show PANC-1 or pancreatic tumor cells isolated in a flask with Dulbecco's Modified Eagle Medium (DMEM) with low concentration of glucose and sodium pyruvate supported cell proliferation. Similarly, COS-7 cell lines or kidney cells

were isolated in a flask with DMEM and promoted growth and survival. Consequently, the cells were split to create more tissue cell lines with DMEM and trypsin for protein hydrolysis. However, PANC-1 and COS-7 will be isolated in the same flask to study the interaction between two different types of cells. Different methods will be tested to grow PANC-1 and COS-7 in the same flask and find more proficient ways to co-culture two distinct cell lines.

POSTER: PHYSICAL SCIENCES

Hydrophobicity of Micropatterned PDMS

J. Fielding Hokanson, Russell M. Bodily, Kylee Stoddard, and Chris Monson
Southern Utah University

We have developed a method to make highly hydrophobic layers of polydimethylsiloxane (PDMS) by dilution in alkane solvent and addition of sacrificial magnesium particles, followed by sonication in hydrochloric acid. Dissolution of magnesium leaves behind pillar-like PDMS structures on the surface of our substrate that exhibit hydrophobic characteristics. Hydrophobicity and layer clarity can be manipulated by changing solvent type, PDMS-to-solvent ratio, and percent magnesium. Aging PDMS slurry can improve hydrophobicity.

POSTER: PHYSICAL SCIENCES

J-Type Aggregation of Cyanine Dye in Aqueous Solutions of Monovalent and Divalent Metal Cations

Ethan Fielding, Alexander Stewart, and Hussein Samha
Southern Utah University

The effect of monovalent cations of sodium and potassium and divalent cations of magnesium, calcium, zinc, and cadmium on the aggregation behavior of the cyanine dye (NK-3796) in aqueous solution was investigated using UV-vis spectrophotometry. J-aggregates are formed in the aqueous solutions of cyanine dye upon incremental addition of salt solutions. The appearance of a narrow single red-shifted band at 652 nm in the UV-vis spectra suggests that the dye monomers are quantitatively converted to J-aggregates in the presence of inorganic salts.

POSTER: PHYSICAL SCIENCES

Semivolatile Organic Compounds Throughout Utah

Sara Nielson, Hannah Verhaal, Hafid Bahena, and Casey Reeder
Weber State University

Semivolatile organic compounds (SVOCs) are a key class of human emissions that negatively impact air quality in Utah. This project tackles four aspects of SVOC chemistry, including their regional concentrations, their presence in chemical products, their transport indoors, and the challenges one encounters when measuring them from mobile platforms.

POSTER: PHYSICAL SCIENCES

Synthesis of (E)-Phenylocten-3-ol from 1-Octyn-3-ol Through TBS Protection, Hydroboration, and Palladium- Catalyzed Cross-Coupling

Raymond Brex Delray and Nathan Werner
Southern Utah University

The 9-borobicyclo[3.3.1]nonane (9-BBN) catalyzed hydroboration reaction of terminal alkynes enables the synthesis of aryl- and alkyl-substituted vinylboronic acid pinacol esters. These vinylboronic acid pinacol esters are useful reagents in palladium-catalyzed Suzuki-Miyaura cross-coupling reactions, which are commonly used in the synthesis of pharmaceuticals and fine chemicals. In this work, we evaluated the tolerance of the 9-BBN-catalyzed hydroboration reaction with alkynes bearing alcohol, ester, and silyl ether functional groups. We found that propargyl alcohol and the acetyl and benzoyl ester and tert-butyldimethylsilyl (TBS) ether derivatives of propargyl alcohol do not undergo productive 9-BBN-catalyzed hydroboration reaction with pinacolborane. The secondary alcohol, 1-octyn-3-ol, was then evaluated. We found that the tert-butyldimethylsilyl (TBS) ether derivatives of 1-octyn-3-ol underwent productive 9-BBN-catalyzed hydroboration reaction with pinacolborane in 61% yield. The hydroboration product, (E)-3-[tert-butyldimethylsilyloxy]octenylboronic acid pinacol ester, successfully underwent palladium-catalyzed cross-coupling reaction with bromobenzene in 66% yield. The TBS protecting group was then removed with tetrabutylammonium fluoride in 66% yield.

POSTER: PHYSICAL SCIENCES

Synthesis and Electrochemical Analysis of [Ir(ppy)2]2BPM

Dylan Tatarian and Matthew B. Prater
Southern Utah University

Binuclear metal complexes have garnered interest in recent decades, yet numerous details remain unexplored. Although many enzymes leverage binuclear catalysis in their processes, progress in applying this phenomenon outside of enzymatic contexts has been limited. Means of improvement over mononuclear complexes generally remains unexplored. Homobinuclear complexes, featuring two identical metal centers within a single complex, pose intriguing challenges, particularly in elucidating exact mechanisms governing traditional organometallic steps such as oxidative addition, migratory insertion, transmetallation, and reductive elimination. Recent advances in the synthesis of Ir complexes offer a promising avenue for construction of novel homobinuclear complexes tailored to investigate electron transfer mechanisms, which we propose will offer insight into organometallic steps. This project marks the initial foray into this research domain. We synthesized the parent complex to facilitate its analysis and are in the process of creating an array of homobinuclear iridium complexes to explore the impact of substituents on Δ_o. These endeavors serve as the preliminary stages of a broader investigation into binuclear complexes.

POSTER: PHYSICAL SCIENCES

The Stability of Extracellular Vesicles

Elley Colledge, Logan Whitney, Jonah Pena Ekker, Kolbe Mason, Charlee Cannon, and Jessica Pullan
Southern Utah University

Extracellular vesicles (EVs) are secreted from cells and play a vital role in the human body's intracellular communication. EVs can easily pass through different barriers because of their size (<200 nm), and they contain a lipid bilayer that is embedded with proteins. These traits have caused EVs to become a subject of interest in drug therapy, and the EV field has grown rapidly. Because the EV field is still being researched, there is no current set standard for long-term isolated EV storage and thawing. We are running a stability study that will cover different

temperatures and thawing techniques over 12 months. An aqueous two-phase system is used to isolate the EVs, then they are stored at -80°C, -20°C, 4°C, and room temperature. At time markers, the isolated EVs are thawed using different conditions and then imaged by scanning electron microscope. We have found that isolated EVs stored at -80°C are uniform and organized at the time points one month and six months. In addition to morphology, size distribution, protein functionality, lipid concentration, and nucleic acid presence will be tested in the future.

POSTER: PHYSICAL SCIENCES

Winter Air Quality Measurements in Richfield, Utah

Audrey Gribble, Jenny Thomas, Blaze Jorgensen, and Ryan Thalman
Snow College

Air quality in winter varies based on location, pollution sources, topography, and meteorology. Ground and airborne measurements in Winter 2024 were taken to assess air quality in the area surrounding Richfield in central Utah. Trends in ozone, particulate matter, nitrogen oxides, vertical mixing of the compounds, and temperature and relative humidity are presented.

POSTER: PHYSICAL SCIENCES

Timing of Magmatism and Genesis of Mineralization in the Silver Island Mountains, Western Utah

Kara Olsen, Logan Knight, Aybree DeGrange, Jon Henroid, and Elizabeth Balgord
Weber State University

The Silver Island Mountains, located in western Utah near Wendover, Nevada, contain the geologic record of at least 500 million years of the evolution of western North America. The purpose of this project was to understand the timing, genesis, and evolution of mineralization, specifically metal deposits, to assess the viability of economic development in the area. We accomplished this by mapping faults, fractures, mineral deposits, and chemical alterations in the field. The

majority of the exposed units in the map area are Paleozoic marine rocks, with abundant fossils, including crinoids, brachiopods and stromatoporoids. Those units were intruded into by undated igneous body. The study area is bisected by a north striking, west dipping, high angle normal and transform fault and an east striking, south dipping moderately steep normal fault. Faults and fracture sets with localized chemical alterations are consistent with a hydrothermal origin suggesting an epithermal mineralization pattern in the area. Numerous skarn style deposits were identified throughout the field area, particularly east of the north striking fault along the intrusion. Samples were collected from the intrusion and zones of hydrothermal alteration for further analysis. We observed crystalline structure using the scanning electron microscope, determined elemental composition using energy-dispersive X-ray analysis and X-ray fluorescence spectroscopy and identified additional crystalline structures and phases using X-ray diffraction spectroscopy. There are zones of highly altered rocks and potentially valuable ore deposits, including the minerals chalcopyrite, malachite, and jasperoid bodies. Timing of mineralization is bracketed by the age relationships between the intrusion and cross-cutting faults. Our analysis shows there are some potentially viable minerals in this area and it is worth continued study to assess economic viability.

POSTER: PHYSICAL SCIENCES

Testing the Use of Lichen Cover on Rock Lines Associated with a Prehistoric Hunting Site (Bison Jump) in NW Wyoming to Date their Construction

Cadence Truchot, Emma Krolczyk, Tammy Rittenour, and Todd Guenther
Utah State University

This research investigates the use of lichenometry to provide age control for archeological features. The Wiggins Fork Bison Jump Complex, a prehistoric aboriginal hunting site in NW Wyoming, was used repeatedly to run buffalo off escarpments and steep slopes to supply tribes with enough food to last the winter. My research investigates the use of lichen cover on piles of placed rocks to date cairn lines associated with the jump, as well as the jump funnel at the mouth of the jump that routed the bison off the escarpment. Cairns are piles of ~2 to 15 rocks that would keep the buffalo in a designated area during this communal hunt process. It is expected that older rock constructions will have greater lichen cover.

This can be tested by comparing the percent cover of the rocks by lichen to optically stimulated luminescence (OSL) dates collected from under the same rock cairns as part of MS thesis research by E. Krolczyk at Utah State University. OSL provides an age for the last time sediment was exposed to light and should provide a date for when the rock was set on the land surface. My research approach of using lichen growth to provide relative cairn construction ages is faster, less costly, and less disruptive of the delicate archaeological features than the use of OSL dating, which requires lifting of rocks to date the sediment underneath. In general, lichenometry from photographs will cause less destruction of archaeological sites, which are viewed as living features and sacred to tribes. The results of this research will provide guidance on the use of lichen-cover to date archaeological rock features at the Wiggins Fork Bison Jump Complex and similar sites throughout the region.

POSTER: SOCIAL SCIENCES

Echoes of Childhood: Elucidating the Complex Web of Codependence and Depression

Bridger Lisonbee, Tara Caplin, Maria Balaceanu, and Dannelle Larsen-Rife
Utah Tech University

Codependence has been shown to be highly correlated with depression. Interestingly, research is still being conducted to determine whether it should be categorized as a personality disorder or if it is a development from a toxic interpersonal environment. Parentification is a toxic boundary violation and can lead to depression. Various traumatic childhood experiences can also lead to childhood parentification and adult codependence. The present study tested the contributions of depression, parentification, and adverse childhood experiences on the development of codependence and the contributions of codependence, parentification, and adverse childhood experiences on depression. Participants (n=382, 73% female, 63% in an exclusive relationship) completed the Center for Epidemiological Studies Short Depression Scale (CESD-10), the Codependence Scale (CCS), the 10-item Adverse Childhood Experiences Scale, and the Parentification Questionnaire (PQ). The independent variables of parentification, depression, and adverse childhood experiences significantly accounted for 31% of the variance in codependence. Additionally, the independent variables of parentification, codependence, and adverse childhood experiences

significantly accounted for 29% of the variance in depression formation. Interestingly, adverse childhood experiences did not significantly contribute to codependence when paired with depression and parentification. Alone, it significantly contributed to 3.3% of the variance within codependence. This suggests that although adverse childhood experiences have a close relationship with depression, which also has a close relationship with codependence, adverse childhood experiences are not as strong a predictor for codependence development than parentification, which could be a type of childhood trauma. This research supports the hypothesis that codependence could be an outcome of a toxic interpersonal environment and emphasizes the mechanism being a result of childhood parentification rather than adverse childhood experiences. Additionally, when considering the expected outcome of depression, when controlling for parentification and adverse childhood experiences, codependence still significantly contributes to 14% of the variance in depression.

POSTER: SOCIAL SCIENCES

Creative Comparison of Human and AI Lyrics

Nathaniel Bruse, Daniel Lewellen, Joshua Olsen, Isaak Thompson, and Nick Marsing
Snow College

In recent years, the rise of artificial intelligence (AI) has become a threat to the arts. AI has recently made bounds in the quality of content creation, reaching the level of human-made writings. There has been much research into algorithm aversion and the inaccuracy that humans have in determining AI-generated content. One prominent study showed how much AI-generated music can affect emotions. However, these sections of music did not have lyrics and, as any Taylor Swift fan will tell you, lyrics are just as important as notation to relate with a piece of music. Other research has been done on poetry and AI versus human capability, but nothing has been done specifically on lyricism. This study will survey students to test whether they can tell AI-generated lyrics apart from human-written lyrics. The lyrics we will have are student-written lyrics, basic AI lyrics, trained AI lyrics, and regular song lyrics. The survey will ask participants why they think a particular sample is AI made or human made. Each question will have 3 parts: The first part will ask about whether or not they think the provided song is written by a human or AI; the second part will ask them how confident they are in

their answer; and the third part will ask them why they answered as they did. It is believed that participants will be inaccurate in determining AI-generated lyrics from human-written examples. This is due to the recent advances in AI, making it possible for AI to create content on the level of humans. However, it is conversely believed that participants will be the most accurate in choosing base AI's lyrics, because that will be the sample with the most grammatical errors. It is expected that participants' reasons for their choice will include topics of grammar, emotion, and originality.

POSTER: SOCIAL SCIENCES

Voices of Resilience: The Memorialization of the Rwandan Genocide

Macy McCormack and Nathan Fowles
Weber State University

During the summer semester, students had the opportunity to assist in research concerning the memorialization of the Rwandan Genocide. This research consisted of literature reviews, interview transcription, and the opportunity to ask relevant questions to faculty mentor, Dr. Stephanie Wolfe. The main subject of this research was the memorialization process that followed the Rwandan Genocide. Researchers were able to hone in on specific nuances, facts, and other information regarding memorials within Rwanda. In this research, it was found that the memorialization process of the Rwandan genocide has become an important feature of Rwandan society. The traditional burial rituals that Rwandans were accustomed to were insufficient for the dramatic increase in deceased relatives due to the genocide. Therefore, memorials both large and small would come to represent a mourning place for those lost in surrounding areas and were to be constructed so that Rwandans could properly grieve their dead. These memorials were built in places of mass death and places of importance. In addition to this research, there was a need for understanding precisely how these memorials were built, what thought processes went into designing them, how they were funded, whose contributions were important, and how they would be maintained for generations to come. This presentation will encompass the findings of the student researchers throughout this summer research period.

POSTER: SOCIAL SCIENCES

We Are Not Alone: Examining the Impact of a Tween-Teen Diabetes Day Camp

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Type 1 diabetes (T1D) is a chronic disease that influences all health aspects. The self-determination theory (SDT) suggests that three psychological needs of competence, autonomy, and relatedness are necessary for motivation to engage in healthy behaviors. Through medical specialty camps, these needs can be met by educating campers on how to manage T1D and realize they are not alone. The volunteer-based, five-day, inaugural REACH teen/tween camp for youth with T1D was held at WSU. Camp activities were engineered around the three basic needs described by the SDT. These needs were promoted by physical and educational activities and meeting friends. Pre- and post-evaluations were given. Two measures were significant. Autonomy showed the greatest difference from pre test (M=3.93, SD= .75) to post test (M=4.49, SD= .56), with t(25) = -6.258, p= <.001), effect size r = 1.2. Blood glucose for time in range was collected through an online platform that allowed staff to monitor campers' levels, with the week's average being 152 mg/dL. This study explored the use of SDT to examine the effectiveness of a diabetes camp for youth and hopefully result in better physical and emotional health thus mitigating the risk of complications.

POSTER: SOCIAL SCIENCES

Stigma Management Communication (SMC): A Systematic Review

Tia Zebe and Sydney O'Shay
Utah State University

A communication theory, stigma management communication (SMC), developed by Rebecca Meisenbach, describes the different methods individuals use to manage stigma communicatively. Meisenbach's SMC strategies—accepting, avoiding, explaining, and challenging—were found to be used by adult people who had family members who misused

opioids. Stigma affects everyone. According to sociologist Gerhard Falk, stigma will always exist, allowing people to ascribe differences that include or exclude people into in-groups or out-groups. People manage stigma in many ways, including through humor and support. A systematic review of SMC was conducted to compile existing knowledge on how people communicatively manage stigma. This systematic review aimed to answer the research questions: How have applications of SMC illuminated, refined, extended, and contradicted the theory? And, what critiques of SMC have been raised by existing applications of SMC? To conduct this literature review, the research team used Covidence, a systematic review software to screen articles according to inclusion and exclusion criteria that the research team determines. In the first round of screening, 661 studies were imported to Covidence, with 7 duplicate articles identified manually and 280 duplicate articles identified by Covidence. After the first round of screening, 374 studies were left to be screened for the second round. Of these, 290 studies were found to be irrelevant. This left 88 studies to be assessed for eligibility. Of those 88 studies, 18 were found to meet the study's inclusion criteria to be used for the systematic review. Results and analysis will be presented.

POSTER: SOCIAL SCIENCES

Attractiveness in Online Dating Profiles

Joshua Vernon, Kaydence Draper, Ali Spencer, William Geddes, and Nick Marsing
Snow College

The dating landscape has undergone significant transformations over the years, marked by a profound shift propelled by technological advancements. This evolution has introduced increased complexity to the dating process, notably with the widespread adoption of online platforms as a popular means to forge new connections. As dating becomes mainstream into short profiles and descriptions, it prompts a critical conversation into whether our standards of attractiveness have changed due to the new medium of connection. In the past, dating was based solely on physical interactions. Past studies have found the true power of natural attractiveness has always aided in a physical courtship. Now with modern dating being partially virtual, the playing field has evolved. With this change in mind, studies have been done on online dating and the effect of "dating profiles" on a rating of attractiveness. The findings showed little effect, admitting that natural attractiveness

reigns supreme. But curiosity forces a study to look through the eyeglasses of culture. After researching we've come to the question, how do variables such as mission service and ambitions affect the rating of attractiveness and successful connection on dating apps in a religious context? To research this question, we will have each participant randomly assigned a dating profile and rate attractiveness and potential relationships with that profile. The survey will collect data through Qualtrics. The survey will start by asking basic data-collecting questions. These questions may include, name, age, gender, and sexual preference. The survey will have 4 different profiles, 2 male and 2 female. These profiles will have photos from the internet that are free to use. Depending on the gender and sexual preference, 1 of these 4 profiles will be randomly shown to the participant. They will be asked to review the profile and answer some basic questions.

POSTER: SOCIAL SCIENCES

Are You a Cheater?

Christopher Lowery, Brittney Hoaldridge, Chandler Barclay, Dafne Mejia, Romeo Tiumalu, and Nick Marsing
Snow College

Infidelity has been a widespread issue facing relationships for many years. Several studies have shown that poor communication and betrayal can damage a relationship, and this can lead to separation or divorce. The American Psychological Association recorded that 20-40% of all divorces are linked to an instance or continuation of infidelity. A big question that arises from this issue is: How do we reduce infidelity? After reading the results of the relation of adultery to poor communication, our group decided that a potential solution would be breaking down the definition of cheating. We believe that a survey would be a good way to get different people's ideas on what unfaithfulness is to them. Our survey will have a wide range of questions from different categories of cheating. Those categories consist of physical, mental, emotional, online, and other forms of disloyalty. Ideally, we want as many different groups of people as possible to take our survey, including people from different ages, ethnicities, and sexuality groups so we can have many diverse results. The goal of our project is that after people take our survey, they will open up conversations with their partners that will help establish what infidelity means to them. We are aiming to help people have fewer arising problems from betrayal in their relationships. We also set out to

gather more research that supports the claim that the definition of cheating has changed throughout generations. This definition will continue to change throughout lifetimes so, it would be smart to start opening the ability to define adultery. We hope that this survey opens up that very conversation about how important it is for people to talk about these sorts of things when they get into relationships. Hopefully, this project will live on to help people learn and communicate about cheating.

POSTER: SOCIAL SCIENCES

Mythical Threads of Love

Jadyn Littlefield, Tylee Leishman, Elise Peery, Aiyana Santiagio, and Megan Parodi
Snow College

Different forms of love have been shown throughout time. Love has been portrayed with ideals that are, for the most part, unreachable. How have individuals skewed their idea of love, specifically regarding how their religious beliefs influence the acceptance of "love myths"? To find the answer to this question, a survey will be created. This survey will ask participants questions about what they believe about love. The participants will not know that they are being asked about "love myths." Because of the culture, region, and popular religious demographic of the area where the survey is being created, opportunities will be given to individuals through snowball methodology, social media, and other forms of contact to provide a mixture of answers. Providing a mixed religious and cultural background to the results of this experiment is crucial to receiving unbiased and accurate results. A Spanish language version of the survey is also going to be provided and translated correctly so the phrases do not lose meaning during the translation to reach the larger demographic presented earlier. The outcome for this research is expected to be that Christians will have a stronger belief in these love myths than other religions. In addition, it is thought that the more active an individual is in a religion will make them believe in the love myths more.

POSTER: SOCIAL SCIENCES

The French Media on the Marshall Plan

Eve Harding
Brigham Young University

This paper explores the French media reaction to the Marshall Plan during April 1948 in Paris, with express focus on two main newspapers. Excerpts of these two newspapers were examined in the original language of French on microfilm and then translated by the author. The two rival papers are Le Monde and L'humanité, one with a positive outlook on the plan and the other with a negative. The purpose was to explore what the media were conveying to the public and how they regarded the plan, as a hoax or as an act of charity. Le Monde presented the plan positively and praised America for their benevolence, whereas L'humanité regarded the plan as another way of bringing France into foreign slavery/occupation. This paper seeks to prove that the second newspaper lacked evidence to support their claim that the plan was not beneficial to the nation and examines the relationship of the two newspapers and their editors and the way that relationship influenced the papers ideologies. In conclusion, the Marshall Plan was beneficial and Le Monde was better able to support their argument than L'humanité.

POSTER: SOCIAL SCIENCES

Does Exposure to True Crime Media Influence our Safety Behaviors?

Tayla Bair, Lilly Binks, Sami Flanagan, Seli Ha'angana, Taesi Higgs, and Nick Marsing
Snow College

Previous researchers have talked about and experimented on the connection between personalities and true crime, or the ethical dilemma of true crime, but not one research study is linked or connected to true crime and safety measures. This led us to form the research question of whether true crime media and exposure to true crime media affect safety behaviors. Does watching or consuming true crime media influence safety behaviors, especially in college students? The study will be narrowed to college students, therefore narrowing our true crime content to college students as well. Interestingly, when true crime media first became a phenomenon, women were highly drawn to it, and not

surprisingly, to this day, surveys always resulted in women being more interested in true crime content versus men. We will make sure that we gather a fair amount of both men and women in our research and make sure that our definitions of "safety measures" are the same. We will have our participants listen to a podcast of true crime based on college students and watch a true crime documentary. We will observe their safety behavior, if any, before or when they are on their way to the study location. We then will measure their reactions and the safety measures they took after that. Such safety measures include safety objects such as pepper spray or a pocket knife. Others include if someone will be on their phone while walking alone at night or checking the back of their seat before getting into their car. We expect at the beginning of this research that women would tend to be more cautious and relay more safety behaviors such as owning self-defense objects such as pepper spray or a flashlight. For men, we expect that they would not have any safety measures or safety behaviors.

POSTER: SOCIAL SCIENCES

Exploring Stress Responses to Spine-Chilling Narratives

Olivia Larson, Bailey Cox, Jacob Williams, Ash Ellenburg, and Nick Marsing
Snow College

Scary stories have been a common occurrence for the entirety of human history. Throughout cultures and periods, different stories and monsters have brought fear to all age groups. How do geographical location and proximity influence the creation, evolution, and cultural significance of scary stories? What mental factors contribute to the varying perspectives of fear linked to specific places in different cultures? Although there are a variety of research studies into fear and fear responses, the examiners want to start the research on what aspects of a scary story make it 'scary.' Specifically, the examiners will focus on how location, and one's proximity to the scary story, influence the stress response their body has to the story. The research consists of having volunteers listen to prerecorded stories instead of reading the stories to limit external factors. The stories will be based on common ghost stories and monsters here in the US. Why are individuals scared of stories such as La Llorona or vampires? Four stories will be used in total. One story will be a neutral story to give a baseline. The other stories include the Wendigo, the

Skinwalker, and a ghost story local to here in Sanpete County, Utah, where the experiment will be performed. The Wendigo is a story more commonly known in the eastern United States. The Skinwalker is based in the western United States. By using galvanic skin response sensors, researchers plan to see whether the location where the story takes place influences the listener's fear response as well as research where an individual has grown from a child to an adult influences their reaction to the stories. The expected results are that an individual's location and proximity correlate directly to their response to the designated story.

POSTER: SOCIAL SCIENCES

Does One's Religion and Religiosity Affect Whether One Is More Likely to Believe in Conspiracy Theories

Alec Mitchell, Roman Gause, and Nick Marsing
Snow College

Conspiracy theories have become more of a widespread term that is thrown around to explain the unexplained. It provides people answers to events that are not fully explained by the parties involved or for which evidence does not provide the answers that people need. Theories include subjects like "JFKs Assassination" to less common but still notable ones such as "Birds aren't real." Although these events still happen, researchers ask the question: "What is the underlying cause for belief in these conspiracy theories?" Can other outside forces influence one's ability to believe in such things? Many studies show a wide range of explanations for why people believe or do not believe in conspiracy theories and what these people do or do not have in common. One thing they may have in common is their belief or nonbelief in religion. Studies show that religious individuals that are a part of a religious community have a tendency to primarily rely on information from their community and are skeptical of outside sources. Our study focuses on whether one's religious beliefs can impact his or her views on alternate explanations for historical events that have taken place. We will be focusing on the last 100 years of events and sending out a survey to over 300 people to gather the information needed to see whether there is a strong correlation between one's belief and activity in their religion and whether they are more keen to believe in conspiracy theories. This survey will be distributed using QR codes around our institution, and Qualtrics will be used to distribute it to people all over the country (USA). The questions will range from demographic questions such as race and

religion/religiosity, and will then ask about a range of conspiracy theories from the past 100 years. Respondents will answer on a scale of 1-5 about how believable the conspiracy theories are.

SOCIAL SCIENCES

Exploring the Intersections of Social Impact, Systems Thinking, and Equity-Centered Design

Summer Valente, Cassie Bingham, Sean Crossland, Ezgi Sertler, and Stevie Munz
Utah Valley University

This interactive panel will bring together an interdisciplinary group of academic and practitioner experts in social impact education, design thinking, systems thinking, and impact measurement to discuss the intersections between these approaches. The panelists will explore how these strategies can be integrated into social impact work and how they can enhance community engagement. The discussion will also touch on the challenges of implementing these approaches, how to address them, and the potential impact they can have on creating positive social change. Additionally, the panel will provide attendees with practical insights and strategies they can apply in their work, as well as food for thought on how these approaches can be integrated into their organizations and communities. The session will be innovative, creative, and engaging, inspiring attendees to think critically about the intersections between these strategies and their potential to drive positive social change. The objectives of this panel are that (1) Participants will gain a deeper understanding of the Pathways model and its six distinct pathways and how they can be applied to develop comprehensive social impact learning experiences for students; (2) Participants will learn about design thinking and systems thinking as strategies for social impact, including the principles of design thinking, its intersection with systems thinking, and how these approaches can be applied to address complex social issues; and (3) Participants will explore the importance of theory of change and impact measurement in social impact work, including how to assess impact, identify areas for improvement, and create effective social impact solutions. They will also discuss the challenges of measuring impact and how to address them.

SOCIAL SCIENCES

Playing with Race in Dungeons and Dragons

Christopher LeCluyse
Westminster University

As the fantasy role-playing (RPG) game Dungeons and Dragons (D and D) marks its fiftieth anniversary, it is more popular than ever. Although the game has from its inception attracted players who do not conform to the stereotypical image of D and D players as young white cisgendered heterosexual men, its player base is arguably also more diverse today than at any time in its history. This presentation analyzes the results of semi-structured interviews with 16 people of color who play D and D as part of a larger investigation of how the game portrays race in the first study of its kind. Representing a wide range of racial, ethnic, and gender identities, US geographical regions, and levels of experience, participants shared how they engage with race in the game, whether to reflect their real-world racial identities or to escape them. They identified particular fantasy races, most notably orcs and drow, that reflect real-world racial biases and discussed to what extent they use the game to engage with or challenge such depictions. Although most participants portrayed their own gaming communities as inclusive and welcoming, some also shared experiences of racism and sexism at the gaming table and in gaming stores. By far the most common theme in participants' responses was of fantasy as freedom. Playing D and D and other RPGs affords people of color choices about how they signify racially that they cannot make in daily life. The ways in which RPGs cultivate agency in making such choices aligns with psychological research on the role of stories in shaping both general and racial/ethnic identity. In a fantasy realm of wizards and dragons, perhaps the greatest imaginary leap is to inhabit a world free from racism, sexism, and exclusion.

SOCIAL SCIENCES

Becoming Fannibals: Identity and Engagement in the "Hannibal" Fandom

Francis Vales
Salt Lake Community College

"Hannibal," a TV crime drama based on Thomas Harris's book series of the same name, aired on NBC from 2013 to 2015 and has garnered a

large following that continues to grow even 10 years after the show's debut. This paper analyzes the fandom surrounding NBC's "Hannibal," why it has been so prolific, and how its fans interact with the show, each other, and fan-made content online. It also examines how the "Hannibal" fandom operates and the motivations, experiences, and identities of those within it. To understand the experiences of fans of "Hannibal," a 39-question, anonymous Google Forms survey was promoted in social media groups dedicated to the show. A majority of participants identified as 2SLGBTQIA+ (two-spirit, lesbian, gay, bisexual, transgender, queer and or questioning, intersex, asexual, etc.), white, and neurodivergent and as having a mental health condition. Many respondents reported feeling represented or seen by "Hannibal," being inspired by the show to create art, and feeling a part of a community in the fandom. Some people said that "Hannibal" stands out among TV shows with 2SLGBTQIA+ representation and that the gory and horrific nature of the show is an integral part of its appeal to 2SLGBTQIA+ fans. Some participants reported a feeling of pride and accomplishment in their fan-made content, especially fan art and fanfiction. Many said that "Hannibal" helped them understand or question their gender or sexuality and that the show and fandom have inspired them to pursue interests in psychology, film, art, and criminology. Most participants appreciate the show for its visual aesthetic, writing, and themes. Some people discuss appreciating how "Hannibal" adapted its source media and that this adaptation provides better 2SLGBTQIA+ representation as well as more opportunities to engage with the media.

SOCIAL SCIENCES

Observer Observer on the Wall Who is Most Biased of Them All?

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Utah Tech University

Observer bias of obesity is increasingly important for medical outcomes; an overestimation of weight negatively impacts the quality of care an individual receives, thus hurting the patient–client relationship and promoting mistrust and anxiety in the client. It was expected that female observers would provide more accurate reports of female and male participants' weight than male observers' reports of male and female participants' weight. Participants were comprised of students and faculty present at a small university in the Western United States. Participants

had to be over 18 years of age to participate. Observers estimated participants' weight, which was compared with the participants' (N=117) self-reported weight. The female observers were more accurate in their observation of weight in both female (mean = -10.18) and male (mean = -6.61) participants compared with the male observers' estimation of female participants' weight (mean = -11.62) and female participants' weight (mean = -10.48). These results demonstrate the gender of the observer and the gender of the participant impact the observation of weight. Female observers were best at observing weight overall. When observing weight, if an observer of the female gender is unavailable, the observations are more likely to be incorrect. Potentially with training focused on this bias, male observers may overcome this problem. Furthermore, these results also reveal a potential cultural bias relating to weight. Female participants' weight was consistently underestimated by both female (SD = 16.83) (CI = -15.23, -5.12) ($p < .001$) and male observers (SD = 28.72) (CI = -22.54, -.6954) ($p = .038$); the significant p-values demonstrate that social factors potentially play a role when observing weight. Moreover, when male participants had their weight observed the same effect was not present (SD = 32.68) (CI = -22.55, -.6954) (p=.403) and (SD = 36.78) (CI = -25.62,4.66) ($p = .116$), with a wider confidence interval revealing a wider range of variation.

SOCIAL SCIENCES

Planning for Growth: Toward a Mixed-use, Transit-oriented, Walkable Urban Future on the Wasatch Front

Jeremy Bryson and Charles Leech
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Utah is growing, and quickly. The state has approximately 3.5 million people right now and estimates suggest that the state will be home to over 5 million people by 2050. Much of the current population and projected growth is happening on the urbanized Wasatch Front. For years, planners and policy-makers have, to varying degrees, attempted to encourage Wasatch Front growth to adopt practices that involve mixed-use, transit-oriented developments with higher levels of walkability This paper will begin by exploring these "smart growth" characteristics and then proceed by examining how these planning principles have been applied in cities along the Wasatch Front. This paper will then look forward to future mixed-use, transit-oriented, and walkable

developments, specifically The Point and Utah City, and assess the potential impact of these developments. In short, this paper explores how Wasatch Front communities have used smart growth principles in the past, and how upcoming developments will use those same planning tools to address the continued population growth along the Wasatch Front.

SOCIAL SCIENCES

College Students' and Professors' Perceptions of a Student with ADHD: Does the Gender Matter?

Jackson Anderson, Aonika Russell, Rick Anderson, and Kathryn Sperry
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Attention-deficit/hyperactivity disorder (ADHD) is an increasingly prevalent disorder, affecting between 3% and 12% of children and adolescents and between 2 and 6% of the adult U.S. population. The symptoms alone make it difficult for students to thrive academically, and mental health stigma adds a layer of arduousness through their academic journey. The present study examined the perceptions of male and female college students who have ADHD. Participants (n = 281 students; n = 101 professors) were randomly assigned to read one of two vignettes detailing either a male or female student with symptoms consistent with ADHD. Participants were given the following measures: Attributions for ADHD Questionnaire, Anticipated Behavior Form ("How likely is it that…Eric/a will do his/her share of the workload"), Social Distance Scale ("How likely would you be to…exchange phone numbers with Eric/a"), ADHD stigma, Expectation of Disruptive Behaviors, and Deservingness of Academic Accommodations. Findings indicated that male and female college students with ADHD were perceived similarly on several measures. Professors had more positive perceptions of the student with ADHD compared with the undergraduate participants. This was true on the anticipated behavior form, $F(1, 373) = 18.93$, $p < .001$, and on the likelihood of disruptive classroom behaviors, $t(139.40) = 6.93$, $p < .001$. Professors were more likely to agree that students with ADHD deserve academic accommodations compared with student participants, $F(1, 372) = 55.66$, $p < .001$. Consistent with the aforementioned findings, professors also had lower levels of ADHD stigma on five out of the six subscales of the ADHD stigma scale. Findings suggest that the gender of the target did not impact perceptions

of college students with ADHD, but students exhibited more negative perceptions on several measures compared with professors.

SOCIAL SCIENCES

The Demography of Apostasy, Conversion, and Retention Among Members of The Church of Jesus Christ of Latter-day Saints in Utah

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This paper used a sample of 1152 Utahans to examine the demographic characteristics of people who have switched religious denominations or forsaken religion entirely. We focused primarily on The Church of Jesus Christ of Latter-day Saints (LDS), by far the largest denomination in the state. We compared the demographic characteristics of lifelong Latter-day Saints with those of converts and with those who have left the LDS Church. Using a stratified sampling strategy to adjust for Utah's population characteristics, we found that an increasing number of Utahans have abandoned organized religion and now report no denominational preference. We also found that self-identified members of The Church of Jesus Christ of Latter-day Saints are no longer a majority in the state. Our estimates show that the proportion of Utahans belonging to the church has declined from two-thirds in the early 1990s to about 42% today. Even more so than other Utahans, those who have left the LDS Church have not joined another denomination and describe themselves as having no religion. We discuss the implications of these findings for Utah's politics and culture.

SOCIAL SCIENCES

I Know What You Researched Last Summer!

Joshua Milliner, Jai K. Earhart, Grace Winder, and Xin Zhao
Weber State University

Our time as research assistants in Professor Zhao's lab was an enriching experience, culminating in the Expert Interviews project, which is aimed at enhancing a widely used, professor-updated, open-source psychology

textbook. Tasked with filming, conducting, and integrating video interviews of diverse and practicing professionals, we not only enriched the textbook's content but also bridged the gap between academic knowledge and real-world application. Our responsibilities extended from performing thorough literature reviews to organizing and analyzing data, as well as learning to strategically plan our own experiments. A pivotal part of our project was the innovative use of artificial intelligence technologies, including ChatGPT and Bard, to analyze textbook chapters, gauge trends among psychology students, and develop tailored interview questions for each expert. This multidimensional approach not only improved the textbook's inclusivity and relevance but also equipped us with valuable skills in research methodology, data management, and the ethical application of artificial intelligence in academic settings. The project's success lies in its potential to influence psychology education nationwide, making it more representative, engaging, and aligned with current professional practices.

SOCIAL SCIENCES

"I Read the News Today, Oh Boy": Oppositional Consciousness-Raising in British Invasion Rock

Theresa Martinez
University of Utah

British Invasion rock bands emerged within a particularly unique societal context. World War II had a significant and lasting impact on generations of British youth growing up in the economic hardship of its immediate wake. There were, in fact, quite a lot more youth to go around with a postwar baby boom of sorts, mirroring a similar boom in the U.S. These youth were, in addition, directly impacted by the change in British conscription laws that ended the draft, leaving idle a generation of working-class teenagers who would create their own unique identities. At the same time, English youth were influenced by a late 1960s zeitgeist made up of various facets, including a counterculture that questioned authority as well as antiwar demonstrations against a brutal and costly war in Southeast Asia. These elements would have a profound influence on the British Invasion rock bands caught up in such transformation and turmoil. This paper focuses on a lyrical and thematic analysis of the work of three legendary British Invasion bands as they reflect on and respond to the sociohistorical context of their times. The paper specifically unpacks the lyrics of our British Invasion bands through a theoretical

lens that evokes oppositional cultures or cultures of resistance within distinct social locations or cultural formations—a distinctive brand of oppositional consciousness-raising within a most turbulent time.

SOCIAL SCIENCES

Analysis of Gene Expression Related to Learning and Ethanol Tolerance Development in Honey Bees (*Apis mellifera*)

Rachel E. Robinson, Zachary D. Tadler, Hannah M. Hughes, Chandler M. Peterson, Lindsey R. Aune, Brennan M. Brown, Jackson T. Anderson, and Timothy E. Black
Weber State University

Apis mellifera are a model of learning and ethanol consumption behaviors. By analyzing the ability of honey bees to develop a color bias under conditioning, we observed their ability to learn under different ethanol concentrations. Gene expression was measured using RT-qPCR. It is hypothesized that as the quantity of ethanol ingested by bees increases, there will be changes in HSP70 and BKP expression while learning capacity will decrease.

SOCIAL SCIENCES

Trust as the Wormhole of Organizational and Social Change and Transformation: Building Bridges and Accelerating Progress

Jonathan H. Westover
Utah Valley University

In the vast cosmos of organizational and social change and the mysteries of the universe, there exists an intriguing parallel between the hypothetical concept of wormholes and the transformative power of trust in driving societal transformation. Just as wormholes are theoretical tunnels that connect distant points in spacetime, trust acts as a metaphorical bridge that connects individuals, communities, and organizations in the pursuit of organizational and social change and transformation. The connection between wormholes and trust invite us

to transcend conventional boundaries and explore new possibilities. Just as wormholes challenge the limitations of spacetime, trust challenges the barriers and divisions that hinder progress and organizational and social transformation. By recognizing the power of trust and nurturing meaningful relationships, we can harness the potential of these metaphorical wormholes to bridge gaps, amplify efforts, and create a future that is characterized by collaboration, equity, and positive change. Let us embark on this journey of trust, harnessing the energy of connections, and propel ourselves towards a brighter, more inclusive, and transformative tomorrow. This developmental conceptual paper will explore the connection between wormholes and organizational and social change, highlighting the role of trust as the catalyst that propels collective action, accelerates progress, and enables the traversal of barriers and limitations.