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Editor
Kristin L. Kraus

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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: The best paper presented in every division is given a 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.

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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 of Sciences, Arts, and Letters* 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 section editor of the appropriate section by the indicated deadline. Contact information for the section editors 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.

Among the bibliographic services listing at Bowker Serials Bibliographies and The Standard Periodical Direction. Indexing and abstracting services that cite articles in the journal include Arts and Humanities Citation Index, Biosciences Information Services, Current Geographical Publication, Chemical Abstracts, Mathematical Reviews, MLA Biography, Sociological Abstracts, Excerpta Botanica, Social Planning, Policy and Development Abstracts, Language and Language Behavior Abstracts, Index to Scientific Technical Proceedings, and Index to Social Sciences, and Humanities Proceedings.

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DISTINGUISHED SERVICE AWARD

The Distinguished Service Award is given to an academic professional for exceptional service to the higher education community in Utah.

Gloria M Prah

Gloria Prah was raised on a small farm east of Flint, Michigan, along with her three sisters. She started her education in a two-room, country school and, by the end of kindergarten, had decided that she would be a teacher when she grew up. After high school, she was offered a full scholarship to Central Michigan University (CMU), but her parents would not allow her to go. She ended up attending a two-year college and continued to work on the family farm.

After two years of college, she was invited to join a CMU education program and, in spite of her parents' objections, she moved to Flint and started her career as an educator. This leap of faith was made possible only because of the help of her friends—including her future husband. With their support, it still took a total of five years before she graduated. Just getting to that point inspired her to eventually work to help other women follow their career dreams.

Gloria and her husband retired in 1993 and moved to southern Utah. She joined the American Association of University Women in 1994 and ultimately served as the President of the St. George branch for six years and the state-level treasurer. Under Gloria's leadership, the St. George branch grew to be the largest in Utah and they created a scholarship fund to help local women attend college, raising tens of thousands of dollars annually. In 2010, Gloria continued to lead the group as they created the eSMART Summer Camp to help local girls explore careers in Science, Technology, Engineering, and Math (STEM) camp she ran for four years. Both the scholarships and camp were designed to help support local girls and women pursue futures in higher education in a community where women are still less likely to attend college or major in a STEM field compared to the rest of the nation.

In all of these efforts, from going to college to helping other women get there, her husband has been her greatest supporter. Gloria stepped down from running camp to care for him until he passed away in 2015.

She currently splits her time between Utah and Michigan where she still has family, including her son. In her free time, she plays and teaches bridge, weaves, sews, volunteers with archaeologists and at a local community theater, runs a small community gym, and has recently returned to lead a group at AAUW, St. George focused on local, state, and federal policies that impact girls and women.

ACADEMY FELLOW 2020

Peter Kraus (1968–2020)

University of Utah

Peter was an Associate Professor at the J. Willard Marriott Library at the University of Utah for 21 years (to the day). During his time there, he had varying roles as, among other titles, Federal Documents Librarian, Political Science & Public Administration and German Language and Literature selector, Outreach Coordinator, Information Services Librarian, and Interim Assistant Head of Faculty Services Division, and as a Special Assistant to the Dean for legislative outreach with the Utah Academic Library Consortium. He was an active member of the American Libraries Association and its Government Documents Roundtable, which recently recognized his “contributions to the field of librarianship, and to the specialty of government information.”

Peter served on many University Committees, volunteered at the University’s Office of Research Grants Boot Camp, and served on the Executive Board of the Utah Library Association and as Chair of its ACRL section. In 2015, he took a sabbatical at St. Stephen’s House at the University of Oxford, UK. Before coming to the University of Utah, Peter worked for 5 years at the New York Public Library. He graduated from Florida State University with a BS (’91) and MLS (’93).

Peter’s career was dedicated to two of his life’s passions: teaching and government affairs. Helping students with research was a joy of his career. He was a true academic, partnering with colleagues throughout the entire university, attending conferences, and publishing in academic journals. His love of academia and “the liberal arts” led to his connection with the Utah Academy of Sciences, Arts, and Letters. Peter served for over a decade on the board as the Scholarly Communications Chair. In this role, he helped get the Journal included in the H.W. Wilson and Ebsco databases to promote the work of Utah scholars. His tireless support of higher education was at the heart of his enthusiasm for his work with UASAL.

Peter was active in local politics and ran for a seat in the Utah Legislature in 2014 and 2018. He felt that his position in the middle of the political spectrum was an asset to the community. Peter took great pleasure in traveling with his wife Kristin throughout the U.S. and internationally. He was a zealous fan of college football, enthusiastically tailgating at Ute games and rooting for FSU. Peter made friends everywhere, welcoming people with fascinating conversation, his kind and generous heart, and his gregarious personality.

O.C. TANNER LECTURE

“In the Land of Rainbows and Unicorns: Forensic Science of a 76-million-year-old Tyrannosaur Mass Mortality”

Alan Titus

Tyrannosaurids, including the mega-celebrity *Tyrannosaurus rex*, one of the largest terrestrial carnivores of all time, dominated the Northern Hemisphere during the Late Cretaceous (66–100 Ma). Rare tyrannosaur mass mortality sites in both east Asia and North America have been used as arguments that they were social animals, possibly grouped into cooperative packs. Site 14UTKA-8, inside Grand Staircase-Escalante National Monument, also known as the Rainbows and Unicorns Quarry, has yielded the remains of at least four individuals of the advanced tyrannosaurine *Teratophoneus curriei* buried in close proximity. Examination of the geological, faunal, stable isotope, taphonomic, and charcoal evidence at the site appears to confirm the tyrannosaurs died as a group in a catastrophic single event, rather than through some attritional process like a predator trap. As a result, some level of social behavior can be inferred for *T. curriei*, a species much more closely related to *T.-rex* than any from previously documented sites.

JOHN & OLGA GARDNER PRIZE

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

Alan Titus

Dr. Alan Titus has worked as the monument paleontologist at Grand Staircase-Escalante National Monument for the last 20 years. He was the first full-time permanent paleontologist hired after the Monument's creation and has overseen the entire Kaiparowits Basin megafaunal renaissance. In 2013, he was honored with the naming of the horned dinosaur *Nasutoceratops titusi* in recognition of his contributions to the region's paleontology. He administers permits, coordinates and conducts research, manages partnerships with universities and museums across the country, runs the paleontology lab, conducts field surveys and excavations, and conducts much public outreach such as lectures, tours, articles, and books.

His current research interests include magnetic stratigraphy, marine reptiles, ammonite diversity, history of a multi-individual tyrannosaur bonebed, dinosaur thermo-regulation, and the classification of early hadrosaur-like dinosaurs.

Originally from Nevada, Titus has lived in Kanab for the last 16 years, where he enjoys hiking, skiing, mountain biking, and playing guitar in a classic rock cover band (named Mesozoic of course), when not out looking for fossils.

HONORARY MEMBER 2020

Susan R. Madsen, PhD

Dr. Susan R. Madsen is the Inaugural Karen Haight Huntsman Endowed Professor of Leadership in the Jon M. Huntsman School of Business at Utah State University. She is also the Founding Director of the Utah Women & Leadership Project, which focuses on strengthening the impact of Utah girls and women through increasing college completion rates and helping girls and women find their voices and become leaders.

Professor Madsen and her team have written many Utah research and policy briefs, research snapshots, impact reports, newspaper editorials, and other resources. They host 20–30 events each year to support the mission of their work.

Susan is also a well-known global scholar, authoring or editing six books and publishing hundreds of articles, chapters, and reports.

Madsen's research has been featured in the U.S. News and World Report, The Atlantic, The New York Times, Parenting Magazine, Chronicle of Higher Education, The Washington Post, and she is a regular contributor to Forbes.

She is a sought-after speaker in local, national, and international settings. For example, she has presented at the New York Times, Argentina Parliament Palace, House of Commons in England, Lithuania President's Palace, and NGO sessions at the United Nations. She advises and/or serves on many nonprofit, community, and education boards and committees, including Silicon Slopes, Envision Utah, Better Days 2020, Real Women Run, United Way of Utah County, Utah Financial Empowerment Coalition, Women's Leadership Institute, and more.

Madsen received a bachelor's degree from BYU, masters from Portland State, and a doctorate from the University of Minnesota.

She and her husband Greg are the proud parents of four adult children and two grandchildren.

2020 BEST PAPER AWARDS

Art

Pleasure and Meaning in Islamic Art: Toward a Naturalist Framework

Barry Wood

Dixie State University

Biological Sciences

Urbanization Effects on Genetic and Species Diversity in Southern Utah Ant Populations

Johanna Garavito,¹ Carrie Bucklin,¹ Laurie Maugher²

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Social Sciences

Ripple IN Still Water

Theresa A. Martinez
University of Utah

Healing Trauma in the Art Classroom

Audrey Reeves

Utah Valley University

Abstract

Many U.S. students experience individual, social, and collective trauma, including systemic forces and oppression of minorities. This article addresses how a K–12 art education curriculum should better support students who have/are experiencing trauma. The author proposes more attention to four aspects of curricula, advocating for art teachers to guide students between art for self-expression, art to critique students' circumstances, art to imagine a joyful future, and art as an escape. It is important to balance all of these aspects of curricula, as solely expressing and critiquing trauma is a disservice to students. Art teachers need to also give space in the curriculum for hope and joy to promote student healing.

Healing Trauma in the Art Classroom

What will your world look like in 100 years? I moseyed around an art teacher's classroom looking over 6th grader's shoulders, peering into their minds, their imagined worlds, some hastily sketched onto crinkled lined paper from the recycling bin, others carefully rendered into sacred art journals. Students drew Jetson-like houses and futuristic cars

hovering through the air; an old lady in a rocking chair (a self-portrait); and insanely tall skyscrapers. I halted abruptly at a space view of a hazy brown world engulfed in flames. The student sensed my surprise and explained nonchalantly “with global warming and pollution, our world won’t be livable in 100 years.” Questions raced through my head: Were they studying environmentalism in science? Is this the result of the news? Was this what I thought about in 6th grade? Maybe she was right, but why the perspective of impending doom instead of hope?

The purpose of this article is to propose more attention to four aspects of curricula for K–12 art teachers with students with trauma, advocating for teachers to guide students between art for self-expression, art to critique students’ circumstances, art to imagine a joyful future, and art as an escape. Before I dive into the curriculum, first I discuss what trauma is and what it looks like in schools. Finally, at the end, I give a tip for teachers with students with trauma regarding how to sustain themselves.

Trauma Definition

Climate change is not the only traumatic circumstance students are anxious about. I was surprised to learn that more than 46% of students in the United States have had at least one adverse childhood experience (ACE), which includes “physical, sexual, or emotional abuse; physical or emotional neglect; who witness domestic violence; and/or those who live with individuals who abuse substances, have mental illness, or are incarcerated” (Kay & Wolf, 2017, p. 26). This definition of trauma only encompasses individual trauma, though.

Trauma should be expanded to individual, social, and collective trauma, including systemic forces and oppression of minority races, ethnicities, genders, sexual orientations, social classes, and disabilities. Art therapist Karcher’s (2017) definition of trauma considers the misogynistic, xenophobic, and racist rhetoric and oppression of marginalized groups in today’s political climate. Policies that are overtly anti-immigrant, anti-LGBTQ, anti-women’s rights, and racist, alongside hate crimes and microaggressions target anyone whose values are non-dominant. The rhetoric isn’t new but has received unparalleled attention on news and social media, leaving marginalized students feeling unsafe in their everyday lives.

Furthermore, Salas (2020), a trauma therapist, explains COVID-19 has had social, mental, and cultural impacts. COVID-19 can be classified as psychological trauma and can result in long-term mental health consequences such as post-traumatic stress disorder. The pandemic has resulted in students being isolated, stressed, anxious, and fearful.

Additionally, some students may have experienced sudden losses in their lives. COVID-19 may have especially exacerbated the circumstances of students with pre-existing trauma, for example those living in poverty or students who live in a house containing domestic violence. This gives the topic of trauma a renewed sense of urgency for art teachers.

Student Trauma in School

Teachers often know about students' situations of trauma but also may not know students who have/are experiencing trauma. Student trauma that teachers may not know about can show as "anxiety, denial, depression, despair, rage and anger, grief, numbness, hypervigilance, fear, hopelessness, and feelings of shame" (Karcher, 2017, p. 124). Students may also overtly share stories of trauma with art teachers. While I was teaching an art education class at Ohio State University, I was surprised at how many students shared intimate stories with me: a struggle with bisexual identity with unsupportive parents; a battle with anorexia; being raped by a father; a mother dying slowly because of brain cancer; and feeling unsafe as a Muslim American post 9/11 just to name a few.

Art teachers who educate students with trauma face many challenges: knowing so many students have/are experiencing trauma; addressing each unique student's situation; legalities surrounding reporting; having time on top of academics to reach each student within large class sizes; having time to communicate with teachers/faculty for a team-wide approach; and getting students to go and open up to counselors (Reeves, 2019).

Art teachers are struggling to sustain their many students who have trauma. Thankfully, the interest in student trauma is growing among educators; there are increased efforts at local, state, and federal levels to make teachers' pedagogies trauma-informed (Lang et al., 2015). But how can curricula in art education support students who have/are experiencing trauma?

Art for Self-Expression

The field of art therapy is a great example of using art as a means for personal self-expression to heal. Art therapy views artmaking as nonverbal expression and resolution of thoughts and feelings to heal and enhance life (Malchiodi, 2003). Art therapists help patients communicate their feelings through creative expression to cope with experiences of trauma (Ulman, 2001). The goal of art therapy is for patients to process hidden emotions and thoughts and allow unconscious images to emerge (Malchiodi, 2007).

Although art educators are not art therapists, we can still utilize art for self-expression in our curriculum. However, art teachers should not fully assume the responsibility for addressing students' emotional needs, being careful not to engage in psychotherapy or analysis (which they aren't trained for) or to replace support services. Furthermore, art teachers are mandated reporters, legally required to report their concerns about students' health and safety to their principals and school counselor, especially if the student is at risk themselves or plans to put others at risk.

Art education can be helpful to students that fall short of mandated intervention and cannot receive special services as well as support and benefit all students using therapeutic art processes. It does have crossover with art therapy as many art educators encourage students to create art that expresses and communicates their thoughts, feelings, and understandings of their inner world (Alter-Muri, 2017; Kay & Wolf, 2017). The art room is a great space for students, especially those with trauma, to express and process their "anger, confusion, and grief" (Kay & Arnold, 2014, p. 33). Teachers creating curricula that encourage self-expression may help students with trauma learn about and regulate their emotions, leading to increased agency for the students in understanding and working through their trauma (Sassaman 2019; McCoy, 2019). Therefore, one important aspect of art education curricula to help students with trauma is art for self-expression.

A practical example of an art lesson plan that centers self-expression, that can be used for students from Kindergarten through 12th grade, is for students to engage with abstract expressionism as a kind of meditation practice to paint how students feel and then share their experiences and describing their emotions and thoughts to other students (Bassi, 2020).

Art to Critique Student Circumstances

Another aspect of art therapy that art education can and does utilize to help students with trauma is exploration of social ideas or social issues related to one's identity (Kay & Wolf, 2017). Many art educators prompt students to explore significant social issues in their surrounding local, country, or global communities through artmaking (Gude, 2007; Freire, 1993). Art teachers should regularly design meaningful and relevant art projects that encourage students to interrogate and critique social problems. The social problems explored may overlap with students' trauma and allow them to work through feelings and personal reactions to their individual, social, and/or collective trauma (Kay & Wolf, 2017; Vriend Van Duinen & Mawdsley Sherwood, 2019). It is powerful to ground curriculum in the needs of students with trauma that are

“struggling to navigate the seemingly hopeless realities of their everyday lives” through intellectualizing their pain and making critical sense of their reality, problematizing their notions for self and social change through engaging in art (Duncan-Andrade, 2009 as cited in Camangian, 2011, p. 458-459; Vriend Van Duinen & Mawdsley Sherwood, 2019, p. 26).

Many contemporary artists can be used to inspire art lessons that explore varying types of student trauma, as contemporary art trends involve activist, socially engaged art. A curriculum can use contemporary artists like Ai Weiwei, Schellekens and Peleman (artwork about refugees); The Names Project, Felix Gonzalez Torres (HIV and AIDS); Luke Jerram, Michael Aaron Williams (homelessness); Damon Davis, Michael Skolnik (police brutality); Yong Soon Min, Carrie Mae Weems (Eurocentric standards of beauty); Carl Fredrik Reuterswärd (gun violence); Laylah Ali (race relations); Sidney Goodman, Sonia Boyce (family issues); Sam Taylor Wood (male gender roles); Shirin Neshat (Middle Eastern gender); Ana Serrano (the beauty of low-income housing); and Pepon Osorio (incarceration) (Boyd & Hoeptner Poling, 2019). A trauma-informed art education curriculum should help students critique current social issues that relate to students’ narratives, which many contemporary artists investigate.

Although some educators might think discussions about complex social issues should take place at a later stage, I would advise these discussions take place early on. Racism occurs daily in families of color, and parents need to explain early on to their young child that the color of their skin means they may be killed if in the wrong place at the wrong time. Sheltering children from these issues is a position of privilege. It is never too early to teach students not only to critically think about social issues but also to teach empathy. A practical example of an art lesson plan that centers critique of social ideas for K–12 is for students to analyze gender stereotypes in visual culture such as toy advertisements. Another art lesson plan is using as an example Myles Loftin’s “HOODED” photo series (Sargent, 2017), which was created in response to Trayvon Martin’s death to confront media bias against black male teens. Art teachers can ask students to break a stereotype that is meaningful to them through photography. Many other lesson plans and resources involving critique of social issues for K–12 can be found on the website Teaching Tolerance (<https://www.tolerance.org/classroom-resources/lessons>).

Art to Imagine a Joyful Future

For some students with trauma, simply expressing and sharing their experiences, although incredibly hard, may be liberating, creating “a sense of healing in the telling of the stories” (Woywod & Deal, 2016, p. 44). For others, moving past solely telling their stories to understanding and critiquing their stories may be more impactful. Even though art teachers have good intentions, self-expression and critique of traumatic circumstances is not enough, as this is only one part of a student’s narrative that defines them only by their suffering (Wong & Peña, 2017).

Instead of asking students to continually reiterate traumatic narratives, art teachers should provide more space for joy-centered curricula to “disrupt and dismantle ... conditions of oppression” and promote healing (Wong & Peña, 2017, p. 130). The curriculum should push students to imagine or create action toward a more just forward-thinking future, or what Paris describes as social dreaming for a more just world (Paris, 2012 as cited in Paris & Alim, 2017; Gutierrez, 2008 as cited in Paris & Alim, 2017). Teachers can help students “acquire a new vision of the world which is based on a critical awareness of social inequities,” giving students a critical voice, but also enabling hope in changing their circumstances, supporting visions for freedom (Freire, 1978, p. 72; Wong & Peña, 2017). It is important for teachers to guide students in critiquing trauma but also to use positive actions to alter their circumstances and create spaces where caring and courageous communities can emerge (Gude, 2007). Art teachers should enable students to focus on their strengths to transcend the negative, promoting change and working toward “a literacy of joy and pleasure that lives beside a proactive attentiveness to discomfort and pain” (Kay & Arnold, 2014; Wong & Peña, 2017, p. 133).

This idea mirrors Sedgwick’s (2003) discussion of critical versus reparative approaches. She argues a person’s energy isn’t best used in continually tracing, revealing, and exposing oppression because this doesn’t yield useful results (Sedgwick, 2003). By taking a critical approach, students block the useful, “potentially operative goal of seeking a positive affect” (Sedgwick, 2003, p. 136). Instead of only focusing on what is problematic, we should seek pleasure and allow room for joy (Sedgwick, 2003). Therefore, students with trauma should explore the possibilities for a sustainable, joyous life and future.

This is also similar to Afrofuturism, which puts focus on celebrating black culture and envisioning possible black futures instead of the usual depiction of pain and suffering. Although Afrofuturism was developed in the early 1900s, recent artworks have embraced Afrofuturism. Afrofuturism moves beyond oppression to celebrate the

uniqueness and innovation of black culture and reclaim agency (Dery, 1993). Recent Afrofuturistic artworks express an imagined liberated future, real or abstract, which “eventually creates conditions for sustainable, even thriving black life” (Gaiter, 2018, p. 300).

Students experiencing trauma need to create artwork that allows them to see themselves in an optimistic future despite their distressing past and present (Gaiter, 2018). Art education should teach students the “tools and methods of liberation” to mobilize and reclaim agency over their story (Foner, 1995, p. 42, as cited in Gaiter, 2018, p. 302).

A practical example of an art lesson plan that prompts K–12 students to imagine a joyful future is using the examples of visual artist Stephen Hamilton and/or the movie *Black Panther* (Coogler, 2018) for students above age 13 years. Students can utilize their own traditional culture’s artmaking processes to imagine their culture thriving in a technologically advanced future, situated in fantasy, myth, and imagination (Acuff, 2020). This gives students “agency to actively create their existence and futures” (Acuff, 2020, p. 20).

Art as an Escape

Although curricula that emphasizes self-expression, critique, and imagining a better future support students with trauma, some students with trauma may not want to engage with their trauma at all for a variety of reasons. When this occurs with individual students, teachers need to provide the student the choice to create art unrelated to their trauma, or art as a temporary distraction. Similarly, if all students are going through collective trauma, teachers should ask the class what would help them the most: exploring the trauma or giving everyone a break and diverting attention away from the stress.

Art teachers should never force students to open up and discuss their experience of trauma. Exploring students’ trauma should happen “via their own agency and on occasions of their own choosing” (Rufo, 2017, p.6). Some teachers may feel the urge to push students to confront their trauma, but this is not the answer. Although permanently avoiding trauma does not yield the best long-term results, temporary distractions give students time to minimize and reduce their emotional distress related to their trauma so they can manage it better later. One art teacher explains, “if they [students] choose to use art as more of an escape, it’s still a way healthier, a creative type of risk than other escape mechanisms” (Reeves, 2019).

Artmaking in general is healing and restorative, even without exploring or critiquing trauma. The art environment creates a calm space where students can pause with themselves, in a place where time turns

liberal (Collins, 2016). Art also encourages “spontaneous and interactive invention, imagination and play,” which can help students heal (Collins, 2016, p. 204). A practical lesson utilizing art as escape is exemplified by Rapp Boggess (2017) explaining that her students with trauma loved creating pottery and gifting it to someone important in their lives. Enabling students to give to others leads to students being happier and healthier. This is a great example of an art lesson that averts trauma yet is healing. It is important to give students the choice to use art to explore how they feel, to critique their situation, and/or to imagine a better future, but it is also equally crucial to allow students the option to use art as an escape to their trauma.

Balance

Art teachers may feel torn between choosing a critical approach to curriculum or promoting art as an escape with their curriculum. It is important for teachers to address social justice issues, but it is not helpful to get stuck in a negative framework rather than a generative one. Joy lives beside pain, “as it always has, even in the midst of the most somber and painful moments of our history” (Wong & Peña, 2017, p. 133). It is helpful to use art to escape or “extend and imagine joy for the sake of happiness,” not just as relief from struggles (Wong & Peña, 2017, p. 132).

Art curricula should explore students’ narratives, critique the society their narratives are a part of, and help students imagine change. But it is equally important to heal through escape and to have time in the curriculum for students to give to others, to doodle, and to laugh. There needs to be a balance of critique of society with art for fun, and both should emphasize hope and joy. Considering the drawing of earth in flames, I realize now that the student was just utilizing art to critique her trauma. But I should have prompted her toward a positive change, perhaps asking her “What steps can you take to make a difference in climate change? What invention could you create to change the world’s future? How do you imagine a healed world?”

Cautionary Tip for Teachers

Interacting with students with trauma everyday combined with exploring social injustice can lead to teacher compassion fatigue, which can eventually lead to teacher burnout and dropout (Reeves, 2019). My dissertation asked how empathetic art teachers cope with student trauma and how teachers develop and practice self-care to buffer compassion fatigue and continue being empathetic art teachers. Student trauma demands great energy and is a difficult burden to take home every night

and every weekend. The best thing teachers can do is give themselves a boundary, exemplified by the mantra that the teacher I worked with created: “I’ve done all I can do for today and now it’s time to go home and take care of my family and myself” (Reeves, 2019). Creating boundaries and emphasizing self-care is equally as important as centering hope and joy in the curriculum in order to buffer compassion fatigue.

Conclusion

I currently teach pre-service art teachers. During our second class, I ask my students what inspired them to become an art teacher and what impact they wish to have. I give them a list of 50 purposes of art education and tell them to choose their top five purposes (Bolin & Hoskings, 2015). I have been surprised at how many of my students share they want to teach art so students are “provided a therapeutic outlet” (Bolin & Hoskings, 2015). When discussing this choice in their top five purposes, most state the reason why they choose an art education career is because their art teacher and/or making art helped them through hard times, which I would classify as trauma. I, myself, create art for therapeutic purposes, and I see many students in my classes create art in a therapeutic way every semester. Art teachers, both K–12 and in the university, need to remember they are not art therapists, and artmaking should be centered and skill and product should be emphasized alongside process and meaning, but they can plan their art education curriculum so that therapeutic impact becomes a secondary benefit to help their students with trauma heal. By guiding students among art for self-expression, art to critique students’ circumstances, art to imagine a better future, and art as an escape, as well as by giving space for hope and joy, art can become a powerful agent of change.

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From Dancing in the Desert to *Dancing with the Stars*: Contributions of Latter-day Saint Culture to Dance in Utah

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Abstract

The following paper examines the relationship of dance in Utah with its pioneer beginnings. We first look at the role of dance in the lives of the early members of The Church of Jesus Christ of Latter-day Saints who trekked west and settled in present-day Utah. Their recreative culture and doctrinal views on the body helped foster the practice of dance in their tightly knit community. Later descendants of these original pioneers carried forward the traditions of dance, reaching new levels of professionalism and performance. Although there are many contributors to dance in Utah, this paper takes a particular look at the work of Willam Christensen and Virginia Tanner as dance educators and catalysts of the perpetuation of ballet and modern dance in the Beehive State. With the legacy of these and others, Utah continues to produce professional dancers who go on to teach and perform both locally and internationally.

Beginning with the Latter-day Saint pioneers, dance has been a common cultural activity for members of The Church of Jesus Christ of Latter-day Saints in Utah and elsewhere. From singing and dancing in Primary to youth dances and “Mormon Proms,” dance remains a unique part of their church culture. Religious practice aside, dance artists and educators in Utah are critically acclaimed and many internationally recognized celebrities continue to come out of the Utah performing community. What’s in the water? In this essay, we will examine some of the history of dance in Utah and how its ties to the restored Church of Jesus Christ have continued to foster dance excellence to the present day.¹²

Pioneer Roots

Dance has been a part of the lives and culture of members of the Church since its restoration in 1830. At the time, Protestant and many other Christian faiths viewed dance and music as taboo and even “of the devil.”¹³ The pilgrims who traveled from Europe to the New World resented the idleness and pleasures of their leisure-class oppressors from the Old World, which manifested in their attitudes towards recreation, singing, and dancing. Yet the Latter-day Saint philosophy of dance, music, and recreation was radically different. They not only allowed dance and play but were vocal advocates and sponsors of it. Reflecting on her time as a young girl traveling with other Saints from Nauvoo to Winter Quarters in the late 1830s, Rachel Simmons wrote, “The Saints are a dancing people.”¹⁴

¹ This paper does not claim a full rendering of dance history in Utah. We, the authors, have chosen to focus only on certain aspects of the state’s history to highlight various contributions of Latter-day Saint culture in the workings of dance in Utah and have chosen a mere handful of powerful contributors to the perpetuation of dance in Utah. We wish to acknowledge the many other important contributors and factors that have led to the wealth of dance and art in this state, many of which were not researched or fully developed in this paper.

² We express special thanks to the women who have assisted us in our research, namely Pam Musil, Marilyn Berrett, Shani Robison, and Angela Banchero for taking the time to interview with us individually. We are also very grateful to Linda C. Smith, artistic director of Repertory Dance Theatre, for the letter she wrote describing some of the history of RDT and Virginia Tanner’s important involvement therein. Lastly, we would like to thank our Dance History professor and faculty mentor, Marin Roper, for her extended help and advice.

³ Holbrook, Leona, “Dancing as an Aspect of Early Mormon (Church of Jesus Christ of Latter-day Saints) and Utah Culture.” 1972. Retrieved February 18, 2020, from <https://files.eric.ed.gov/fulltext/ED110412.pdf>.

⁴ Shumway, Larry V. “Dancing the Buckles off Their Shoes in Pioneer Utah.” *BYU Studies* 37, No. 3 (1997), 2.

Styles of dancing in the early days of the Church

Early Latter-day Saint dancing followed trends of American social dance in the 19th century. The dances were basically “figure or pattern dances, most commonly called cotillions or quadrilles,” but Saints also participated in rounds, squares, reels, polkas, minuets, and waltzes.⁵ These are now commonly called “folk dances,” although they were the “social dance” form of that century.⁶ Movements themselves were natural and instinctive, full of vigor, simplicity, and vitality. Their dancing allowed abandonment and freedom of expression and did not require previous formal technique or training. Such liveliness and jubilee reflected a sense of celebration, displaying feelings of joy for the privilege of possessing a body—an important element of Latter-day Saint doctrine.⁷

Ties with doctrine

Members of the Church believe that, “...the spirit *and* the body are the soul of man” (*italics added*).⁸ They believe in caring for and respecting the physical body, which is reflected in how they eat and drink.⁹ They also believe that after death, the body will reunite with its spirit, because of the resurrection of Jesus Christ.^{10,11} Unique to their time, the early Latter-day Saints believed that having a body was necessary to experience joy fully in this life and exaltation in the life to follow, and their dancing reflected these beliefs.¹²

Early Church president Brigham Young encouraged members to exercise their bodies in dancing and other activities saying, “Fiddling and dancing give me a privilege to throw everything off and shake myself, that my body may exercise and my mind rest what for to get strength and be renewed and quickened and enlivened and animated.”¹³

⁵ Shumway, Larry V.

⁶ Holbrook, Leona

⁷ Cieslewicz, Lindsay Stewart, 2000. “Dance and Doctrine: Shaker and Mormon Dancing as a Manifestation of Doctrinal Views of the Physical Body” Masters thesis. <https://scholar.archive.byu.edu/cgi/viewcontent.cgi?article=5600&context=etd>.

⁸ *The Doctrine and Covenants of The Church of Jesus Christ of Latter-day Saints*. Salt Lake City, UT: The Church of Jesus Christ of Latter-day Saints, 1981. Section 88, verse 15.

⁹ *The Doctrine and Covenants of The Church of Jesus Christ of Latter-day Saints*. Section 89.

¹⁰ *The Book of Mormon*. Trans. Joseph Smith, Jr. Salt Lake City, UT: The Church of Jesus Christ of Latter-day Saints, 1981, Mosiah 15:19-20.

¹¹ *The Book of Mormon*. Alma 40:23.

¹² For more analysis on Latter-day Saint doctrines of the physical body, see Cieslewicz, Lindsay Stewart, 30-39.

¹³ Cieslewicz, Lindsay Stewart, 2000.

Church leaders supported dancing that was “virtuous, lovely, or of good report or praiseworthy.”¹⁴ Appropriateness of dancing revolved around the context, time, place, and environment in which it was performed. Brigham Young concluded that in appropriate circumstances and atmospheres, dancing had a strong potential to uplift the people, but if it were ever used in a spirit of vulgarity or profanity, it was forbidden. Saints were encouraged to conduct and attend their own dances to ensure the context was suitable.¹⁵

Role of dance for Latter-day Saints

Dance served many purposes for Latter-day Saints. Notably, it served as relief and relaxation, to build community, and occasionally even as a form of worship. Perhaps the moments it became most important for Saints were in times of persecution and struggle. Dance served as a diversion from the many toils and hardships they endured throughout their early history, beginning with bitter persecution in the eastern United States, and continuing with their arduous journeyings West.¹⁶ As they trekked across the plains, they often would clear the brush, pull out their fiddles, and dance on the barren ground. Music and dance acted as the grease that helped the rough wheels of pioneer life turn more smoothly. An anonymous author wrote, “No matter how difficult the journey had been during the day, when dusk came and the camp had been pitched, the evening meal eaten[,] the weariness of the day was forgotten in a dance.”¹⁷

As Saints endured frigid temperatures, with lack of food, shelter, and hope while waiting to travel West at Winter Quarters, Brigham Young felt inspired to bolster the people’s spirits. On January 14, 1847, he is credited with having had a revelation, which reads in part: “If thou art merry, praise the Lord with singing, with music, with dancing, and with a prayer of praise and thanksgiving”.¹⁸ Following this revelation, the Saints heeded their prophet’s directive and danced, which sustained them as they trekked into an uncertain and treacherous future. Dancing kept the emigrants in hopeful accord and spirits, bringing joy and survival in their difficult journey to Utah.

¹⁴ Joseph Smith, “Article of Faith 13,” in *The Pearl of Great Price*, 1842.

¹⁵ Shumway, Larry V. 1997

¹⁶ Cieslewicz, Lindsay Stewart, 2000.

¹⁷ Shumway, Larry V. 1997

¹⁸ Holbrook, Leona

Settling in the Salt Lake valley

When they arrived at “the right place” in July 1847, the dancing did not stop! The Saints continued dancing during those first years of settlement on dirt floors and in log cabins. These dances “were a regular and important part of their lives.”¹⁹ As the Salt Lake Valley developed, so did the dancing venues. The earliest settlers built two large boweries, temporary arbor-like structures used for public functions and dancing. Dancing also took place in private homes, many of which were fashioned with a large room to accommodate more bodies.²⁰ Additionally, Saints danced in public spaces like churches and school houses and eventually dance halls and even schools. The most famous recreational facility of the early pioneers was the social hall located on State Street in the center of Salt Lake City between South Temple and First South. It was formally opened and dedicated on New Year’s Day, 1853, by Heber C. Kimball, one of the leaders of the Church, who called the meeting to order.²¹

Latter-day Saints danced successively as their circumstances allowed, first on barren ground, then on rough floorings, and finally in amusement halls.²² Pretty soon, the Saints’ mountain home would become a stronghold for dance schools and performance halls, producing pioneers of another kind: that of high-class art and entertainment that would shine as a spectacle for all the world to see.

Ballet in the West: Willam Christensen’s Legacy

Willam Christensen was one of these major contributors and “pioneers” of dance in the newly developing Utah. His story is an example of how the early social dancing of the time has since expanded to other genres. Willam’s great uncle Lars Christensen immigrated to America from Denmark in 1854 with other Latter-day Saint Pioneers, settling in Brigham City, Utah. There he taught Danish folk and social dances to the young people, including to his large family of 23 children. Two of Lars’s sons, Peter and Christian, took a particular interest in the arts and eventually opened a New Academy of Music and Dancing. Willam and his brothers Lew and Harold studied there under their uncles. Later, as Christensen’s talent grew and was realized, he studied under many renowned teachers in New York such as Michel Fokine and Stefano Mascagno. Following their training, Willam and his brothers

¹⁹ Holbrook, Leona

²⁰ Holbrook, Leona

²¹ Shumway, Larry V. 1997

²² Holbrook, Leona

performed in many vaudeville shows across the country. Returning home with exceptional training, experiences, and a love of dance, they were able to make a lasting impact on Utah.²³

In 1947, the State of Utah and the Church of Jesus Christ sponsored a musical entitled *Promised Valley*, a musical rendition of the pioneer trek from Missouri to the Salt Lake Valley. It was choreographed originally by Helen Tamiris, a well-known modern dancer, but was re-staged in 1950 with choreography by Willam Christensen. These shows sparked Utahans' interest in dance, spurring the production of more musicals and operas by local groups. "Audiences totaling 50,000 a season looked forward to seeing those productions. Clever, witty, and wonderful dances sparked every show. Grand and silly singing and the sound of a good orchestra playing good music floated in the open air on beautiful summer nights."²⁴

In 1951, Willam Christensen became a part of the University of Utah faculty as Director of Ballet under the theater department head, Dr. C. Lowell Lees. This established the first ballet major in the United States. Soon, the school began to receive exceptional training from a teaching staff consisting of Barbara Barrie from the Royal Ballet, Gordon Paxman, Bene Arnold, and Conrad Ludlow, all master teachers and solo performers from the San Francisco Ballet (which was cofounded by Willam and his brother Lew). The University was a base for young dancers who later became educators to foster ballet education throughout other areas of Utah. One of those students, Sandra Birch, later established and codirected the dance program at Brigham Young University (BYU) in Provo, Utah.²⁵

Willam Christensen worked to improve educating not only ballet dancers, but also audiences. "Dance festivals had always been a part of the ["Mormon"] tradition and in the 1950's large-scale dance productions, with every young person in the valley participating in costume, were supported and sanctioned by [the Church]. Selling the community on dance was not the issue. Selling classical ballet to the community was the challenge."²⁶ Before performances, Christensen would give a short lecture demonstration, including a portable barre to show traditional, technical exercises required to train classical ballet dancers. Dancers would perform a pre-set, abridged combination of

²³ Deseret News. 2020. Brigham City's Christensen Family Created A Top U.S. Dance Dynasty. [online] Retrieved April 13, 2020, from <https://www.deseret.com/2004/6/18/19835260/brigham-city-s-christensen-family-created-a-top-u-s-dance-dynasty>.

²⁴ Walkington, S. and Welsh, J., 1999. *Memories Of 50 Years Of Ballet In Utah*. [Place of publication not identified]: [publisher not identified], 9.

²⁵ Walkington and Welsh, 1999, 10.

²⁶ Walkington and Welsh, 1999, 15.

ballet barre while Willam extemporaneously explained how each exercise contributed to the dancer's facility and strength. Afterwards, the recital would proceed with one or more choreographed, costumed pieces. Christensen used this approach early, stating, "You had to, nobody knew what dance was."²⁷ Christensen's dancers performed for a variety of audiences, wherever those audiences were. At least once, the Utah dancers performed on a tennis court, tattered pointe shoes and all. Christensen staged these performances everywhere and anywhere, attracting, educating, and preparing patrons and audiences for ballet in Utah.²⁸

Ballet continued to grow; in 1963, Willam Christensen established the Utah Civic Ballet with the help of the Ford Foundation grant. In 1968, The Federation of Rocky Mountain States (Utah, Idaho, Montana, Wyoming, Colorado, New Mexico, and Arizona) declared the troupe the official ballet company for the region, and the name was changed to what we know today: Ballet West.²⁹

Christensen's company, Ballet West, continues to flourish, offering its 35 dancers the rare advantage of 52-week contracts. (The New York City Ballet only guarantees its dancers an average of about 40 weeks of work each year.) This makes Utah one of the best and most secure places to work as a professional ballet dancer. Christensen's contributions also make it one of the best places in the country to train as a ballet dancer. The University of Utah, BYU, Utah Valley University (UVU), Ballet West Ballet School, and Jacqueline School of Ballet are just a few of the highly ranked dance schools in Utah. Robert Fairchild, former principal dancer of New York City Ballet and recent star in the film *Cats* (2019), is just one example of the many professional dancers that have come out of Utah.³⁰

"Willam Christensen had a real gift to give. He really believed in dance and the arts," said Shani Robison, a professor in dance history and ballet at BYU. Although we know Willam Christensen was not an incredibly religious man, he grew up in Brigham City, as a member of The Church of Jesus Christ of Latter-day Saints. Professor Robison suggests that the core beliefs he learned as a child—i.e., to value the body and mind, to work on self-improvement and service—influenced his approach to art making and educating.³¹ Christensen's pioneer ancestors

²⁷ Walkington and Welsh, 1999, 18.

²⁸ Walkington and Welsh, 1999, 18.

²⁹ Adams, Kathy. "WHat's UP WiTH Utah." *Dance Spirit*, 10, 2010, 78-80, 82.

³⁰ Adams, 2010

³¹ Robison, S., 2020. How Has The Culture In Utah Shaped By The Church Of Jesus Christ Of Latter-day Saints Cultivated Dance There? Masters thesis, Brigham Young University, Provo, UT.

were important in his dance training and prepared him to become an influential dancer, artist, and artistic director. This background and cultural upbringing also prepared him to connect to Utah audiences who were predominantly Latter-day Saints.

Modern Dance in Utah: Virginia Tanner's Legacy

In 1915, another Utah dance pioneer was born; Virginia Tanner, would become a driving force for the development of modern/contemporary dance in Utah. Born in Salt Lake City, from "pioneer stock," her family supported her love of dancing. Her dance experience began with ballet, but she felt inhibited by its formality and structure.³² As she turned to dancing on her own, she eventually found her way to Washington, D.C., where she studied modern dance and pedagogy with Evelyn Davis. From there, she began performing with Doris Humphrey and Charles Weidman and taught at the Humphrey-Weidman School of Dance in New York. She was described as "a nice Mormon girl" whose dance was "...fueled with a tremendous passion and with the knowledge that dancing can both be its own religion and operate affirmingly within a religious community."³³

Eventually, Virginia's desire to inspire young people brought her back home to Utah, where she attended the University of Utah, and directed the dance department of the McCune School of Music and Art in SLC in the 1940s. In 1949, she organized the Children's Dance Theatre (also known as Tanner Dance), which formed a permanent partnership with the University of Utah.

Quite immediately, the Tanner dancers gained critical acclaim and recognition. Doris Humphrey was in attendance of their first formal concert at Kingsbury Hall, remarking afterwards: "Your children have left an indelible impression with me of true creative dance... [They] offer a wonderful proof of the power of the young artist, guided wisely, untarnished by dogma or routine, unstereotyped, and lovely..."³⁴ Humphrey went back to the East Coast and began arrangements for the Tanner dancers to perform there.³⁵

³² "Virginia Tanner." History to Go. Utah Division of State History, March 31, 1965. Retrieved March 19, 2020, from <https://historytogo.utah.gov/tanner-virginia/>.

³³ Dils, Ann, and Rosalind Pierson. "'Dance with Us': Virginia Tanner, Mormonism, and Humphrey's Utah Legacy." *Dance Research Journal* 32, no. 2 (2000): 10. <https://doi.org/10.2307/1477978>.

³⁴ "About Tanner Dance." Tanner Dance. Retrieved April 13, 2020 from <https://tanner-dance.utah.edu/about/>.

³⁵ "Virginia Tanner." History to Go.

After being invited by Ted Shawn to perform at the Jacob's Pillow Festival in 1953, dance critic Walter Terry said the following:

...none, I think, have conveyed so perfectly [as these children] the bright (not pallid) purity of child-dance. It is difficult to describe even the most potent intangibles and the best I can do is to say that the children danced as if they had faith in themselves, had love for those of us who were seeing them, actively believed in their God and rejoiced in all of these.³⁶

Another glowing review of the talent and spirit of Children's Dance Theatre's dancers and director was given in 1978, by José Limón:

Salt Lake City is the most blessed city in the world to have the world's master children's dance teacher. There isn't any place, and I include New York, London, Paris, Moscow, that has anyone who can touch her genius for teaching children the exciting purity of the dancing arts.³⁷

Children's Dance Theatre/Tanner Dance continues to thrive today, performing original works annually at the Capitol Theatre for the Salt Lake public. They are founded on the philosophy of Virginia to "not only [develop] excellent dancers, but more importantly, [develop] young people who are useful, imaginative, worthwhile human beings."³⁸

With international recognition, Virginia Tanner was invited to meet with the Rockefeller Foundation in 1959. Upon meeting, she was told, "Anything you want in Salt Lake City, dream away." From there unfolded the creation of another dance company in Salt Lake, this time with the focus on "the performance, creation and preservation of American modern dance" repertoire—the first of its kind in the nation. With the help of generous grants from the Rockefeller Foundation over the course of several years, Repertory Dance Theater was founded in 1966.³⁹

One of Tanner's students, Linda C. Smith, who had gone on to dance in the Limón Company, was recommended to help start this professional dance company. In a letter to the authors recounting RDT's beginnings, Linda describes several defining traits of this pioneering company. First was its mission to create a repository of American

³⁶ Dils & Pierson, 7

³⁷ "About Tanner Dance." Tanner Dance.

³⁸ "About Tanner Dance." Tanner Dance.

³⁹ Linda C. Smith (Salt Lake City, Utah, 2020).

modern dance works—something common for the ballet world but that had not been tried to that point in modern dance history. Second, the company began as a partnership with the University of Utah, a collaborative endeavor for education and professional dance. Third, and perhaps most risky, the company began with a purely democratic structure. Linda cites Virginia Tanner's words describing this as such: "...a democracy of artists, in keeping with the traditions of the west and the Mormon community, the company would work together and be guided by their joint vision, rather than by the vision of an artistic director." Linda describes this as "a bold attempt at artistic democracy which gradually evolved as the company selected artistic leadership within its own ranks." She and Kay Clark were selected in 1976 to be the company's codirectors. In 1983, Linda was appointed as the sole artistic director, a station in which she continues in today, carrying forward the original vision and goals of Virginia Tanner.

Why did the Rockefeller Foundation choose to support a professional modern dance company at this time in Utah rather than, say, New York City? Angela Banchemo, UVU professor and long-time member of RDT, describes the story as such:

[The Rockefeller Foundation...wanted to] start a company in the country, not on the coast. ...[But, you can't just] fold it in half and say, "Kansas City, okay, that's the middle of the country!" You have to put a company in fertile ground. ...So, they looked around and said, "Where is a place where there is an art-going audience?" ...That place was Salt Lake City. We had Ballet West, ...we had the symphony, we had a dance program at the U, we had Children's Dance Theatre. ...The [Foundation] realized ...this is a cultured people. They are used to seeing the arts, they're used to supporting the arts, they have arts in the schools...they're building [both] future artists [and] ... an audience. So, [they decided that] Salt Lake would be a good place to put a company—and that's how RDT got here.⁴⁰

Because of the already-thriving arts appreciation and education of Utah, set in place by people such as Christensen, Tanner, and others, companies such as RDT and Ririe-Woodbury were able to come into

⁴⁰In the original interview, Angie had referenced the NEA as the grant provider for RDT. However, through further correspondence between her and Linda, we have corrected the quote to reflect the actual grant provider: the Rockefeller Foundation.

being. The arts-appreciating culture initiated by predominantly LDS audiences gave a place for these companies to grow roots and to thrive.⁴¹

A Sensation of an Education

Private dance studios

Another area of dance that thrives in Utah is within the studio scene. Students coming from Utah dance studios have gone far as professional dancers in companies, on Broadway, and on national/international television series. In the recent years of TV dance competitions such as *So You Think You Can Dance?*, *Dancing with the Stars*, and *World of Dance*, dozens of Utah-born dancers have competed and excelled, including Derek Hough (two-time champion of *Dancing with the Stars* and judge on *World of Dance*),⁴² Chelsie Hightower (SYTYCD), Sabra Johnson (SYTYCD winner), and more.⁴³ The numbers of stars that come out of Utah are surprising, considering its relatively low population. One article suggests, "...the recipe for success seems to be a combination of dedication to community, strong work ethic, and exceptional training."⁴⁴

Dance in public schools

But studio prominence is not the end of Utah's dance magic. Marilyn Berrett and Pam Musil, former and current faculty members at BYU, agreed that Utah's dance representation in public schools sets it apart from the rest of the United States and the world. Strong dance programs are found not only at the university level, but also in elementary, junior high, and high school levels.⁴⁵ This can be thanked, in part, to the Beverley Taylor Sorenson Foundation, which has been

⁴¹ Banchemo, Angela. "Angie Banchemo Interview." Diana Brewster. In-person. Utah Valley University, March 5, 2020.

⁴² Welch, Derek. "Did You Know Mormons Dominate Competitive Dancing?" World Religion News. World Religion News, October 9, 2017. Retrieved March 28, 2020 from <https://www.worldreligionnews.com/religion-news/did-you-know-mormons-dominate-competitive-dancing>.

⁴³ Wagner, Danielle B. "How Latter-day Saints Are Absolutely Dominating the Dance World." LDS Living, September 27, 2018. Retrieved January 30, 2020, from <https://www.ldsliving.com/How-Latter-day-Saints-Are-Dominating-the-Dance-World/s/89264>.

⁴⁴ Adams, Kathy. *Dance Spirit*.

⁴⁵ Berrett, Marilyn, and Pam Musil. "Interview with Pam and Marilyn." Diana Brewster & McCall McClellan. In-person. Brigham Young University, February 21, 2020.

dedicated to putting art in Utah schools since 1995.⁴⁶ As Banchero said, this educational foundation has cultivated students who are both art-makers and art-appreciators—creating future dancers, dance audiences, and dance educators who keep the cycle going. “Utah produces remarkable dance educators,” says Banchero. “There’s nothing like it.”⁴⁷

Worldwide recognition of Utah dance and performing artists

BYU has a particularly diverse set of opportunities and course offerings for its dance program participants, claiming the largest Cultural Dance program of its kind in the nation.⁴⁸ Out of this comes the International Folk Dance Ensemble and Living Legends, which tour statewide, nationwide, and worldwide on a regular basis. BYU is also home to the performing/touring groups of Theatre Ballet, Contemporary Dance Theatre, Cougarettes, the Young Ambassadors, and the BYU Ballroom Dance Company, who consistently receive national and global recognition and awards.⁴⁹

One example of BYU’s unique dance department can be seen through their decades-long relationship with China. Since an unlikely tour by the BYU Young Ambassadors in 1979 (the very year the United States and China regained diplomatic relations), 30 other performing tours have followed. Performances have been recorded, televised, and viewed by millions of Chinese citizens throughout the years, making the university’s name recognizable in many Chinese households. Last year, eight BYU groups joined together to perform in Beijing, Xi’an, and Shanghai in celebration of the 40 years of friendship between the country and BYU. The following reads the response of one audience member:

Among the audience at BYU’s first 2019 performance in Beijing was a college dean at the prestigious Peking University, carefully holding her ticket. Following the performance, she told her BYU friends that she intended to keep the memento with another treasured keepsake—the ticket stub she had saved

⁴⁶ “About Beverley.” Beverley Taylor Sorenson Arts Learning Program, July 21, 2015. <http://btsalp.com/about/about-beverley/>.

⁴⁷ Banchero, March 5, 2020.

⁴⁸ Admin. “World Dance.” BYU Department of Dance. BYU Department of Dance, November 22, 2019. Retrieved April 8, 2020, from <https://dance.byu.edu/world-dance/>.

⁴⁹ Wagner, LDS Living.

from decades before, when she saw another performance by students from BYU, the famous American university.⁵⁰

Conclusion

Although this essay is but a small documentation of the information and influence of Utah dance “pioneers,” we conclude that dance in Utah can be traced to the first pioneer Saints who brought their dancing spirits with them across the plains, cultivating excellence in this and other arts since the 1830s. Dance has continued to grow and blossom in this mountain home with influential artists, dancers, and educators—some professing the same faith as these early members of the Church, and others not—but all benefiting from the roots established by them. The focus placed on the divine role of the body, self-improvement, and community are all apparent in the teaching and propagation of dance here, ultimately producing the hive of strong dancers and dance-appreciators Utah upholds today.

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⁵⁰ Gardner, Peter B. (Fall 2019) “A Bridge to China.” *BYU Magazine*. Retrieved April 8, 2020, from <https://magazine.byu.edu/article/bridge-to-china/>.

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Pleasure and Meaning in Islamic Art: Toward a Naturalist Framework

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Abstract

A recent exchange of criticisms over a display of Islamic art illustrates the division of Islamic art history into two main schools. The disagreement was occasioned by the 2006 exhibition entitled Cosmophilia: Islamic Art from the David Collection, Copenhagen. The exhibition explicitly placed emphasis on the objects' visual form and the pleasure it gives, and the objects were arranged according to a traditional division of Islamic ornament into four themes. This occasioned a reaction from a prominent representative of the dominant trend in the academic study of Islamic art, who took the organizers of Cosmophilia to task for promoting a view that strips the artworks of their meaning. In this essay, I consider each of these viewpoints critically, point out a premise they share, and propose a fresh perspective under which to study works of Islamic art, one that takes into account the meaning of pleasure as a natural phenomenon.

Introduction

Islamic art is a vast and challenging field of study. The field comprises objects from the 7th century to the modern era and a geographic range from Morocco to Malaysia. Moreover, unlike other broadly construed traditions of art, such as medieval European art or Chinese art, Islamic art consists in the main not of painting and sculpture, but of ornamented utilitarian wares, which are not overtly meaning-laden and are thus more difficult to interpret in the usual ways—e.g., as an expression of religious concepts. A statue or painting of Christ or the Buddha can be interpreted (at least in part) by reference to an explicit conceptual framework, the belief system of its culture of origin; the case is not so straightforward with a dish with flowers on it, say, or a window screen carved in a geometric pattern. Much of the methodological difficulty in studying Islamic art thus centers on the question of meaning. What does exquisite decoration mean, if anything, and how might we tease it out? Or should we even be looking for meaning in the objects? Is Islamic art best explained as an appeal to the sense of beauty and nothing more?

Answers to such questions have long been divided into two main schools of thought, which I shall refer to here as formalism and contextualism. The former guided the formation of the field and was the dominant approach for much of the 20th century. The latter came into prominence only a few decades ago, but it now the prevailing viewpoint in academic Islamic art history. In this essay, I will examine these two schools and their competing views of the nature and value of Islamic art. In particular, I will look at one prominent scholar's criticism of a 2006 museum exhibition and the organizers' rebuttal, an exchange that brings the tension between these two approaches into unusually clear focus. It turns out, in fact, that both formalism and contextualism share a crucial premise regarding the nature of aesthetic pleasure, and that by digging deeper into this concept, we arrive at a new and, hopefully, fertile way of looking at Islamic art.

Formalism and Contextualism

Islamic art history as a discipline came of age during a period when formalism reigned supreme. As a term and as an approach to art, formalism dates back over a century, to the works of critics like Clive Bell and Roger Fry. In the sense I am using it, it refers to an art-historical method requiring the scholar to consider first and foremost the visual qualities of the objects under study: their shapes, patterns, formal commonalities with similar objects or designs, and so on. This, for formalists, is sufficient for a complete understanding of the artworks.

Some of the early adherents of this approach, such as Arthur Upham Pope, waxed lyrical about the profound metaphysical implications of form (Wood 2000), and there is still a vocal community that claims Islamic art is suffused with spiritual significance (Ardalan and Bakhtiar 1973; Nasr 1987; Critchlow 2013). For the most part, though, the value that formalists find in the artworks is quite secular, namely the sensory or aesthetic pleasure they bring the viewer. Some 20th-century scholars of Persian miniature painting, in fact, explicitly advised their readers to ignore speculation about the images' deeper meaning and instead relish the "intoxicating potency" of Persian color and the "physical thrill of pleasure" afforded by a good Persian line (Wood 2000: 125–26).

The aim of formalist art history follows from this view of the nature of art. Formalists generally eschew attempts to dig out the hidden meaning of the objects, preferring instead to rely on expert analysis of form to sort them into the correct chronological and taxonomical categories. In Islamic art history, scholars long ago determined that the whole panorama of art of the Muslim world, from the 7th century to the present and from Morocco to Malaysia, can be organized into four basic "themes." In no particular order, these are vegetal, geometric, calligraphic, and figural decoration.

Vegetal decoration characterizes much Islamic art; it includes the famous coiling vine motif known as the arabesque, but is more broadly understood to encompass any ornament based on floral or vegetal models, such as the Ottoman-era plate from the Turkish city of Iznik shown in Figure 1.



Figure 1: Ceramic dish with a floral design, Iznik (Turkey), ca. 1545–60. Metropolitan Museum of Art, acc. no. 56.185.2. Public domain. <https://www.metmuseum.org/art/collection/search/453599>.

A second main theme of Islamic art is geometric decoration. Geometry was widely used by craftsmen as an aid in the layout of various design types, but it also became a decorative principle in itself, as seen in this window screen from Mughal India (Figure 2).

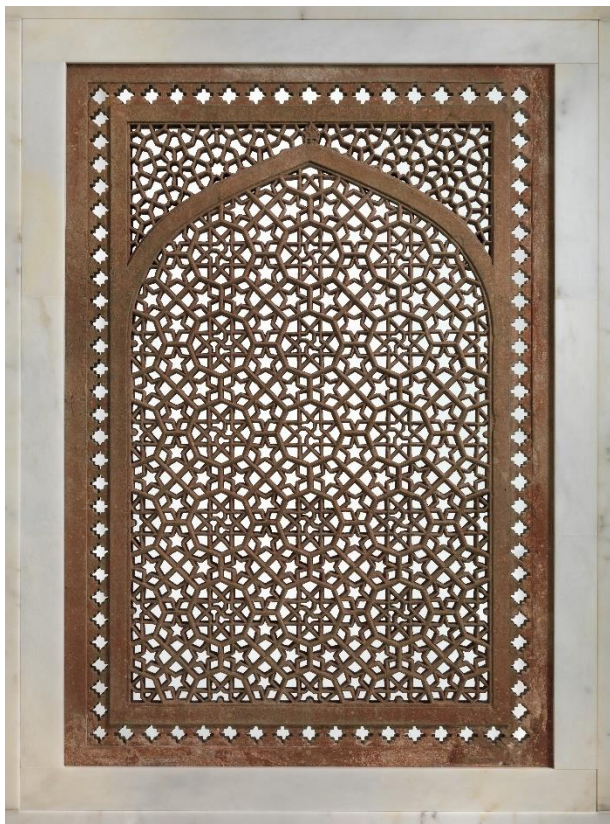


Figure 2: Jali (pierced window screen), India, second half 16th century. Metropolitan Museum of Art, acc. no. 1993.67.2. Public domain. <https://www.metmuseum.org/art/collection/search/453344>.

Calligraphy is recognized to be the most prestigious form of art in the Islamic world, because it can carry the word of God. Islamic artists over the centuries developed a variety of styles of the Arabic script, with some intended to be easily legible and others intended to be visually striking. Calligraphy can form the main decoration on some Islamic objects, such as this glass lamp that once illuminated a mosque interior (Figure 3).



Figure 3: Mosque lamp, Egypt or Syria, 14th century. Metropolitan Museum of Art, acc. no. 91.1.1539. Public domain. <https://www.metmuseum.org/art/collection/search/444718>.

Finally, figural decoration is an important theme in Islamic art, despite the conventional wisdom that the Qur'an forbids the depiction of living beings. Artists have included birds, beasts, and people in the ornamentation of Islamic objects from the earliest years of that civilization. In the example shown in Figure 4, a 16th-century Iranian designer has filled this carpet with animals, many of which are hunting others.

It should be pointed out, too, that Islamic artworks do not limit themselves to one of these themes, but freely mix them. This can be seen in a silk from Islamic Spain (Figure 5), which combines geometric decoration with highly stylized calligraphic inscriptions in horizontal bands. The words "eternal glory" and "happiness" repeat in letters with knotted-together verticals.

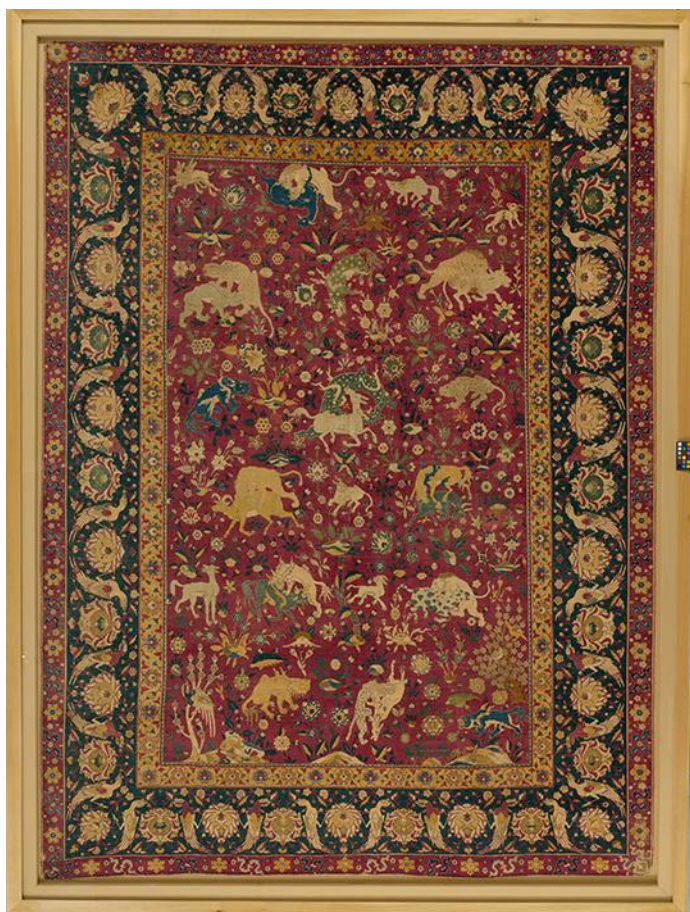


Figure 4: Silk carpet with animal motifs, probably Kashan (Iran), second half 16th century. Metropolitan Museum of Art, acc. no. 14.40.721. Public domain. <https://www.metmuseum.org/art/collection/search/446642>.

The preceding discussion gives some idea of the range of Islamic art and of the categories into which formalist art historians divide it. The work of categorization, and of art-historical research generally, is, for formalists, really just a way of creating highly informed art appreciation, of providing background information for the enjoyment of exquisite objects. A formalist would, for example, point out that the bowl in Figure 1 represents an important moment in the development of Iznik ceramics, when the characteristic “look” of the style was beginning to flower (as



Figure 5: Textile fragment, Spain or North Africa, 14th–15th century. Metropolitan Museum of Art, acc. no. 46.156.16. Public domain. <https://www.metmuseum.org/art/collection/search/450734>.

it were). He or she might explain that the geometric window screen in Figure 2 is a local (Indian) adaptation of a well-established mode of ornament transplanted from Iran, that the lamp in Figure 3 shows the Mamluk mastery of ornamental *thuluth* script in enamel, that Figure 4 is the pinnacle of Safavid carpet design, and that Figure 5 is one of a number of similar pieces showing the popularity in the Islamic West of eight-pointed stars and highly stylized inscriptions, reminiscent of local architectural decoration. All of this information, though, is to be understood as offering an intellectual backdrop to what is essentially an aesthetic encounter with superb works of art.

Late in the 20th century, formalism in art history began to be supplanted by a new approach, that of contextualism. Contextualists take issue with formalism at its root. They argue that the salient feature of art, Islamic or otherwise, is *not* primarily a matter of the creation of eye-pleasing form, but of the construction of meaning in various contexts—social, political, intellectual, and so on. In other words, the objects were

made not merely to appeal to the sense of sight, but to signify things to people. It follows that contextualists are not content to stop with the mere categorization of artworks according to formal characteristics. Their agenda is much more oriented toward semiotic concerns. An object such as the Iznik dish in Figure 1, for example, would be of interest not for its place in the chronological development of Ottoman ceramics, but for the potential symbolism or semantic content it carried to contemporary users—for example, as a cultural identity marker used by the Ottoman ruling class. The animal carpet in Figure 4, too, might be examined in light of potential poetic references, or the broader symbolism of animal combat, or (more prosaically) the quest for a new market for luxury carpets. Form, for contextualists, is a secondary consideration; for them, the artworks were not made to be ends in themselves, but rather to point *past* themselves toward some other, usually more abstract or conceptual content. One recent book title sums this view up nicely by dubbing medieval Islamic objects *Arts of Allusion* (Graves 2018).

It should be noted that these two approaches to Islamic art are tendencies, not rigid dogmas, and there is overlap in practice. Some formalists are interested in the cultural context of the artworks, and some contextualists do take notice of formal qualities. In terms of their essential premises, though, formalism and contextualism are at loggerheads. One emphasizes perceptual qualities over meaning; the other, meaning over perceptual qualities. The tension between the two was made clearly apparent in a clash of criticisms over an exhibition of Islamic art mounted in 2006 in Boston and Chicago.

Cosmophilia

This was an exhibition of objects from the David Collection in Copenhagen, a world-class private collection that was, at the time, closed for renovations. Two Boston-based scholars of Islamic art took the opportunity to request a loan of over a hundred objects, which they mounted in an exhibition they titled *Cosmophilia: Islamic Art from the David Collection, Copenhagen* (Blair and Bloom 2006). “Cosmophilia,” the authors explained in the catalog, was a neologism intended to mean “love of ornament,” because that was the organizing principle of the exhibition. The artworks were divided into the four themes of Islamic art described above, with a fifth section devoted to “hybrids,” or works that combine one or more themes. As a result, the exhibition displayed a vast variety of works from completely different times and places side by side. To pick a random sequence, catalogue no. 69 is a metal jug from Afghanistan made in 1512, catalogue no. 70 is a wooden pen-case from India made in the early 1600s, and catalogue no. 71 is a cut-glass bowl

made in Iran or Iraq in the 800s or 900s (Blair and Bloom 2006: 144–46). The point, then, was not to explain the objects' historical contexts or tell the story of various developments, but simply to display the panoply of design ingenuity exhibited over the centuries by Islamic craftsmen. This was helpfully illuminated by the inclusion of a list of 10 unifying principles of Islamic art, such as color, repetition of motifs, symmetry, and juxtaposition. The catalogue also included a brief section commenting on the question of meaning, which Blair and Bloom put with admirable candor: "Does all this visual delight have some deeper significance or is it all just superficial candy for the eye?" They proceed to point out that various attempts to find in Islamic art the equivalent of Christian or Buddhist religious symbolism have foundered on the sheer lack of confirmatory evidence, and conclude that "[i]n our quest to find subtle and learned meanings for these extraordinary works of art, we may have overlooked their primary meaning as invitations to stop what we are doing for a moment and contemplate, think, and let our minds explore the beauties before our eyes" (Blair and Bloom 2006: 25ff.).

Cosmophilia was a success. One reviewer praised the spectacle of "brilliant color, extraordinary detail, mathematical patterning, and ingenious technique," which she said "dazzles, mystifies, and comforts"; although she did note that the organizers had "throw[n] historical context and geography to the winds" and that "the lack of context frustrates," she ultimately concluded that the deliberate "focus on beauty, rather than time and place, reflects the power of ornament throughout Muslim cultures" (McQuaid 2006). The explicitly formalist approach of *Cosmophilia* did not, however, win over everyone. It positively scandalized the contextualist community, one of whose most illustrious representatives, Gülru Necipoğlu, took the exhibition organizers to task in a catalog essay of her own (Necipoğlu 2007).

Cosmophilia, Necipoğlu writes, is a prime example of the formalist fallacy of ignoring meaning entirely in favor of eye candy, thereby passing over the "semiotic density" of the objects. These works, she goes on, were not made simply to look nice to people, and exhibiting them as if this were their unifying characteristic has the effect of making all Islamic art look the same, of categorizing it as "pure decoration" that may look good, but ultimately means nothing. The "purely visual, decontextualized approach" taken in *Cosmophilia*, she wrote later, feeds into the popular stereotype that Islamic art is "predominantly decorative and hence devoid of meaning or contextual specificity" (Necipoğlu 2012: 7–8). Instead of singling out visual appearance, Necipoğlu calls for delving into the objects' "semantic horizons," carefully mining historical documents for clues as to the various abstract meanings the artworks must have had for the people who made and used them.

Necipoğlu has contributed some of the most sophisticated and respected contextualist art history of her generation. She has analyzed medieval Islamic geometric decoration, for example, not for its particular patterns, but for its purported link to contemporary Neoplatonic cosmological theory and the influence such thinking would have had on philosophically literate craftsmen, who are seen as having sought to concretize metaphysical teachings in the form of elaborate patterns on buildings and objects (Necipoğlu 1995). More recently, Necipoğlu has characterized the development of art in 16th-century Turkey as “a deliberate project of early modern place-making and culture-making” (Necipoğlu 2016). According to this interpretation, the well-known Ottoman aesthetic of quasi-realistic floral motifs, an early example of which is seen in Figure 1, arose as the craftsmen of the imperial court workshops generated a distinctively Ottoman “regime of visibility,” a clearly visible style of decoration that both defined the borders of the empire and “cement[ed] the hegemonic collective identity and esprit de corps of the multiethnic Ottoman ruling elite” (Necipoğlu 2016: 154). This, she says, was done in part as a conscious reaction to the much more conspicuously figural visual language developing in neighboring Iran (Figure 4), which was at once a political and religious rival to the Ottomans. Interpretation like this is informed by extensive archival research as well as by a rich awareness of contemporary academic art theory; this level of sophistication is what Necipoğlu and other contextualists found missing from the *Cosmophilia* exhibition, and the reason they criticized it as shallow and retardataire.

The debate over *Cosmophilia* did not stop there. The exhibition’s organizers rebutted Necipoğlu’s criticisms in an essay entitled “Cosmophilia and Its Critics: An Overview of Islamic Ornament” (Blair and Bloom 2012). In effect, they doubled down on their formalism, pointing out that displaying the objects according to their formal categories was the most accessible way to introduce the museum-going public to the variety and beauty of Islamic art. Moreover, they insist that the fundamental characteristic of Islamic art is, in point of fact, its decorative quality. In support, they invoke one of the objects themselves, a silk textile made in Islamic Spain (catalogue no. 109; very similar to Figure 5) that features a repeating inscription of Arabic verse reading, “I exist for pleasure, welcome, for pleasure am I; he who beholds me sees joy and well-being.” This is all there is or needs to be, Blair and Bloom hold. Although the objects undoubtedly had some meaning to someone, they write, the quest for deeper abstract significance is fraught with peril—and here they reiterate some of the most damning criticisms of Necipoğlu’s own contextualism, including her overreliance on documents and her assumption, rather than demonstration, of a

connection between philosophical theory and practical craftsmanship (Blair & Bloom 2012; see also Allen 2004 and Allen 2016). Better to stick with what we know, conclude Blair and Bloom, namely that the only message the ornament carries is a “positivist” one, namely the bringing of pleasure to the eye (2012: 47).

The *Cosmophilia* controversy, as we may call it, is a neat illustration of the conflict between competing visions of Islamic art and how we should understand it. As suggested above, it seems that the two schools are arguing across an unbridgeable gulf, with one side insisting on the primacy of visual appearance and the other on the primacy of semantic content. Upon closer inspection, however, it becomes apparent that formalism and contextualism share a vital premise. It is this premise that I will endeavor to unpack here.

Simple Pleasure

The premise on which both Blair and Bloom and Necipoğlu are in unspoken agreement is the nature of aesthetic enjoyment. For all of the criticisms they launch at each other, they implicitly agree on one thing: Aesthetic pleasure, the enjoyment we feel when contemplating certain kinds of visual stimuli such as pattern, is *simple*, an irreducible primary that either cannot or need not be analyzed further.

For formalists, beauty is enough. It is, they believe, the very *raison d'être* of these objects in the first place: People enjoy looking at beautiful things, so they created these works to adorn the world around them, decorating their surroundings with eye-catching patterns, motifs, and inscriptions. Blair and Bloom approvingly cite the assertion of Oleg Grabar (1995) that the main purpose of Islamic art is “literally superficial—to beautify an object and enhance its effect on the viewer” (Blair and Bloom 2012: 43). Contextualists, on the other hand, view the passive and self-contained nature of visual enjoyment as the primary stumbling-block to a proper understanding of Islamic art. Necipoğlu, in particular, is insistent that the appeal to aesthetic pleasure is a methodological dead end. The enjoyment of form, she claims, is an entirely passive experience; it is akin to a reflex, a reaction “triggered” or “induced” by certain formal qualities, pleasant enough but leading nowhere. Meaning, on the other hand, is quite literally where the action is; it is an ongoing *process* of activation, of initiating and continuing the abstract processes of signification, recognition, and valuation that generate intentional networks in which living human beings embed the objects. Necipoğlu thinks we should understand and analyze ornament as “an active agent in the construction of temporality and spatiality” and decorated objects as facilitators of a “signification process” whose

“interaction in specific settings, transactions, ceremonies, and spectacles with the gendered bodies of users and beholders activated diverse responses, informed by the subjectivity of individuals” (Necipoğlu 2016: 154). Indeed, she holds that the notion of “pure decoration” is unacceptable *precisely because* it ignores all this activity and reduces the object to a “semantic black hole,” in her view something unthinkable.

Advocates of formalism, then, hold that pleasure in form is sufficient, that it explains the creation of the artworks and allows us to categorize and classify them, and that the search for meaning is optional. Proponents of contextualism retort that aesthetic pleasure is a mere sensory reflex, that it leads nowhere in terms of actual understanding, and that the serious business is the business of finding the meaning(s) of the artworks. Formalists view aesthetic pleasure as *too simple to be controversial*; contextualists view it as *too simple to be interesting*.

At this point, we should ask whether aesthetic pleasure is really that simple. For if we reconsider this allegedly irreducible primary, we open up a promising new perspective on Islamic art, and on ornament generally. In the remaining part of this paper, I argue that reconceptualizing aesthetic pleasure on more *biologically aware* lines can suggest fresh insights into this universal human experience.

Pleasure and Nature

Certain shapes, patterns, combinations of line and color, and the like give pleasure; this much is indisputable. We enjoy the very act of looking at them—not just seeing them go by in the background, but really *looking* at them, exploring their details with focus and concentration. The act of perceiving the forms is rewarding enough to continue doing it; in fact, sometimes we have to make an effort to tear ourselves away. This is what aesthetic pleasure has in common with other pleasures, such as physical or intellectual pleasures. What, though, is pleasure itself?

Pleasure is not an irreducible primary or explanatory dead end but a psychological state with a *biological* function. Pleasure is nature’s way of telling a conscious living organism that it is doing something right, something that will further its life rather than harm it (Binswanger 1990). Pleasure is the basic survival signal for conscious organisms and forms the guiding mechanism for animals in their pursuit of life. Animals are impelled to the right course of action—“right” in the sense of “contributing to their continued existence”—because a given thing in their habitat feels or smells or tastes good, just as they are guided away from harmful things by the pain those things bring and the avoidance response this creates. Human beings are no different, at least from an

evolutionary point of view; the essential principles governing selection and adaptation are the same across species. People cannot rely *solely* on pleasure as their guide to life, as phenomena like drug addiction show, but the fact remains that, biologically speaking, pleasure is an adaptation that indicates successful action in the struggle for life: Things feel good to us that helped our ancestors survive, from eating and sleeping to reproduction.

Considered in the context of life in nature, then, pleasure *per se* is not mysterious. The problem arises when we move to the level of psychological as opposed to physical experience, as is the case with aesthetic pleasure: We do not know precisely *how* an enjoyable reaction to a given visual form is promoting our survival. Happily, this gap in our understanding opens a new avenue of inquiry.

In terms of aesthetics, if we treat the pleasure taken in form not as a crudely simple reflex, but as a complex biological signal, we create a new perspective from which to view ornament. The pursuit of aesthetic pleasure, that signal of successful survival-pursuit, is revealed as part and parcel of the human striving for survival in the natural environment. An object like the Iznik dish in Figure 1, then, represents in all its details a physical record of the artist's pursuit of positive feedback from nature: In every moment of the creative act, the craftsman had to think, "This line looks good here; that color looks right there; I should turn my brush this way now"—and the result was a tangible artifact embodying the triumphant achievement of life's reward, the condensation into physical form, as it were, of a distinct sense of successful activity in the world. The same is true for the craftsmen who made the jali, the mosque lamp, the animal carpet, and all such works. Their skill, guided by their sense of pleasure in form, allowed them to create material objects of both utilitarian and aesthetic value, contributing to the furtherance of their lives in the physical *and* psychological realms.

Works of decorative art, then, are best viewed primarily neither as baubles nor as "signifiers," but as *the natural outcome of a biological process*—a living organism's modification of its environment, guided by the feeling of pleasure toward the end of advancing its existence. The creation of beautiful objects like those in Figures 1–5 is fully as natural as the building of nests by birds or dams by beavers, only in this case it is geared toward some as yet poorly understood survival need of consciousness, rather than of just the body.

This kind of approach to ornament—which, for lack of a better term, we may call *naturalist*—has distinct advantages over both formalism and contextualism. For one thing, it takes the artworks more seriously as objects of intellectual (even philosophical) inquiry than does formalism. As has been observed many times (Brett 2005), decoration

has long been ignored or abused as an irrelevant distraction from the real issues in aesthetics; understanding pleasure in ornament as a signal of the successful pursuit of life should go a long way toward earning it the respect it deserves. (A first step would be to acknowledge the active nature of perception and its role in the enjoyment of beauty, as against the presumed reflex-like passivity of aesthetic response; a tentative effort is Wood 2019.) A naturalist approach to ornament also helps to shed the class-snobbery connotations of connoisseurship; the field of Islamic art was in no small part germinated by wealthy dealers and collectors who reveled in exquisite detail and craftsmanship, with the result that the valuation of form has ever borne the stigma of “privilege.” Studying ornament in light of the facts of biology, rather than the tastes of distinguished gentlemen, may help do away with that stigma.

As against contextualism, a naturalist approach avoids the tendency of that school to overabstraction. After all, what flesh-and-blood human being ever picked up an exquisitely decorated object—or, for that matter, spent hours a day for years practicing to master the skills required to make it—primarily to activate a “signification process”? There is no denying that people bestow meaning on their creations, particularly beautiful ones, but acknowledging the biological roots of aesthetic pleasure lets us avoid precipitate leaps to abstract semiotic networks at the expense of real-world human experience. Indeed, a naturalist perspective lets us put semiotics in its place: The appreciation of form is an aspect of the naturally inbuilt survival mechanism of the individual and is thus logically prior to meaning-bestowal; there can be no interpersonal communication without persons. The objects are saying something, just not the things contextualists are looking for; they are saying “You, the individual, are on the path to survival.”

Conclusion: Toward a Research Program

When we observe that human beings have developed a pleasurable response to certain objects of perception, it becomes apparent that we need to frame this fact of life in the science of life. We need to ask of aesthetic pleasure the same question biologists ask of *every* aspect of a living being, from cellular structure to niche construction: How is this adapted to further the survival (and reproduction) of the organism in nature? In the present context, this becomes: What are we doing right in the eyes of nature, so to speak, when we alter our environment by making shelter, tools, clothing, and so on with not just their functionality, but their *appearance* in mind? What evolutionary adaptation is being encouraged when we take pleasure in what we see, just for what it looks like? What survival benefit accrues from adding purely visual,

nonfunctional elements to buildings and objects—or even just from attending to their shapes, as with pointed arches or curvaceous handles? How are these intentionally stylized percepts serving life? And how does this fit into the context of human value-pursuit generally, including the higher-level activities beloved of contextualists, such as meaning bestowal, identity construction, status signaling, etc.? When we understand better how the production of pleasing form fits into the “big picture” of the process of winning survival in nature, we will be in a better position to explain both the form and the meaning of art objects, Islamic or otherwise. We have to realize that “decorative” is not a dirty word and “inducing pleasure” is not shallow (as compared with a supposedly rich and deep semantic system); it is, rather, precisely the nature of the pleasure taken in decorative forms like those of Islamic art that speaks so profoundly to human nature—to the nature of man as a living being pursuing survival in the world.

I do not pretend to have the answers to these questions, but I think I have made a case that these are the right questions to be asking. Putting aside the false dichotomy of beauty *versus* meaning, we can ask afresh what the meaning of beauty is to a living being; passing beyond the opposition of form *versus* context, we can build our understanding of Islamic art on the premise that “art in context” ultimately means “environment modification in pursuit of survival.” By thus placing the objects in the framework of life, by seeking to understand the significance of ornament not merely as the stimulation of some innate and irreducible reflex but as an activity rooted in the natural survival needs of the human being, we can better hope to analyze both pleasure and meaning in Islamic art.

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Electric Hand Dryers Serve as a Microbial Reservoir for Contamination

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Abstract

Electric hand dryers, particularly jet-air dryers, are a relatively new method of drying hands and claim to be a more efficient and sterile method than using paper towels. Our purpose for performing this research was to determine whether electric hand dryers in public restrooms are antiseptic, or if they could be a source of bacterial contamination to your hands during drying. Initially, restrooms at Weber State University were selected that had a high frequency of foot traffic, making them good sampling locations. Testing was done in men's and women's restrooms in three buildings on campus, testing four bathrooms for each group in each building. Samples were collected by swabbing a 25-cm² area of the top, middle, and bottom of the hand dryer chamber using a 3M Quickswab. Pour plates using TSA were used to enumerate samples. Plate counts were determined at 48 hours after incubation at 37°C. Results showed the bottom of the dryer chamber in both the men's and women's restrooms had the most bacterial contamination, with an

average of 311 CFU/25 cm² in the men's rooms and an average of 299 CFU/25 cm² in the women's. The middle section was the second most contaminated averaging 144 CFU/25 cm² for men and 145 CFU/25 cm² for women, while the top section was the least contaminated, averaging 107 CFU/25 cm² for men and 51 CFU/25 cm² for women. Results showed that electric hand dryers can serve as a source of bacterial contamination after hand washing. The overall level of bacterial contamination was higher in hand dryers in men's restrooms. As a preventative measure, the inside of these dryers should be cleaned on a daily basis to prevent people from contaminating their hands immediately after washing them, thus reducing the spread of bacteria.

Introduction

Electric hand dryers are considered a more environmentally friendly alternative to using paper towels because they reduce paper waste. They also are advertised to be more sanitary than paper towel dispensers because they eliminate direct contact with the dispenser and towels (Ansari et al., 1991). With the widespread use of electric hand dryers (either warm-air or jet-air designs), often the only option in restrooms, their antimicrobial nature has been put into question (Gustafson et al., 2000). Recent studies suggest these type of hand dryers can spread bacteria through the air during use in restrooms (Snelling et al., 2010; Margas et al., 2013; Best et al., 2014; Ma 2020). Dawson et al. (2016) found that hand dryers in public restrooms transfer aerobic microorganisms, with an average transfer of 58 CFU transferred per drying cycle, but did not determine the source of bacteria. They suspected the bacteria were environmental organisms already present in the air.

A comparison of ultra-rapid hand dryers (air-blade dryers) and conventional warm-air hand dryers showed that air-blade dryers transferred fewer bacteria than warm-air dryers but that the longer hands were in the dryer chamber the less significant the difference (Snelling et al. 2010). Suen et al. (2019) swabbed electric hand dryer air outlet nozzles, finding an average of 1460 CFU/cm² on the air outlets. This study did not determine the source of these organisms but suggested the bacterial source was individuals touching the dryer during hand drying. This was supported as they determined the majority of identified isolates could be considered part of the human microbiota. Huesca-Espitia et al. (2018) found that hot-air hand dryers can deposit bacteria on hands during drying and can disperse bacteria throughout buildings. They also used a swabbing technique to suggest the source of bacteria was from air

being passed through the dryer and not from bacterial deposition on the dryer. Reynolds et al. (2020) reviewed nearly 300 papers comparing hand dryers and drying methods and found mixed results when comparing bacterial contamination between electric hand dryers and paper towels. In addition, they found only a few papers quantified microbial risk assessment for hand dryer types, with most not specifying the exact source of microbial contamination spread by the drying air.

Our objective in this experiment was to see whether there were bacteria on electric hand dryers and whether hand dryers could serve as a reservoir for bacteria that could potentially reinoculate a person's hands. We also compared the number of microorganisms present in the drying chamber between two different types of hand dryers and compared the microbial load in dryers found in men's and women's restrooms.

Methods

Testing locations

Twenty-four total commercial electric jet-air hand dryers were tested on the campus of Weber State University, Ogden, Utah. Three buildings were tested, with 4 men's bathrooms and 4 women's bathrooms selected in each building. The buildings were Tracy Hall, Shepherd Union, and the Stewart Library. The Shepherd Union building and the Stewart Library restrooms use Dyson Airblade hand dryers (Dyson Inc., Chicago, IL), whereas Tracy Hall restrooms contain Mediclinics Dualflow Plus hand dryers (Mediclinics S.A., Barcelona, Spain). Restrooms were selected at locations in each building based on assumed higher foot traffic areas to sample dryers that had higher use.

Sampling and media

Commercial sterile 3M Quickswabs (3M Microbiology, St. Paul, MN) were used for collecting bacteria samples from the hand dryers following the manufacturer's protocol. These swabs contain 1 mL of sterile letheen broth, which was then used for the pour plates. Pour plates used to enumerate the bacteria contained tryptic soy agar (TSA) (Hardy Diagnostics, Santa Maria, CA). TSA was used because it contains non-selective nutrients allowing for propagation of a large variety of bacteria, including organisms that are components of the human microbiota.

Experimental protocol

Samples were collected using the 3M Quickswabs from three different locations in each hand dryer chamber. One location was at the top of the dryer chamber above the air vents, one location was in the middle beneath the air vents on the internal part of the dryer chamber where hands are moved through the flowing heated air to facilitate drying following the manufacturers' instructions, and one location was at the bottom of the dryer chamber where water drops can collect (Figure 1).

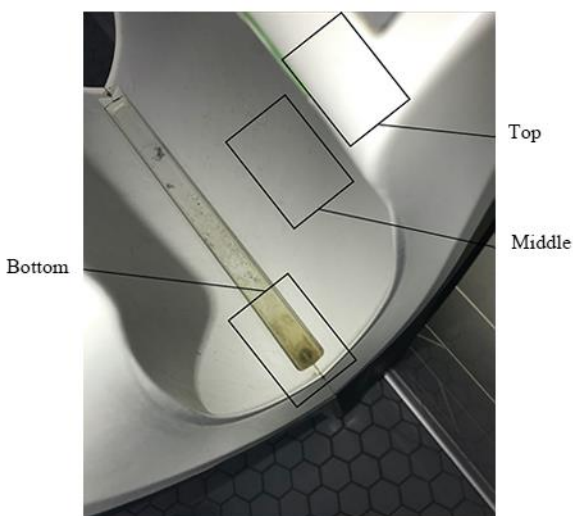


Figure 1. Picture of a hand dryer showing the three location where samples were taken using the swabs.

Several electric hand dryers had observable standing water at the bottom of the dryer. For each swab, a 25-cm² area (5×5 cm) was swabbed by carefully rolling the moistened sterile swab over the dryer chamber surface and going over the test area in two directions. The swab was then placed back in the 1 mL of letheen broth in the Quickswab container, which was vortexed for 30 seconds before plating to transfer bacteria from the swab to the broth. This 1 mL was transferred to a sterile petri dish along with approximately 20 mL of sterile molten TSA (50°C). Once poured, the dish was swirled 10 times to disperse the sample evenly in the agar. Pour plates were held at room temperature for 3 hours and then placed in a 37°C incubator for 48 hours. Each plate was then counted to calculate CFU/25 cm², and the results were recorded.

Results

Comparison among buildings

The average bacterial load found in the hand dryers in the men's restrooms in Shepherd Union building were 60 CFU/25 cm² on the top section, 114 CFU/25 cm² on the middle section, and greater than 300 CFU/25 cm² on the bottom section (Figure 2). The average bacterial count in the women's restrooms in the Shepherd Union building were 115 CFU/25 cm² on the top section, 276 CFU/25 cm² on the middle section, and greater than 300 CFU/25 cm² on the bottom section (Figure 3). In this building, three of four test locations showed higher overall bacterial counts for women's restrooms, with only the men's restroom by the bowling alley having a higher total bacterial count. The middle portion of the hand dryer chamber in all women's restrooms sampled contained a much higher microbial load, while the other two sampling locations in the dryer chamber were similar between the two groups.

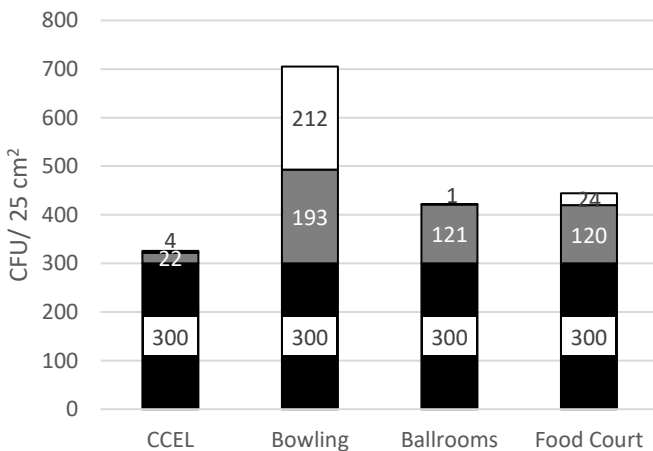


Figure 2. Microbial load of Shepherd Union building men's restrooms (Dyson Airblade). Samples were taken at different locations in the dryer: bottom of dryer (black); middle of dryer (gray); top of dryer (white). Numbers indicate the average cfu/25 cm² quantified in each sample location.

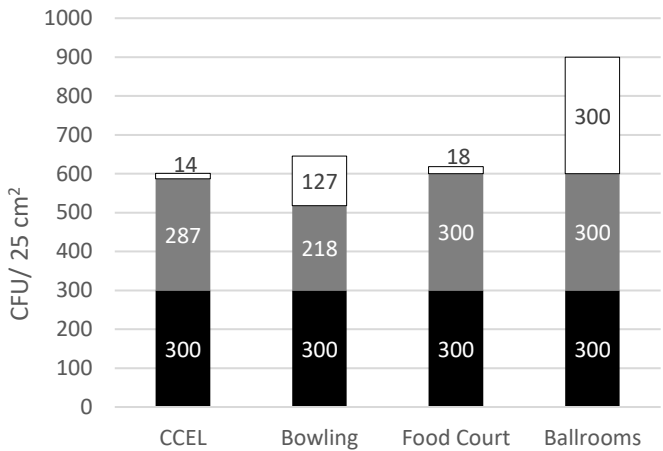


Figure 3. Microbial load of Shepherd Union building women’s restrooms (Dyson Airblade). Samples were taken at different locations in the dryer: bottom of dryer (black); middle of dryer (gray); top of dryer (white). Numbers indicate the average cfu/25 cm² quanified in each sample location.

In the second building tested, Tracy Hall, the average bacterial load in the men’s restrooms electric hand dryers was 224 CFU/25 cm² on the top section, 202 CFU/25 cm² on the middle section, and greater than 300 CFU/25 cm² on the bottom (Figure 4). The average bacterial load in the women’s restrooms was 18 CFU/25 cm² on the top section, 26 CFU/25 cm² on the middle section, and 281 CFU/25 cm² on the bottom section (Figure 5). Overall, dryers in the men’s restrooms had much higher microbial loads, especially in the upper and middle portions of the drying chamber, whereas the bottom of the chamber was nearly identical for both groups. Of interest, the restroom nearest the microbiology laboratories had a much lower bacterial load than the three other sampling locations.

In the final building tested, the Stewart Library, the average bacterial load for men’s electric hand dryers were 37 CFU/25 cm² on the top section, 117 CFU/25 cm² on the middle section, and 183 CFU/25 cm² on the bottom section (Figure 6). In contrast, the average bacterial load in the women’s restrooms hand dryers of 22 CFU/25 cm² on the top section, 134 CFU/25 cm² on the middle section, and 217 CFU/25 cm² on the bottom section (Figure 7). Although the highest bacterial load was found in the bottom section of the dryer chamber, there was no discernible pattern for the other two dryer sections.

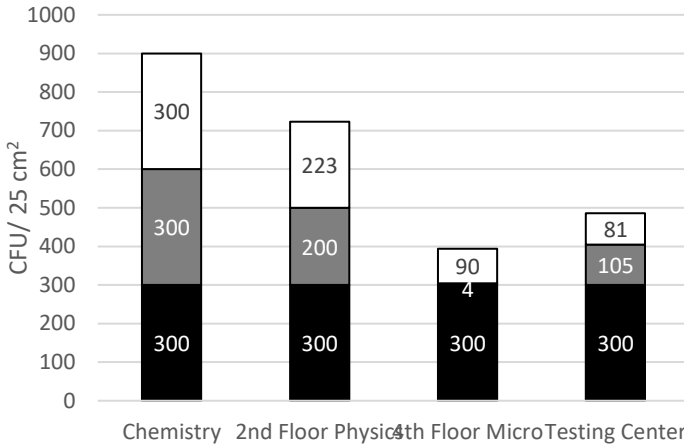


Figure 4. Microbial load of Tracy Hall men's restrooms (Mediclinics Dualflow plus). Samples were taken at different locations in the dryer: bottom of dryer (black); middle of dryer (gray); top of dryer (white). Numbers indicate the average cfu/25 cm² quantified in each sample location.

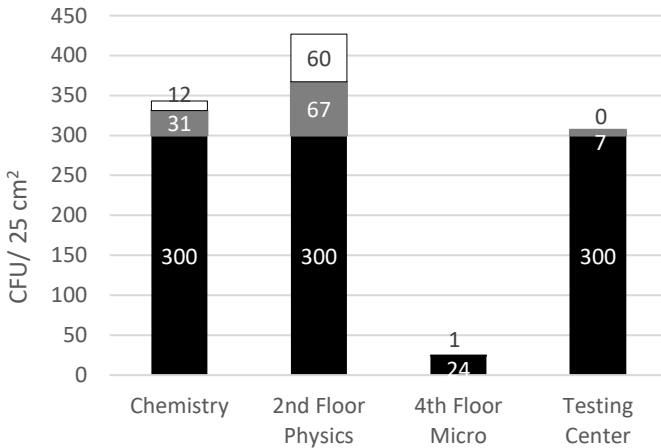


Figure 5. Microbial load of Tracy Hall women's restrooms (Mediclinics Dualflow plus). Samples were taken at different locations in the dryer: bottom of dryer (black); middle of dryer (gray); top of dryer (white). Numbers indicate the average cfu/25 cm² quantified in each sample location.

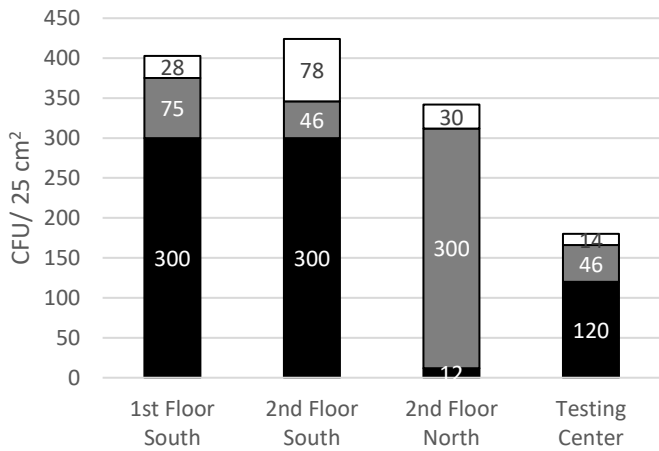


Figure 6. Microbial load of Stewart Library men’s restrooms (Dyson Airblade). Samples were taken at different locations in the dryer: bottom of dryer (black); middle of dryer (gray); top of dryer (white). Numbers indicate the average cfu/25 cm2 quanified in each sample location.

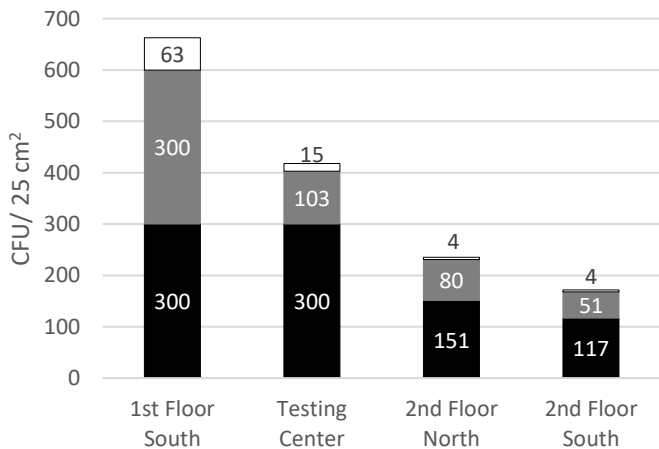


Figure 7. Microbial load of Stewart Library women’s restrooms (Dyson Airblade).). Samples were taken at different locations in the dryer: bottom of dryer (black); middle of dryer (gray); top of dryer (white). Numbers indicate the average cfu/25 cm² quanified in each sample location.

Sample location in the dryer

When results for the 3 buildings and 8 dryers in each building were pooled and the overall average calculated, the average bacterial load for the Dyson Airblade was 58 CFU/25 cm² on the top section, 16 CFU/25 cm² in the middle section, and 250 CFU/25 cm² on the bottom section. The average bacterial load of the Mediclinics Dualflow Plus was 120 CFU/25 cm² on the top section, 114 CFU/25 cm² on the middle section, and 300 CFU/25 cm² on the bottom section (Figure 8). Although the microbial loads were similar for the bottom section of the dryer chamber, the Mediclinics Dualflow Plus had twice the bacterial load in the upper section and 8 times the bacterial load in the middle section.

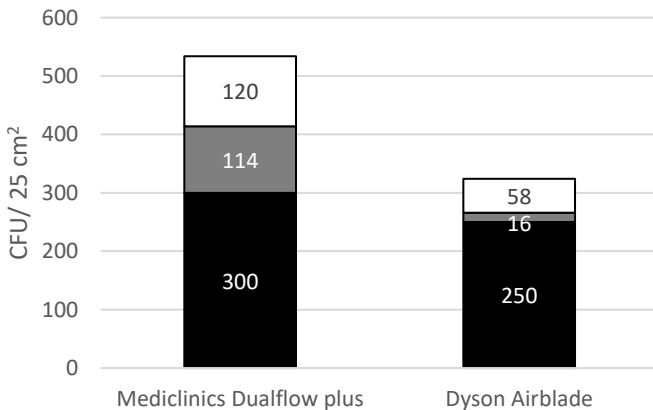


Figure 8. Average microbial load of Mediclinics Dualflow plus vs. Dyson Airblade hand dryers by drying chamber location. Samples were taken at different locations in the dryer: bottom of dryer (black); middle of dryer (gray); top of dryer (white). Numbers indicate the average cfu/25 cm² quantified in each sample location.

Men's vs. women's restrooms based on location

The average bacterial load of the men's restroom hand dryers for all three buildings was 107 CFU/25 cm² on the top section, 144 CFU/25 cm² on the middle section, and greater than 300 CFU/25 cm² on the bottom section. The average bacterial load of the women's restroom hand dryers for all three buildings were 51 CFU/25 cm² on the top section, 145 CFU/25 cm² on the middle section, and greater than 300 CFU/25 cm² on the bottom section (Figure 9). Overall, the only

difference was found in the top section of the drying chamber where the microbial load was twice as high in the men's hand dryers.

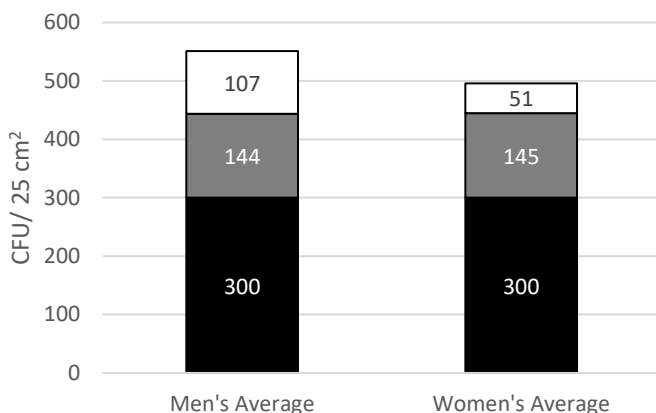


Figure 9. Average microbial load of dryers in men's and women's restrooms. Samples were taken at different locations in the dryer: bottom of dryer (black); middle of dryer (gray); top of dryer (white). Numbers indicate the average cfu/25 cm² quantified in each sample location.

Discussion

These results showed that both brands of electric hand dryers served as microbial reservoirs containing a high number of bacteria inside the drying chamber. A high microbial load was found in every electric hand dryer, both men's and women's, in every building location, and in all three sampling locations inside the drying chamber. There were only two sample locations where no microbial load was found, the top location in the women's Tracy Hall testing center restroom, and the middle location in the women's Tracy Hall fourth floor restroom. Results confirmed that on every dryer bacterial cells attach to the surface of the drying chamber and that viable bacteria are potentially released into the air during drying to contaminate the hands. The bottom of the dryers had the highest levels of contamination, while the middle and top sections had the lowest contamination levels for both men's and women's hand dryers. Suen et al. (2019) found bacteria on the air outlet area of both jet-air (1.48×10^2 CFU/cm²) and warm-air dryers (1.48×10^2 CFU/cm²) but did not swab the drying chamber in either hand dryer type. Margas et al. (2013) sampled the upper portion of the front and back panel of the air-blade dryer after 100 people had used the dryer consecutively, finding an

average of 1,900 CFU/25 cm². They suggested the bacterial contamination was due to individuals touching the panels during drying as opposed to the total number of people drying their hands in the experiment. More research could be done to determine how long bacteria remain viable inside the dryer chamber.

We were also able to determine that the men's restrooms had a higher average microbial load than the women's restrooms on both the top and bottom sections but not on the middle section (Figure 8). We hypothesize that it could be due to men having larger hands than women resulting in more contact with the upper and lower levers of the hand dryers. Our assumption is that bacteria on washed hands are blown onto the inside surface of the drying chamber. Others suggest that bacteria are transferred to the chamber walls when touched (Margas et al. 2013; Suen et al., 2019). It has not been determined whether the bacteria in the drying chamber are transient or if a biofilm can form and be maintained by repeated dryings that release moisture for the biofilm to utilize. Huesca-Espitia et al. (2018) found that hot-air hand dryers in both men's and women's bathrooms can deposit bacteria on surfaces, including recently washed hands, but the source of contaminating bacteria was determined to be the surrounding air drawn into the dryer blower. They did not find evidence of bacteria in the actual dryer as a source of contamination. Our findings are contradictory to those of Huesca-Espitia et al. (2018) because with hand dryers designed with a hand-drying chamber, the chamber can harbor bacteria to contaminate hands as they are being dried. They found an average of only 4 CFU per hand dryer were recovered by swabbing from the air nozzles, indicating the dryers are not a source of bacteria.

Lastly, we were able to determine which dryer type was less susceptible to contamination. The average bacterial load for the Dyson Airblade was twofold less than the average bacterial load for the Mediclinic Dualflow Plus on the top section, sevenfold less than the average bacterial load for the Mediclinic Dualflow Plus in the middle section, and 1.2-fold less than the average bacterial load for the Mediclinic Dualflow Plus on the bottom section (Figure 9). Snelling et al. (2010) noted that air-blade hand dryers had significantly less bacterial transfer than other dryer designs, but our results indicate this style of dryer can harbor high levels of bacteria in the drying chamber. This was also the result in other studies, as bacterially contaminated air was found to be emitted whenever a warm-air dryer was running, even when not being used for hand drying (Alharbi et al. 2016; Gustafson et al., 2000). Margas et al. (2013) showed that when compared with warm-air hand dryers, air-blade hand dryers produce more ballistic droplets during use, contaminating large areas of restrooms, and have the potential to retain

bacteria on the hands and body of users. We suggest the higher bacterial load in Mediclinics Dualflow Plus dryers is caused by the collecting trough at the bottom of the dryers, unique to this dryer design as compared with the Dyson Airblade dryer, which does not have a trough at the bottom. This feature could be a source of continual bacterial contamination to the dryer chamber and also harbor bacterial biofilms when not regularly cleaned.

Conclusion

To counteract the large amounts of bacterial contamination found in electric hand dryers, it is our recommendation that the dryer be turned off and the drying chamber cleaned with an antimicrobial cleanser each day as part of the routine restroom cleaning protocol. Tunggal et al. (2020) suggested a hand dryer equipped with an ultraviolet sterilizer, and this may be valuable in reducing bacterial contamination. We also recommend using a commercial electric hand dryer design that does not contain a trough in the bottom section because this significantly increases the bacterial load in the bottom of the dryer. This would greatly limit the number of bacteria on the inner surface of these dryers, lessening bacterial contamination on washed hands by the air when hand dryers are used.

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Behavior and Bacteria as Contributors to Chytridiomycosis Resistance in *Hyla arenicolor*

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Abstract

*Chytridiomycosis has contributed to worldwide amphibian decline. The canyon tree frog (*Hyla arenicolor*) appears to be resistant to this disease even when the causative agent, *Batrachochytrium dendrobatidis*, is present. This resistance has been attributed to the frogs' tendency to bask in the sun in the summer. However, no population declines have been observed in the cooler months when the frogs are unable to bask, indicating that other factors may contribute to their chytridiomycosis resistance. As part of an ongoing study on the prevalence of *B. dendrobatidis* in *H. arenicolor* populations in Washington County, Utah, we brought wild frogs to the laboratory to control for the effect of basking on fungal load. Although the low prevalence of the fungus at most field sites appears to indicate that basking may contribute to chytridiomycosis resistance, the asymptomatic laboratory frogs suggest that the species may possess additional adaptations that allow them to survive the cooler seasons when infected with *B. dendrobatidis*.*

Introduction

Chytridiomycosis, a disease caused by the fungus *Batrachochytrium dendrobatidis*, has been identified as a leading cause of worldwide amphibian decline (Berger et al., 1998; Carey et al., 1999; Garner et al., 2006; Van Rooij et al., 2015). To date, resistance has been observed in multiple species, including the African clawed frog (*Xenopus laevis*) (Weldon et al., 2004), some populations of boreal toads (*Anaxyrus boreas boreas*) (Park et al., 2014), and several species from the genus *Hylidae* (Brannelly et al., 2013; Olson et al., 2013). Resistance protects these species from the negative effects of chytridiomycosis, but they may also act as a vector, spreading the disease to other amphibian species in their vicinity. Several mechanisms of resistance have been observed in these species, including peptides found in cutaneous secretions and beneficial bacteria on the surface of the skin (Brannell et al., 2013; Olson et al., 2013; Park et al., 2014). Understanding these mechanisms could help identify other resistant species.

The canyon tree frog (*Hyla arenicolor*) is a chytridiomycosis-resistant member of *Hylidae* native to southwestern deserts of the United States. Although wild *H. arenicolor* have frequently tested positive for *B. dendrobatidis*, there have been no recorded deaths from chytridiomycosis in this species (Bento et al., 2019; Eng and Walker, 2011; Hilton et al., 2018; Shepherd et al., 2014). Throughout their range, these frogs have been observed basking in the sun during the hottest, driest parts of the summer. This behavior could reduce chytrid load in many ways; the fungus is known to be sensitive to ultraviolet light, low humidity, and high temperature (Hite et al., 2016; Piotrowski et al., 2004), which may explain the resistance of *H. arenicolor* to chytridiomycosis. Several laboratory studies have determined that the ideal temperature range for *B. dendrobatidis* growth is 17–23°C (Longcore et al., 1999; Piotrowski et al., 2004). Field temperatures above 30°C significantly reduce infection rates in the northern leopard frog (*Lithobates pipiens*) (Forrest and Schlaepfer, 2011). *H. arenicolor* only experiences temperatures above 30°C when basking, which may contribute to the low prevalence observed in populations studied during the summer (Eng and Walker, 2011; Shepherd et al., 2014). However, these frogs do not seem to be adversely affected during the cooler months, suggesting that there are additional mechanisms that contribute to their resistance.

To date, the beneficial bacterium *Janthinobacterium lividum* has been excluded as a mechanism of resistance in this species, but it is possible that the cutaneous secretions of these frogs or a different symbiotic species of bacteria is responsible for keeping the fungal load

in check when the frogs are unable to bask in the sun (Hilton et al., 2018; Park et al., 2014; Woodhams et al., 2010). The capability of overwintering frogs to survive *B. dendrobatidis* infections without basking has not yet been conclusively demonstrated. We predict that a combination of behavioral adaptations and skin flora of *H. arenicolor* inhibit the growth of *B. dendrobatidis* in the skin. This study aims to confirm the existence of an additional mechanism of chytridiomycosis resistance in *H. arenicolor*.

Methods

Ethics statement

All live *H. arenicolor* specimens that were captured and kept for long-term study were housed in 10-gallon aquaria with no more than four frogs to one aquarium. They were fed 3–4 four gut-loaded crickets each on alternating days. Each frog was given an alphanumeric designation and identified using distinctive spot patterns on the dorsal surface and band patterns on the hind legs to maintain a consistent labeling method for samples and to avoid invasive identification techniques such as tagging or toe clipping (Fig. 1). All experiments were conducted with the approval of the Dixie State University Institutional Animal Care and Use Committee (IACUC).



Figure 1: From left to right, captive *H. arenicolor* specimens A3, A1, and A2.

Sample collection

Throughout the summer of 2019, swab samples were collected from adult *H. arenicolor* specimens at various sites located on public land in Washington County, Utah (Table 1, Fig. 2). Adults were identified as *H. arenicolor* by the presence of toe pads, yellow-to-orange coloration on the ventral thighs, and light brown coloration with darker brown spots on the dorsal surface and darker brown bands on the legs (Parker and Brito, 2013). At each site, every adult *H. arenicolor* that was captured was swabbed using a sterile swab 25 times in the axillary region and an additional 25 times along the thighs. To determine the infection rates in the study populations, we captured and swabbed 54 adults; 42 were released immediately after the swab was collected and 12 were kept for further study. All frogs that were captured were swabbed. Captured frogs from the same site were taken back to the lab in a watertight plastic container (Imlay Canyon Keg, 6.4 L, Imlay Canyon Gear) lined with paper towels that were saturated with water from the pool nearest to the site of capture. At sites where *H. arenicolor* tadpoles were present, several tadpoles were captured using nets sanitized with Formula 409 and dried in the sun between specimens. Tadpoles were identified as *H. arenicolor* by observing mottled coloration with yellow-to-gold coloration on the cheeks (Parker and Brito, 2013). Captured tadpoles were observed for dekeratinization of mouthparts, as this has been observed in some species as an indicator of *B. dendrobatidis* infection

Table 1: Locations and dates for collected samples					
Location	Coordinates	Date	Adult frogs swabbed	Tadpole mouthparts collected	Adult frogs kept
Leap Creek	37.36432, -113.26783	31-May-19	5	0	3
Cowboy Pools	37.27451, -113.74295	6-Jun-19	4	7	1
Big Hollow	37.23303, -113.43936	14-Jun-19	8	0	5
East Quail Canyon	37.26326, -113.41638	21-Jun-19	15	4	3
Water Canyon	37.03867, -112.95546	28-Jun-19	12	3	0
Guacamole Trail	37.22245, -113.12063	12-Jul-19	0	10	0
Fat Man's Misery	37.20298, -112.87202	19-Jul-19	10	6	0

(Navarro-Lozano et al., 2018). The tadpoles were then euthanized, and the mouthparts were removed and stored in nonsterile 1.5-mL microfuge tubes. All *H. arenicolor* specimens were handled with clean nitrile gloves to prevent cross-contamination. In the laboratory, swabs and mouthparts were stored at -20°C, and captive specimens were placed in the aquaria, which had been prepared with gravel substrate, large sandstone rocks, and shallow dechlorinated water.



Figure 2: Map of locations used in this study.

After six months, 11 of the captive frogs were swabbed. (At the time, three frogs had died due to an unrelated accident, and we were unable to swab one of them before preservation.) These swabs were stored in the same manner as those collected in the field.

Parasite identification

One month after capture, we observed orange spots on the ventral side of each captive frog. We lanced a single orange spot from each frog using a sterile 33-gauge lancet and extracted the parasites (Sladky et al., 2000). We mounted the extracted parasites on glass slides and observed them at 400× magnification.

Protein extraction and control preparation

Each swab or tadpole mouthpart and positive and negative controls were lysed for western blot with 990 μ L of Triton X buffer (100 mM, pH 8.5) and 10 μ L of protease inhibitor cocktail. The positive control was a colony of *B. dendrobatidis* from the JEL230 isolate obtained from Dr. Joyce Longcore at the University of Maine. Following centrifugation for 10 minutes at 10,000 RPM ($11200 \times g$) at 4°C, 25 μ L of protein

extract and 10 μ L of 5% β -mercaptoethanol loading buffer were added to samples and controls. Tubes were vortexed, heated to 95°C for five minutes, and stored on ice.

Electrophoresis and western blotting

Samples and controls were loaded onto 4–15% SDS-PAGE gels. Electrophoresis was run at 220V for 25 minutes, then the gels were transferred to a 0.2- μ m nitrocellulose membrane at 120V for 1 hour. Membranes were then blocked in a 10-mL solution of 5% nonfat dry milk in TBS-T for 30 minutes at 4°C. On a plate rotator, membranes were rinsed 3 times in 10 mL of TBS-T for 5 minutes, incubated for 45 minutes in a 1:1000 solution of 5C4 IgM mouse anti-chytrid monoclonal antibody, which targets an unspecified glycoprotein (ISCA Diagnostics, Exeter, United Kingdom) in TBS-T, and again rinsed in the same manner, incubated in a 1:1000 dilution of Alexa Fluor 647 IgM goat anti-mouse IgM antibody (Abcam Biochemicals, Cambridge, United States) in TBS-T for 30 minutes, and again rinsed in the same manner. Membranes were imaged using the Cy5 exposure setting on an Azure c600 Gel Imaging System.

Skin secretion susceptibility test

Skin secretions were collected from 9 individual *H. arenicolor* specimens. A solution of 0.01% epinephrine was prepared using deionized water to stimulate the production of secretions. Each frog used in this portion of the study was placed in a cheesecloth-covered weigh boat containing 25 mL of the epinephrine for 15 minutes. Fluid from each weigh boat was collected and centrifuged at 800 RPM ($72 \times g$) and 25°C for 10 minutes to concentrate secretions. The aqueous layer was removed until only 5 mL remained in each tube and 500 μ L of 100 μ g/mL ampicillin were added to each tube to prevent bacterial contamination and chilled to 4°C. Diffusion discs were then prepared from each tube containing *H. arenicolor* skin secretions or chilled 0.01% epinephrine.

Thirty-six 1% tryptone plates were streaked with *B. dendrobatidis*. After each plate had been inoculated, two diffusion discs were placed on each plate: one disc saturated in 0.01% epinephrine and one saturated in skin secretions from each frog in quadruplicate. All plates were sealed with a double layer of Parafilm and incubated at 22°C. Colony growth on the plates was observed for 5 days. While the control side of each plate showed normal chytrid colony growth after 5 days, a biofilm had spread from each of the diffusion discs that had been prepared using skin

secretions and overwhelmed the chytrid colonies that had begun to appear around day 3.

Staining and selective media

Resistance to chytridiomycosis resulting from the presence of cutaneous bacteria has been observed in other Anurans. To identify the contaminant, a Gram stain was performed using a randomly selected plate from each frog. MacConkey agar, mannitol-salt agar, sheep's blood agar, and bile-esculin agar plates were streaked from the same initial bacterial cultures as the Gram stain and incubated for 48 hours at 23°C.

Behavioral study and animal husbandry

To mimic conditions the frogs would experience in the wild during the spring and fall, captive *H. arenicolor* specimens were kept at an ambient temperature that remained fairly consistent at 22°C while the water in their tanks remained close to 18°C, and lighting was controlled using a timer for a 14-hour day (6:00 am to 8:00 pm) and a 10-hour night cycle. The temperature of both water and air during this study were also within a favorable range for *B. dendrobatidis* growth (Piotrowski et al., 2004).

An ethogram was compiled of all observed behaviors of the frogs while in captivity (Table 2). After 7 months, 9 frogs were observed at different hours of the day (6:00 am, 10:00 am, 3:00 pm, and 8:00 pm) for 2 days. At the beginning of each minute for every hour-long block, a scan was taken and the total number of frogs performing each behavior listed on the ethogram was recorded. At the end of each hour block, each change in behavioral state or performance of a fixed action pattern by a

Table 2: Ethogram for behavioral study sorted alphabetically by behavioral category

Behavioral State	Fixed Action Pattern
Floating	Amplexus
Fully submerged	Calling (chuck)
Resting (horizontal)	Calling (trill)
Resting (touching)	Crawling (horizontal)
Resting (vertical)	Crawling (vertical)
Submerged (eyes out)	Grooming
	Jumping
	Shedding
	Swimming
	Turning

frog in the study was added on a minute-to-minute basis and the average activity level for the hour was calculated from these data. At the end of the study period, all data were analyzed using a one-way ANOVA with t-tests used for post-hoc analysis.

Results

Of the 54 adults swabbed in the field, 17 tested positive for *B. dendrobatidis* by western blot (31%, Fig. 3). Of the 28 normal tadpole mouthparts collected, 5 tested positive for *B. dendrobatidis* (18%). Two of the collected mouthparts were identified as dekaratinized in the field, and both of these tested positive (100%). Out of the 12 frogs that were captured and taken back to the laboratory to remove the effect of sun basking on disease progression, 5 were positive for *B. dendrobatidis* when they were captured (42%, Fig. 4). All 11 frogs tested positive after 6 months in captivity (100%, Fig. 4). Prior to this, they all tested positive for a *Hannemania* infection (Fig. 5).

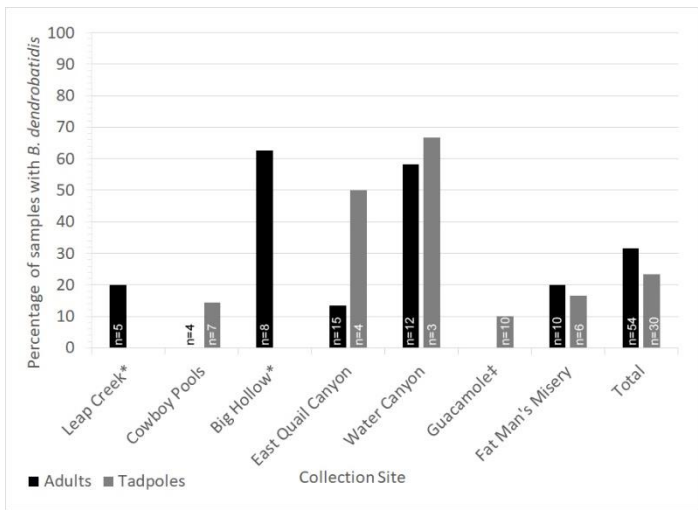


Figure 3: Percentage of *B. dendrobatidis*-positive samples by location as determined by western blot. (*Indicates no tadpole samples; † indicates no adult samples.)

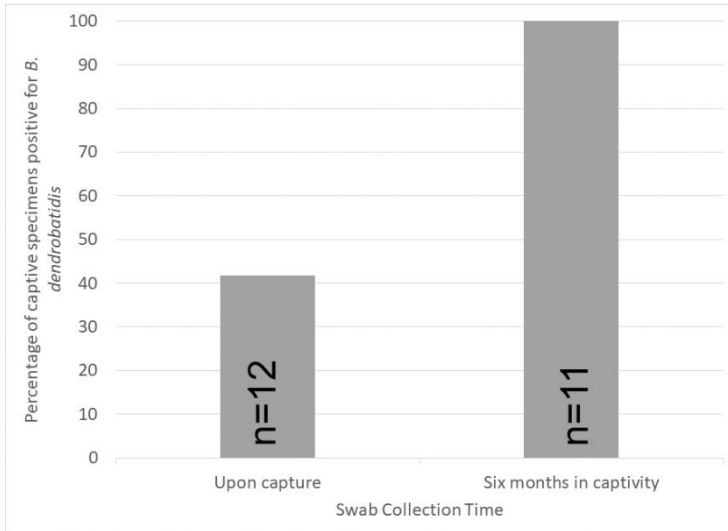


Figure 4: Percentage of *B. dendrobatidis*-positive samples corresponding to frogs collected for laboratory analysis.

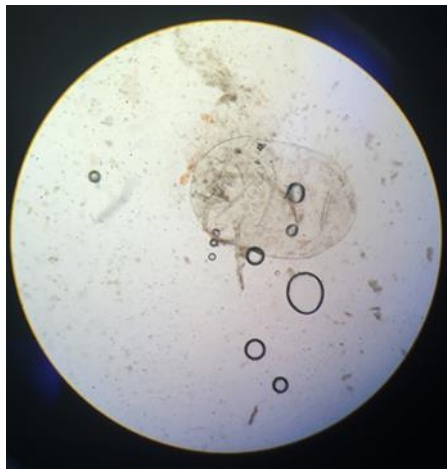


Figure 5: *Hannemania* extracted from *H. arenicolor* specimen C1.

Although the control side of each plate showed normal chytrid colony growth, a biofilm spread from the diffusion discs prepared using skin secretions and completely inhibited the growth of chytrid on that side of each plate. Gram stains of these bacteria appeared to indicate that

an ampicillin-resistant Gram-negative rod species was present on each *H. arenicolor* specimen (Fig. 6). When grown on MacConkey agar, this bacterium formed colonies that showed some pink after 24 hours but were completely white after 48 hours, indicating that while a lactose-fermenting species may have been present, the majority of the colony was comprised of non-lactose-fermenting bacteria. No growth was observed when this species was cultured on mannitol–salt agar. When cultured with the unknown bacterium, the sheep’s blood agar showed no evidence of hemolysis and the bile–esculin agar did not undergo a color change nor show any signs of growth. The bacterium appears to be from the genus *Pseudomonas*, but the species cannot be confirmed without further testing.

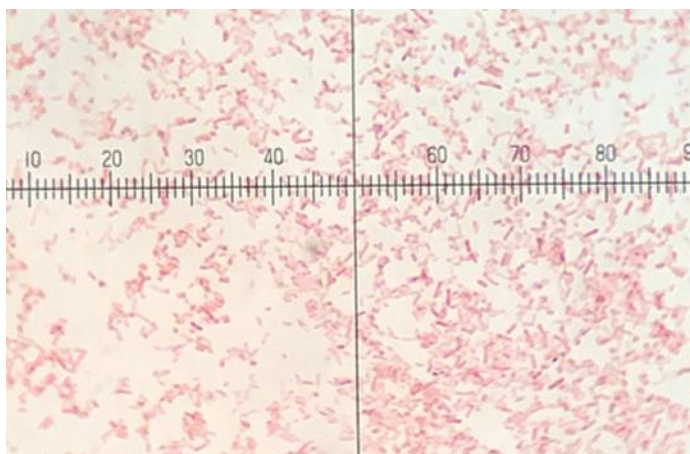


Figure 6: Gram-negative rods from a pure bacterial culture grown from skin exudate collected from *H. arenicolor* specimen A1 under microscope set to 1000 $\times$ magnification with oil immersion.

The behavioral study showed a rise in activity levels throughout the morning with a peak in the mid-afternoon when outdoor sunlight is most intense. The difference in activity levels observed at different times was significant ($F_{3,476}=92.760$, $p<0.001$). By dusk, the activity levels in *H. arenicolor* were roughly equivalent to the activity that was observed in the mid-morning (Fig. 7). Post-hoc t-tests showed significant differences between 6 am and 11 am ($t_{169}=-6.344$, $p<0.001$); 6 am and 3 pm ($t_{142}=-15.518$, $p<0.001$); 6 am and 8 pm ($t_{164}=-8.185$, $p<0.001$); 11 am and 3 pm ($t_{206}=-9.706$, $p<0.001$); 3 pm and 8 pm ($t_{213}=8.183$, $p<0.001$) (fig. 7). There was no significant difference between 11 am and 8 pm ($t_{234}=-1.706$, $p=0.089$) (Fig. 7).

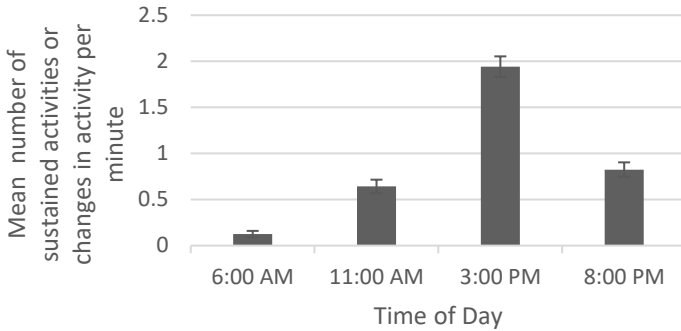


Figure 7: Average captive *H. arenicolor* activity level by time of day. Activity was calculated by the number of frogs that had changed between behavioral states between scans or were engaged in a fixed action pattern during a scan. Activity levels differed by time-of-day observed when comparing means by ANOVA ($F_{3,476}=92.760$, $p<0.001$). Post-hoc t-tests showed significant differences between 6 am and 11 am ($t_{169}= -6.344$, $p<0.001$); 6 am and 3 pm ($t_{142}= -15.518$, $p<0.001$); 6 am and 8 pm ($t_{164}= -8.185$, $p<0.001$); 11 am and 3 pm ($t_{206}= -9.706$, $p<0.001$); 3 pm and 8 pm ($t_{213}=8.183$, $p<0.001$). There was no significant difference between 11 am and 8 pm ($t_{234}= -1.706$, $p=0.089$).

Discussion

Our results support the hypothesis that factors in addition to behavioral adaptations contribute to chytridiomycosis resistance in *H. arenicolor*. Over the course of six months, *B. dendrobatidis* spread to all captive frogs in the absence of direct sunlight that they would have experienced in the wild. Despite harboring the fungus, none of the frogs showed any symptoms of chytridiomycosis in that period, making it clear that this species is quite resistant as stated previously (Eng and Walker, 2011; Shepherd et al., 2014). Susceptibility to chytridiomycosis has been linked with comorbid infections (Densmore and Green, 2007). Although every captive specimen was diagnosed with a *Hannemania* chigger mite infection shortly after capture, this did not appear to impair the ability of these individuals to maintain a low fungal load throughout the course of the study (Fig. 5).

The bacterial contaminant that was found in the skin secretions of every frog in the study was tentatively identified as *Pseudomonas*, based on the fact that the genus is Gram-negative and rod-shaped and tends to be ampicillin resistant (Hoogkamp-Korstanje and Westerdaal, 1979). However, further tests are necessary to confirm the identity of the bacterium. If it is confirmed, the presence of *Pseudomonas* may be a

contributing factor in the observed chytridiomycosis resistance. *Pseudomonas cichorii* collected from the skin of various amphibians was able to inhibit growth of *B. dendrobatidis* in culture (Martin et al., 2019), which is what we observed in our study. If the bacterium found in our study is confirmed to be *P. cichorii*, in vivo research should be conducted to determine whether it is a contributing factor to chytridiomycosis resistance in *H. arenicolor*. Our protocol was designed to eliminate bacteria, and although the surviving species may be a contributor to chytridiomycosis resistance in *H. arenicolor*, ampicillin-susceptible species on these frogs should also be identified.

Because of bacterial contamination, no data were obtained during this study on the ability of *H. arenicolor* to resist chytridiomycosis through peptides produced in skin secretions. Peptides found in the skin secretions of certain populations of green-eyed tree frogs (*Litoria genimaculata*) have been found to limit disease progression of chytridiomycosis (Woodhams et al., 2010). Although *L. genimaculata* is not a particularly close relative of the family Hylidae, many amphibian skin secretions have antimicrobial properties, and it is plausible that peptides produced by *H. arenicolor* have a detrimental effect on *B. dendrobatidis* (Rollins-Smith et al., 2005). The green tree frog (*Hyla cinerea*) exhibits similar resistance to chytridiomycosis via an unknown mechanism even when *B. dendrobatidis* is present and the frogs were held under conditions similar to those used in this study (Brannelly et al., 2012). A comparison of secreted peptides in these two species and among other members of the genus *Hyla* may identify peptides that contribute to chytridiomycosis resistance.

The *B. dendrobatidis* prevalence data that were collected in the field portion of this study support the hypothesis that there is at least one additional mechanism behind chytridiomycosis resistance of *H. arenicolor* in addition to their basking behavior. The positive western blot bands from the wild frog samples were very faint compared with the positive control (data not shown). All of the western blot bands from captive samples taken at 6 months were considerably brighter, although not as bright as the positive control (data not shown). New sites were added for the 2019 study and so no past prevalence data are available for comparison. However, Leap Creek and Fat Man's Misery have been used as study sites in the past. All *H. arenicolor* samples collected from Leap Creek and Fat Man's Misery in the summer of 2018 tested positive for *B. dendrobatidis* (Bento et al., 2019).

A variety of environmental factors, including temperature differences, may have led to the dramatic decrease in *B. dendrobatidis* prevalence in adult *H. arenicolor* at these two sites from 2018 to 2019. However, the laboratory methods used to analyze the samples changed,

and that may have contributed to this difference in results. In 2018, the samples were analyzed using DNA extraction and polymerase chain reaction (PCR), which is not the most accurate method of testing for *B. dendrobatidis* infections (Bento et al., 2019; Densmore and Green, 2007). Using western blot analysis for the 2019 samples may have reduced the number of false positives, although future studies comparing PCR and western blot results from the same *H. arenicolor* specimens are needed to confirm this (Densmore and Green, 2007).

This was the first study of tadpoles and *B. dendrobatidis* prevalence in Washington County, and so there are no previous years to which we can compare these data. The two sites with the highest prevalence of *B. dendrobatidis* in tadpoles were East Quail Canyon and Water Canyon (Fig. 3). In Water Canyon and Fat Man's Misery, the prevalence of *B. dendrobatidis* in tadpoles was similar to that in adults, but no correlation was found among the other sites. There was also no correlation between mouthpart dekeratinization and a positive result for *B. dendrobatidis*. Only two tadpoles with dekeratinized mouthparts were found during the study, and so this lack of correlation may be due to low sample size. Previous research has indicated that mouthpart dekeratinization serves as an accurate indicator of a *B. dendrobatidis* infection only at sites where a high prevalence of *B. dendrobatidis* has been observed (Knapp and Morgan, 2006). However, the tadpoles with dekeratinized mouthparts were collected from Cowboy Pools and Guacamole, which both had low prevalence of *B. dendrobatidis*. Every tadpole observed in Water Canyon had a normal mouth, but two out of the three tadpoles that were kept for analysis tested positive for *B. dendrobatidis*. Although mouthpart dekeratinization has proven to be an accurate indicator of *B. dendrobatidis* infection in some Hylidae species, it is not accurate in others (Navarro-Lozano et al., 2018). It is possible that *H. arenicolor* is not a species that can be accurately diagnosed with *B. dendrobatidis* from observation of tadpole mouthparts alone.

The number of people who pass through certain canyons may be a major factor that affected the prevalence data in this study. The three locations with the highest prevalence appear to be ones that are visited frequently (Galyan, 2007). Although Big Hollow did not appear well-traveled, it shares a confluence with the popular Yankee Doodle Canyon, which may have contributed to the high prevalence of *B. dendrobatidis* in the summer 2019, particularly in conjunction with the abnormally high volume of rainfall experienced the preceding spring (Shoup, 2019). Future studies should collect swabs from *H. arenicolor* at the same site over the course of the summer to provide more insight into the effects of temperature and basking behavior on chytridiomycosis resistance in this species.

Because we believed that sunlight likely played a crucial role in keeping *B. dendrobatidis* infection rates low in wild populations of *H. arenicolor*, we conducted studies of frog behavior in the lab. As expected, the results of this behavioral study indicate that *H. arenicolor* activity increases throughout the day beginning with the initial exposure to light with a peak of activity in the mid-afternoon. This behavioral trend appears to be retained from what has been observed in the wild, and it appears to operate independent of temperature. Future studies in both wild and captive populations of *H. arenicolor* that include observations from more hours of the day as well as varied temperatures will provide more insight into the circadian rhythms of this species. Further research on the effects of *B. dendrobatidis* on closely related species that may share similar circadian mechanisms, produce similar peptides in their cutaneous secretions, and have similar cutaneous microbiomes could provide insight on how *H. arenicolor* resists disease progression and mortality from chytridiomycosis even when prevented from basking for extended periods of time.

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Urbanization Effects on Genetic and Species Diversity in Southern Utah Ant Populations

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Abstract

The increase of urbanized areas worldwide can have limiting effects on genetic and species diversity by reducing gene flow and disrupting ecosystem functions. Our research provides a preliminary analysis of the population genetic structure of ant populations in urban and nonurban areas of southern Utah. We collected ants from three location types in Southern Utah University Mountain Center (rural, low-use semi-private land), Three Peaks Recreation Area (rural, moderate-use public land), and Cedar City (urban cluster, high-use public spaces). Ants were classified to the genus with morphological characteristics using a modified dichotomous key. Biodiversity was highest in Cedar City (high-use area; $H'=1.503$; $E=0.840$) and lowest in Three Peaks Recreation Area (moderate-use area; $H'=0.817$; $E=0.589$). DNA was amplified at 10 microsatellite loci for 125 ants. Population genetic parameters were compared among the three areas to investigate the effect of urbanization and land use type on ant genetic diversity. Gene diversities and allelic

richness were statistically different between locations for Dorymyrmex. Our results suggested that urbanization may not have a large effect on ant genetic diversity and that ant species biodiversity may increase in more urban areas.

Introduction

Human development and population growth have a profound impact on biodiversity. Biodiversity, commonly defined as the variety of life in a particular region (Swingland, 2001), is important to maintain ecosystem function and influences the type and amount of recreational activities in the area. Current levels of human population growth have substantially contributed to the loss of biodiversity (Crist et al., 2017) and have had multiple effects on ecosystems. Biodiversity loss can threaten human well-being (e.g., Diaz et al., 2006) and disrupt functioning of trophic groups and ecosystems (e.g., Cardinale et al., 2006). A major human-caused impact on biodiversity is urbanization.

Urbanization has drastic effects on the environment and can impact biodiversity both directly and indirectly (Elmqvist et al., 2016). Impacts of urbanization are seen worldwide and include land use and land cover change (Elmqvist et al., 2016; Liu et al., 2019); changes to biodiversity in a positive (e.g., McIntyre et al., 2001) or negative (e.g., Buczkowski & Richmond, 2012) way; changes in species distribution and richness (e.g., Oliveira et al., 2017; Tiede et al., 2017; Jamieson et al., 2019); habitat destruction, loss, and fragmentation (e.g., Liu et al., 2016); altering ecosystem services (e.g., Elmqvist et al., 2016); and changes to genetic diversity and gene flow (e.g., Miles et al., 2019; Duncan et al., 2020). Monitoring biodiversity changes can be challenging but successful when using indicator species.

Insects are often overlooked in conservation planning in spite of their contribution to their habitat (Ciach et al. 2017). Ants are hypothesized to be indicators of changes in abiotic conditions (e.g., Tiede et al., 2017) and can be indicators of crucial ecosystem processes (Tiede et al., 2017). They play an important role in the maintenance of ecosystems and the biodiversity within these places. They work physically and chemically in the underground world, changing the environment, plants, and microorganisms (Widhiono, 2017). Ants are hypothesized to be a representative group for studying the impacts of urbanization because of their important role in ecosystems (Rocha-Ortega & Castaño-Meneses, 2015).

One way to better understand these ecosystem engineers is through genetic analysis describing the diversity, evolution, and differences

between various ant species. Ant colonies with higher genetic diversity are more resistant to disease (Hughes and Boomsma, 2004) and respond better to fungal parasites (Ugelvig et al., 2010). Sabtu and Majid (2017) found that the genetic diversity of ant species is deeply affected by human activities, such as selection of hosts and application of insecticides.

There is a lack of published research on genetic diversity of ants in southern Utah. The purpose of this study was to have a better understanding of the population diversity of ant genera in southern Utah. Specifically, we addressed the following objectives: estimate (1) the biodiversity and (2) genetic diversity at microsatellite loci of ants in areas of southern Utah with varying levels of urbanization/human impact, and (3) compare population genetic measures among the different collection locations.

Methods

Sample collection

We collected ants from five locations (3 location types) in and around Cedar City in southern Utah with varying degrees of human impact in September and October 2017. The lowest human impact area was the Southern Utah University Mountain Center (MC) (low-use area; n=304; rural, low-use semi-private land) at approximately 2,400 meters (8,000 feet) in elevation. The moderate human impact area was Three Peaks (TP) Recreation Area (moderate-use area; n=242; rural, mixed-use public land); this location has both agricultural and recreation sites. The highest human impact area was Cedar City (CC) (high-use area; n=330; urban cluster, high-use public spaces) and was comprised of three sub-areas: Canyon Park (CP; n=101) housed a playground, picnic areas, and walking trails; Lake on the Hill (LH; n=149) housed a man-made lake, beach, and fishing and picnic areas; and downtown on Main Street (MS; n=80). Moderate- and high-use areas were at approximately 1,825 meters (6,000 feet) in elevation. We characterized ants at morphological characteristics to the genus level using a modified dichotomous key (Allred, 1982).

DNA extraction and amplification

We isolated DNA from randomly selected (whole) ants from each location (low use, n=73; moderate use, n=12; high use, n=40;) with Qiagen's DNeasy Blood and Tissue Kit with the standard protocol except DNA was eluted with 100 µl of buffer AE. Sample sizes represent

the number of ants per location with genotype data for at least 5 microsatellites. We amplified 10 microsatellite DNA loci using previously characterized primers (Butler et al., 2014) Ant10878, Ant11893, Ant12220, Ant2794, Ant9218, Ant3653, Ant5035, Ant1368, Ant8424, and Ant575 via polymerase chain reaction (PCR). We labeled the forward primer of each pair with a fluorescent dye (6-FAM, PET or NED; Thermo Fisher) to allow for the detection and sizing of DNA fragments. The DNA was amplified in 25- μ l reactions containing 12.5 μ l of GoTaq (Promega Corporation; 50 mM Tris-HCl (pH 9.0); 50 mM NaCl; 5 mM MgCl₂; 200 μ M each of dATP, dGTP, dCTP, dTTP; 10 μ g of activated calf thymus DNA; 0.1 mg/ml BSA in 50- μ l reaction volume), 2 μ l each of forward and reverse primer (10 μ M), 1 μ l of MgCl₂ (25 mM), 0 or 1.25 μ l of DMSO (Ant575 and Ant3653 only), approximately 50-ng template DNA, and purified water.

We amplified the microsatellite loci according to the following parameters: initial denaturation at 92°C for 10 minutes, 35 cycles of 92°C for 1 minute, 55°C (Ant3653 and Ant9218), 57°C (Ant12220 and Ant2794) or 56°C (remaining microsatellites) for 1 minute, and 72°C for 1 minute, and a final extension of 72°C for 10 minutes. We lowered the denaturing temperature from the standard 94°C because we conducted PCR at 1,825 meters (6,000 feet) in elevation. Amplified loci were separated on an Applied Biosystems (ABI) 3730xl Genetic Analyzer and sized with LIZ-500 size standard by Eton Bioscience Inc (www.etonbio.com). Genotypes were assigned using the default parameters on PeakScanner 2.0 (Thermo Fisher).

We amplified a fragment of the cytochrome c oxidase I (COI) subunit via PCR from low (n=23)-, moderate (n=32)-, and high (n=68)-use areas to barcode ants and verify morphological identification. The DNA was amplified in 25- μ l reactions containing a GE Illustra Ready-To-Go PCR Bead (2.5 units of PuReTaq DNA polymerase, 10 mM Tris-HCl (pH 9 at room temperature), 50 mM KCl, 1.5 mM MgCl₂, 200 μ M of each dNTP), stabilizers, and bovine serum albumin (BSA)), 0.5 μ l (10 pmol/ μ l) of LCOI490 (5'-GGTCAACAAATCATAAAGATATTGG-3'; Folmer et al. 1994), 0.5 μ l (10 pmol/ μ l) of HCO2198 ((5'-TAAACCTCAGGGTGACCAAAAAATCA-3'; Folmer et al. 1994)), approximately 50 ng of template DNA, and purified water. The COI fragment was amplified according to the following parameters: initial denaturation at 94°C for 3 minutes, 40 cycles of 94°C for 30 seconds, 50 °C for 30 seconds, 72°C for two minutes, and a final extension of 72°C for seven minutes. PCR products were purified using ExoSAP-IT product cleanup reagent. Purified PCR products were cycle-sequenced by ETON Bioscience.

Species and genetic diversity

We estimated species richness (S), Shannon Diversity Index (H'), and evenness (E) for CC, MC, and TP using all 876 ants collected in the project. These calculations were based on morphological identifications using the modified dichotomous key. COI sequences were trimmed and assembled in the DNASTAR program SeqMan Pro. Each cleaned sequence was uploaded into the Basic Local Alignment Search Tool (NCBI BLAST) to barcode our ant sequences. Barcode results were used to verify the accuracy of our dichotomous key. We used the global ant biodiversity informatics (GABI) database and antmaps.org (Guénard et al., 2017; Janicki et al., 2016) to determine whether there were native species for each ant genera identified through our BLAST search.

Data files were converted to formats supported by various genetic programs in CREATE 1.0 (Coombs et al. 2007). We determined the minimum number of microsatellites needed to identify individuals by estimating probability of identity (PI) in GenAlEx 6.503 (Peakall and Smouse, 2012). Allelic richness (A_R) and the number of private alleles (A_{Priv}) were estimated in HP-RARE (Kalinowski, 2005). We estimated the number of alleles, allele frequencies, and gene diversities (GD) in FSTAT 2.9.3.2 (Goudet, 1995). Allelic richness, number of private alleles, and gene diversities for collection locations within a genera were compared with an unpaired t-test. MICROCHECKER (Van Oosterhout et al., 2004) was used to determine whether null alleles were present in each genera and collection location. Homozygote excess for most allele size classes suggested the presence of null alleles.

We estimated expected versus observed number of heterozygotes, departure from Hardy-Weinberg Expectations (HWE) and linkage disequilibrium (LD) in GenePop on the Web (Raymond & Rousset, 1995; Rousset 2008). Departure from HWE was tested using an exact test (Guo & Thompson, 1992) and a chi-square fit test with a dememorization number of 10,000, and 1,000 batches of 10,000 iterations each. Linkage disequilibrium was tested for all pairs of loci used in each genera and each collection location by the log likelihood ratio statistic under the same parameters as HWE. All p-values were adjusted to allow for multiple comparisons. We estimated Weir and Cockerham's (1984) inbreeding coefficient (F_{IS}) for each genera and collection location in FSTAT 2.9.3.2 (Goudet, 1995).

The existence of population structure was estimated in a couple of ways. An analysis of molecular variance (AMOVA) was used to estimate the percentage of variance within and among populations with GenAlEx 6.503 (Peakall & Smouse, 2012) for each genus using 9,999 permutations. This was repeated for all ants collected where a genus was

considered a population. We estimated pairwise fixation index (F_{ST}) for each genera in FSTAT 2.9.3.2 (Goudet, 1995). All p-values were adjusted to allow for multiple comparisons. The number of migrants (N_m) per generation was estimated in GenePop on the Web (Raymond & Rousset, 1995; Rousset 2008) using the private allele method multilocus estimate of the effective number of migrants proposed by Slatkin (1985). All estimated values were estimated for a diploid population and were corrected for population size. The mean pairwise relatedness values of ant populations were estimated in GenALEX 6.503 (Peakall & Smouse, 2012) using Queller and Goodnight's (1989) relatedness coefficient and the null hypothesis that populations were not related. Relatedness coefficients were estimated with 9,999 permutations and 10,000 bootstraps.

Results

The ants collected ($n=876$) across the three locations (low-, moderate-, and high-use areas) represented six genera according to our modified dichotomous key. The most ants ($n=330$) were collected in the high-use area, whereas the fewest ants ($n=242$) were collected in the moderate-use area (Table 1).

Table 1. Genus counts of ants collected from several locations in southern Utah				
Genus	Low-use area	Moderate-use area	High-use area	Total
Dorymyrmex	0	69	55	124
Pogonomyrmex	0	160	150	310
Pheidole	42	0	43	85
Lasius	38	1	16	55
Formica	219	1	49	269
Camponotus	5	11	17	33
Total	304	242	330	876

The high-use area had the highest species richness ($S=6$), Shannon Diversity Index ($H'=1.503$), and evenness ($E=0.840$; Table 2). The low-use area had the lowest species richness ($S=4$; Table 2). The low- and moderate-use areas had approximately the same Shannon diversity index ($H'=0.8$) and evenness ($E=0.6$).

The majority (73.4%) of barcoded ants matched the morphological identifications made with the dichotomous key. Ants that did not match the morphological identification BLASTed to a genus missing from our modified dichotomous key. We identified eight genera of ants in our

Table 2. Biodiversity estimates of ants in several locations in southern Utah

Estimate	Low-use area	Moderate-use area	High-use area	Total
Species richness (S)	4	5	6	6
Shannon diversity index (H')	0.837	0.817	1.503	1.531
Evenness (E)	0.604	0.589	0.840	0.854

samples by barcoding at COI (Table 3). *Dorymyrmex* and *Pogonomyrmex* were not collected at MC. *Pheidole* was not collected at TP (Table 1). Two of the eight genera (*Cataglyphis* & *Tetramorium*) did not have species native to Utah. There are no records of the genera *Cataglyphis* in Utah; however, *Tetramorium* has been introduced to Utah (Janicki et al., 2016; Guénard et al., 2017). Average percent identities ranged from 97.04% (*Dorymyrmex*) to 99.3% (*Pogonomyrmex*) (Table 3). The average e-value for seven out of eight genera was 0, giving us confidence that we were BLASTing to the correct genera. The high level of accuracy for identifications made with our modified dichotomous key allowed us to continue using the dichotomous key identifications for the remaining data.

Table 3. BLAST results from COI barcoding of 69 ant specimens

Genera (BLAST results)	Sample size	% that match key	E-value	Percent identity	Native to So. Utah
Camponotus	1	0	5.00×10^{-21}	97.06	Yes
Cataglyphis*	1	0	0	98.1	No record
Dorymyrmex	21	100	0	97.04	Yes
Formica	20	66.7	0	99.04	Yes
Lasius	14	100	0	98.64	Yes
Liometopum*	9	0	0	99.00	Yes
Pogonomyrmex	54	100	0	99.3	Yes
Tetramorium*	3	0	0	98.5	No

The microsatellites chosen for this study had a PI of 3.3×10^{-7} for increasing locus combinations for 10 loci across all genera and collection locations. The expected number of individuals with the same multilocus genotypes for increasing locus combinations was 4.1×10^{-15} for the 10 chosen loci across all populations. These estimates indicated that there was a low probability that two ants chosen at random would have the same genotype. The presence of null alleles was tested when combining both collection locations for each genus. Null alleles may be present at all loci as suggested by the general excess of homozygotes for most allele

size classes for all genera except Ant2794, Ant12220, Ant575, Ant1368, Ant8424 in *Lasius* and *Pheidole*. There was no evidence of stutter peaks at any loci in any genus. Several locus pairs were in linkage disequilibrium (LD) within each genus.

We identified 267 alleles in the genotypes of the four genera collected in southern Utah across all 10 microsatellite loci. Allelic richness ranged between 2.18 and 4.67 and A_{Priv} ranged between 0.98 and 3.48 for all genera collected at all locations (Table 4). Average AR and A_{Priv} for *Dorymyrmex* were statistically different between the low-use (4.67 and 3.48, respectively) and moderate-use (2.18 and 0.98, respectively) areas (unpaired t-test, $p < 0.001$). These values were not statistically different for *Formica*, *Lasius*, or *Pheidole* collected in the low- and high-use areas. Allele frequencies for each locus ranged from 0 (in genera and/or locations where the allele was not genotyped) to 0.382. Gene diversities ranged between 0.36 and 0.79 and were statistically different for *Dorymyrmex* between the low-use (0.79) and moderate-use (0.36) areas (Table 4; unpaired t-test, $p < 0.01$). Gene diversities were not statistically different for *Formica*, *Lasius*, or *Pheidole* collected in low-use and high-use areas.

Table 4. Genetic variability estimates over all microsatellite loci for ant populations in southern Utah

Ant genus/Sample site	N	AR	A _{Priv}	GD
<i>Dorymyrmex</i> *				
Moderate-use area	12	2.18	0.98	0.36
High-use area	13	4.67	3.48	0.79
<i>Formica</i>				
Low-use area	28	3.50	2.46	0.69
High-use area	12	3.34	2.29	0.76
<i>Lasius</i>				
Low-use area	27	2.95	2.43	0.60
High-use area	8	2.96	2.44	0.64
<i>Pheidole</i>				
Low-use area	18	2.86	2.34	0.57
High-use area	7	3.07	2.54	0.69

N = sample size; AR = allelic richness; A_{Priv} = number of private alleles; GD = gene diversities.

*AR, A_{Priv}, and GD were statistically different when comparing sample sites (unpaired t-test, $p < 0.01$).

All genera ($p < 0.001$) in each location except *Dorymyrmex* in the moderate-use area were removed from Hardy-Weinberg expectations over all microsatellite loci tested (Table 5). *Dorymyrmex* was also

removed from Hardy-Weinberg if both locations (low- and moderate-use areas) were combined in a single population. *Dorymyrmex* (CC, $p < 0.001$), *Formica* (CC, $p < 0.001$; MC, $p < 0.05$), *Lasius* (CC, $p < 0.001$; MC, $p < 0.001$), and *Pheidole* (CC, $p < 0.001$; MC, $p < 0.001$) were not in Hardy-Weinberg over all loci (Table 5).

Table 5. Expected (H_E) and observed heterozygosities (H_O) and inbreeding coefficient (F_{IS}) for microsatellite loci in ant populations

	Dorymyrmex[^]					
	CC^{***}			TP⁺		
	H_E	H_O	F_{IS}	H_E	H_O	F_{IS}
Ant575	10.6	4 [^]	0.63	5.8	6	-0.03
Ant8424	11.7	7 [^]	0.41	8.1	6	0.27
Ant1368	5	1 [^]	0.82	0	0	n/a
Ant5035	4	0 [^]	1	3.1	0 [^]	1
Ant3653	5	1 [^]	0.82	1	1	0
Ant10878	9.5	3 [^]	0.69	3.2	3	0.06
Ant11893	8.3	2 [^]	0.77	0	0	n/a
Ant12220	3.5	0 [^]	1	0	0	n/a
Ant2794	11.1	8 [^]	0.29	4.6	3	0.38
Ant9218	9.8	3 [^]	0.70	4.5	5	-0.11
Over all loci			0.68			0.26
	Lasius					
	CC^{***}			MC^{*^}		
	H_E	H_O	F_{IS}	H_E	H_O	F_{IS}
Ant575	6.5	6	0.09	5.6	4 [^]	0.295
Ant8424	7.2	7	0.03	20.1	8 [^]	0.61
Ant1368	3.8	2	0.5	5.6	1 [^]	0.83
Ant5035	3.4	1 [^]	0.72	17	4 [^]	0.79
Ant3653	3.4	1 [^]	0.72	15.4	11 [^]	0.29
Ant10878	5.1	1 [^]	0.82	10.9	7 [^]	0.37
Ant11893	3.3	2 [^]	0.41	6.8	2 [^]	0.72
Ant12220	1	1	0	9.6	8 [^]	0.18
Ant2794	5.2	3	0.44	14.6	3 [^]	0.79
Ant9218	4	0 [^]	1	2.6	3 [^]	-0.2
Over all loci			0.49			0.46

^{*}low-use area

⁺moderate-use area

^{***}high-use area

[^]loci removed from Hardy-Weinberg expectations ($p < 0.05$). Only *Dorymyrmex* from TP was in HWE across all loci. Only *Dorymyrmex* (all loci, all populations) was in HWE.

Table 5 continued. Expected (H_E) and observed heterozygosities (H_O) and inbreeding coefficient (F_{IS}) for microsatellite loci in ant populations

	Pheidole					
	CC**^			MC*^		
	H_E	H_O	F_{IS}	H_E	H_O	F_{IS}
Ant575	5.1	4	0.226	5.4	1 [^]	0.82
Ant8424	4.7	4	0.16	7.6	3 [^]	0.61
Ant1368	3.2	2	0.41	16.2	13 [^]	0.20
Ant5035	5.2	2 [^]	0.36	8.4	2 [^]	0.77
Ant3653	5.9	3 [^]	0.51	8.4	2 [^]	0.77
Ant10878	4.5	1 [^]	0.79	4.1	1 [^]	0.78
Ant11893	4.8	1 [^]	0.81	4	0 [^]	1
Ant12220	1	1	0	5.2	3 [^]	0.45
Ant2794	3.7	2	0.49	4.7	3	0.38
Ant9218	4	0 [^]	1	0	0	n/a
Over all loci			0.56			0.61
	Formica					
	CC**^			MC*^		
	H_E	H_O	F_{IS}	H_E	H_O	F_{IS}
Ant575	7	2 [^]	0.72	10.5	4 [^]	0.62
Ant8424	6.9	3 [^]	0.58	7.3	7	0.05
Ant1368	4.1	2 [^]	0.54	24.9	13 [^]	0.48
Ant5035	5	2 [^]	0.62	22.3	16 [^]	0.29
Ant3653	5	2 [^]	0.62	23.8	10 [^]	0.58
Ant10878	9.7	6 [^]	0.39	12.0	7 [^]	0.43
Ant11893	2.6	1 [^]	0.67	18.8	9 [^]	0.53
Ant12220	4.81	2 [^]	0.59	5.6	4	0.29
Ant2794	5.48	1 [^]	0.83	17.1	4 [^]	0.77
Ant9218	2.2	1 [^]	0.60	13.5	7 [^]	0.49
Over all loci			0.61			0.49

*low-use area

+moderate-use area

**high-use area

[^]loci removed from Hardy-Weinberg expectations ($p < 0.05$). Only *Dorymyrmex* from TP was in HWE across all loci. Only *Dorymyrmex* (all loci, all populations) was in HWE.

Heterozygote deficiencies were present at the majority of loci for each genus in each location (Table 5). Loci with larger discrepancies between H_E and H_O (i.e., we observed much fewer than expected) had higher inbreeding coefficients than loci with small discrepancies (Table 5). For example, H_E and H_O differed by 0.5 at Ant575 in *Lasius* (CC)

and had an FIS of 0.09, whereas the FIS was 0.82 when these values differed by 4.1 in the same population. This trend was consistent across all loci in all genera and localities. The inbreeding coefficient ranged from 0.26 (*Dorymyrmex* in the moderate-use area) to 0.68 (*Dorymyrmex* in the low-use area) across all loci.

Under analysis of molecular variance, we expect to see the highest proportions of variance within samples in a panmictic population (Mengoni and Bezzicalupo, 2002). Higher variances among individuals supported population structure. We estimated that 19% of molecular variance occurred among populations, while 56% of molecular variance occurred among individuals when comparing molecular variance within genera (Table 6). Most variance was observed among individuals for each genus (40-61%). Variance within individuals ranged from 22 to 31%.

Table 6. Analysis of molecular variance (AMOVA) of ants collected in southern Utah supported the presence of population structure in ant populations

Population	Within individuals	Among individuals	Among populations
Southern Utah	25%	56%	19%
<i>Dorymyrmex</i>	27%	61%	12%
<i>Formica</i>	31%	51%	18%
<i>Lasius</i>	24%	40%	36%
<i>Pheidole</i>	22%	46%	32%

Population differentiation was estimated among collection sites for each genus using F_{ST} (Table 7). Population differentiation ranged from 0.1326 (*Formica*) to 0.3501 (*Lasius*). Only *Dorymyrmex* populations were significantly differentiated from each other. Genera with lower F_{ST} values were estimated to have a higher number of migrants between them for each generation (Table 7). The number of migrants was estimated

Table 7. Genetic differentiation (F_{ST}) among sample sites for each genus and estimated number of migrants per generation (N_m) after correction for size

Genus	F_{ST}	N_m
<i>Dorymyrmex</i>	0.1946*	0.54
<i>Formica</i>	0.1326	0.59
<i>Lasius</i>	0.3501	0.22
<i>Pheidole</i>	0.3321	0.40

*Population pairs were significantly differentiated from each other with an adjusted nominal level (5%) for multiple comparisons ($p=0.05$)

among collection locations for each genus and ranged between 0.22 (*Lasius*) and 0.59 (*Formica*).

We estimated pairwise relatedness (Figure 1) values among different ant groups to test the hypothesis that ants were collected from a single colony under the null hypothesis that ants were not related. Relatedness values were estimated for each genus regardless of collection location. Relatedness values ranged from 0.071 (*Lasius* collected in the low-use area, $p < 0.001$) to 0.632 (*Formica* collected in the high-use area, $p < 0.001$). Worker ants were more related than expected in each genus and ranged from 0.226 (*Pheidole*, $p < 0.001$) to 0.246 (*Dorymyrmex*, $p < 0.001$). Relatedness was estimated in each collected location by combining all ants collected into a single population. When all ants from all collection sites were combined into a single population, the worker ants were not more related to each other than expected (SU, $r = 0.015$, $p = 0.968$).

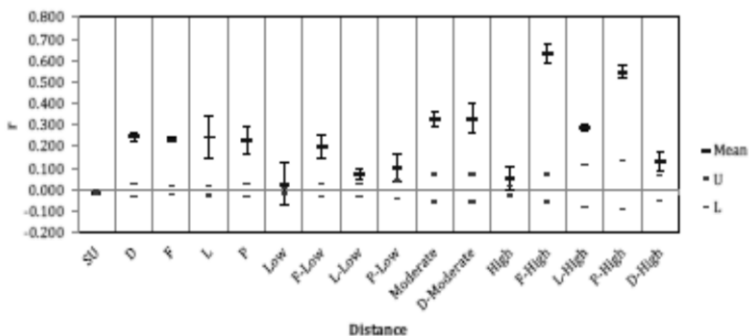


Figure 1. Pairwise relatedness of ant populations in southern Utah (SU=Southern Utah; low=Mountain Center; moderate=Three Peaks; high=Cedar City; D=*Dorymyrmex*; F=*Formica*; L=*Lasius*; P=*Pheidole*). Populations SU ($r = -0.015$, $p = 0.968$), low ($r = 0.024$, $p = 0.01$), moderate ($r = 0.330$, $p < 0.001$), and high ($r = 0.051$, $p < 0.001$) represent the relatedness of all ants, regardless of genera, collected in a location. Populations D ($r = 0.246$, $p < 0.001$), F ($r = 0.231$, $p < 0.001$), L ($r = 0.244$, $p < 0.001$), and P ($r = 0.226$, $p < 0.001$) represent all ants, regardless of location, collected from a specific genera. Populations F-Low ($r = 0.2$, $p < 0.001$), L-Low ($r = 0.071$, $p < 0.001$), P-Low ($r = 0.099$, $p = 0.001$), D-Moderate ($r = 0.330$, $p < 0.001$), F-High ($r = 0.632$, $p < 0.001$), L-High ($r = 0.287$, $p < 0.001$), P-High ($r = 0.546$, $p < 0.001$), and D-High ($r = 0.129$, $p = 0.003$) represent a specific genera (D, F, L, or P) collected in a specific location (low, moderate, high). The upper (U) and lower (L) limits represent the 95% confidence intervals for the null hypothesis that the populations are not related. Worker ants in most populations are more related to each other than expected. Worker ants in southern Utah were not more related to each other than expected when treated as a single population (negative r values are possible if two compared groups differ from the population mean in opposite directions (Queller and Goodnight, 1989)).

Discussion

Understanding how anthropogenic factors influence species and genetic diversity is important to help mitigate changes to the local environment (Duncan et al., 2020). Changes in local environments can threaten human well-being (e.g., Diaz et al., 2006) and the local ecosystem (e.g., Cardinale et al., 2006; Hooper et al., 2005). Finding an appropriate indicator species can be challenging. However, ant populations are providing insights into regional biodiversity differences (Economo et al., 2018) and can be used as indicator species because of their roles in various ecosystems (Rocha-Ortega and Castaño-Meneses, 2015). We evaluated population diversity of ant genera in southern Utah to investigate the effect of urbanization and land use type on species and genetic diversity. Our preliminary results suggested that urbanization may not have a large effect on genetic diversity and that ant species biodiversity may increase in more urban areas.

Cedar City, Utah, is a small, rural city of approximately 33,000 individuals surrounded by natural parks and public land. On the basis of its size, we would not expect to see the drastic impacts on biodiversity that you might expect in larger, nearby cities (i.e., Las Vegas, Nevada). Additionally, previous studies have described conflicting conclusions on the impact of urbanization on ant biodiversity. Some suggest that urbanization has a positive influence (Rocha-Ortega and Castano-Meñses, 2015; Perez and Diamond, 2019), whereas Oliveria et al. (2017) found a positive correlation between richness and stress levels in urban areas. Our biodiversity estimates suggested that Cedar City (high-use area) has the most diverse ant community of our study sites (Table 2). It is important to note that species assemblages varied among the different sites in our study (Table 1). For example, *Dorymyrmex* and *Pogonomyrmex* were not found in the low-use area. These species are typically found in more arid environments, and the low-use area did not provide the proper habitat for these species (MacKay, 1981). Additionally, *Pogonomyrmex* is found at lower elevations than the low-use area (SUU Mountain Center). Nonnative genera (*Tetramorium* and *Cataglyphis*) were only collected in the high-use area.

The intermediate disturbance hypothesis suggests that biodiversity is expected to be maximized at intermediate levels of environmental disturbance (Dial and Roughgarden, 1998). Ant communities have been shown to be robust under limited land use and slow rates of urbanization until land cover changes exceed 30–40%, with biodiversity declining past this level of urbanization (Sanford et al., 2009). We may be observing larger ant biodiversity in our study sites because of the type of land use and urbanization in our study area. Further quantification of ant

population sizes and species assemblages should be conducted in these areas to understand the impact that urbanization in rural areas of southern Utah have on ant biodiversity. Buczkowski and Richmond (2012) suggested that ant diversity is positively correlated with factors that promote ecological recovery. The emphasis that Cedar City (high-use area) places on outdoor recreation and conservation may be positively impacting ant biodiversity.

The 10 microsatellites chosen in this study provided data on the genetic structure of ant genera *Dorymyrmex*, *Formica*, *Lasius*, and *Pheidole* populations in southern Utah. We observed a large genetic diversity for all genera due to a large number of observed alleles at each locus, which is expected for microsatellite loci (Table 4). However, loci were removed from Hardy-Weinberg expectations. In each case, we observed fewer heterozygotes than expected (Table 5). In our study, we estimated positive FIS for each genera/location, and both HO and HE had large differences between them. Previous studies in mollusks (Min et al., 2015) suggested that this is due to inbreeding. Genetic variability estimates only differed between areas of varying human impact for the genera *Dorymyrmex* (Table 4). Allelic richness, number of private alleles, and genetic diversity were significantly higher in the high-use area (urban cluster, high-use public spaces) than the moderate-use area (rural, mixed use public land). These measures did not differ for the other genera (*Formica*, *Lasius*, or *Pheidole*). Khimoun et al. (2020) concluded that *Temnothorax nylander* were not genetically isolated despite inhabiting fragmented, urban habitats. Although ant reproductive strategies are diverse, queens of many ant species disperse prior to mating (Heinze and Tsuji, 1995). This reproductive strategy could reduce genetic differentiation between colonies across urbanized landscapes. Some ant colonies, such as the invasive Argentine ant (*Linepithema humile*), spread colonies up to 150 m/year (Suarez et al., 2001). Because of our small sample sizes and high inbreeding statistics (Table 5), it is possible that all ants of a single genus collected in a single site were members of the same colony. High pairwise relatedness values (Figure 1) suggested that worker ants were more related to each other than expected at random, further supporting that ants were collected from a single colony. Ants are haplodiploid hymenopterans and thus tend to have high relatedness values among sisters, or worker ants (Rautiala et al., 2019). Hymenopterans, such as bees (Pinheiro dos Reis et al., 2011) and the *Formica* genus (Boomsma et al., 1999), have an average relatedness of 0.75 with a single mated queen. Relatedness decreases with multiple mates. Our high relatedness values (Figure 1) across collection sites and estimated number of migrants (Table 7) suggest dispersal between sites and that the colonies were related to each other.

The lack of statistically significant genetic differentiation (F_{ST}) among collection sites for most genera in this study also supported that there is gene flow between the different sites (Table 7). Under analysis of molecular variance, we would expect to see most of the variation arise from within samples in a panmictic population (Mengoni and Bazzicalupo, 2002). Because most of our variation was estimated among individuals, there was evidence of population structure (Table 6). Additionally, our research supported previous claims that ants may be resilient to anthropogenic change such as urbanization (Perez and Diamond, 2019). Understanding the effect of urbanization on genetic and species diversity is a crucial step to maintaining biodiversity in a changing landscape. It is important to continue genotyping ants in these localities to have a better understanding of the impact of urbanization and land use on ant populations in southern Utah.

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Work–Life Balance Characteristics as Predictors of Job Satisfaction Across Generations

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Abstract

There is one commonality across every generational cohort in the workforce: all employees seek satisfaction in their work. Job satisfaction impacts many organizational and worker outcomes, such as employee retention, and also acts as a moderator to work anxiety and stress. Although previous studies have explored job satisfaction determinants, few have examined generational or global differences. This paper compares predictors of job satisfaction across four generational cohorts and 37 countries using data from the International Social Survey Program. Findings indicate statistically significant differences in work–life balance and job satisfaction across generational cohorts. More specifically, job autonomy, interesting work, job security, employee pay, promotional opportunities, and having a job useful to society were significant indicators of job satisfaction for Baby Boomers, Generation X, and Millennials. We also found that work stress had a significant negative impact on job satisfaction across generational cohorts.

Introduction

Job satisfaction continues to generate interest across academic disciplines, from psychology (Argyle, 1989) and sociology (Kalleberg & Loscocco, 1983; Hodson, 2002), to economics (Freeman, 1978; Hamermesh, 2001), management sciences (Hunt & Saul, 1975), and public administration (Wright & Kim, 2004; Jung et al., 2007). The interest in job satisfaction, as much for researchers as for practitioners, is due to several reasons. Satisfied workers are more productive (Appelbaum & Kamal, 2000), deliver higher quality of work (Tietjen & Myers, 1998), and improve a firm's competitiveness and success (Garrido et al., 2005). Conversely, unsatisfied workers are more frequently late for work, absent from work, and motivated to leave the firm (Blau, 1994; Lee, 1998).

This research utilizes data from the International Social Survey Program (Work Orientations IV: 2015—Survey questions on job characteristics and job quality) to examine the role of work–life balance factors and generational differences in predicting job satisfaction.

Literature Review

Brief overview of work–life-balance and job satisfaction

A contributing factor to job satisfaction is work–life balance. Work–life balance describes the interaction and impact of work and family responsibilities with satisfaction in either or both areas as a “core consequence” (Brough et al., 2014, p. 2725). However, outcomes can be either positive or negative depending on whether balance or imbalance is present. Outcomes encompass work-, non-work-, and stress-related variables, such as job satisfaction, turnover, absenteeism, and performance; marital, family, and life satisfaction; and stress, burnout, and substance abuse across the three categories (Allen et al., 2000). Work–life imbalance is associated with high work demands, turnover intentions, psychological strain, and imbalance with family and job satisfaction (Brough et al., 2014).

Brief overview of age and generational differences in job satisfaction

Overall, there is considerable evidence that job satisfaction increases with age (Clark et al., 1996; Crites, 1969; Durst & DeSantis, 1997; Eichar et al., 1991; Hunter, 2007; Josiam et al., 2009; Katz, 2008), with some evidence that the pattern follows a U-shaped curve (Clark et

al., 1996; Durst & DeSantis, 1997, Eichar et al., 1991; Hunter, 2007). Other findings indicate a decrease in satisfaction with age (Bern et al., 1998; Hickson & Oshagbemi, 1999; Jung et al., 2007; Luthans & Thomas, 1989; Oshagbemi & Hickson, 2003). Finally, some studies show no relationship between age and job satisfaction (Ghazzawi, 2011; Jepsen & Sheu, 2003; Sarker et al., 2003; Sharma & Jyoti, 2005, 2009; Tu et al. 2005).

Generation theory posits that individuals growing up in the same period experience similar socioeconomic conditions and world events and thus share similar attitudes and behaviors, which extend to the workplace. However, research on generations indicates that job satisfaction across generations does not vary to the extent one might expect. In a five-generation study (G.I.s, Silent Generation, Baby Boomer, Generation X, and Millennial), millennials reported somewhat more overall satisfaction with their companies and jobs as well as with job security, recognition, and career development and advancement, but similar levels of satisfaction with pay, benefits, work itself, and turnover intentions compared with Boomers and Gen Xers (Kowske et al., 2010). However, effect sizes were small.

Overview of work–life balance and job satisfaction across generations

In what follows, we provide brief reviews of four key generational cohorts, including the Silent Generation, Baby Boomers, Generation X, and Millennials.

Silent Generation

The Silent Generation based their sense of worth on work ethic for many reasons. Their births between 1925 and 1945 placed them into an era of contention. They witnessed the Great Depression, the aftermath of the First World War, the uncertainty of a Second World War and its aftermath, and an early adulthood fearing the spread of communism in the Cold War (Abramson, 2018). Strict rules such as a “children are seen and not heard” mentality in their youth created a generation that valued keeping traditions (Abramson, 2018; Freides, 2012). The forced struggle of major world events in their time bonded this generation together, causing them to collectively put their heads down and work tirelessly to survive, earning them the title of “Silent Generation” (Abramson, 2018; Freides, 2012). Hard work was not in vain for this generation, as they entered the labor market in a booming economy; by the time this generation reached maturity, it had amassed more wealth than the generations before them (Howe, 2014). This gave them another name,

The Lucky Few (Howe, 2014). This was because this generation contained one-third the members as the Baby Boomers and they lived in fortunate times of economic expansion (Duffin, 2017).

Baby Boomers

The assassinations of John F. Kennedy, Robert F. Kennedy, and Martin Luther King Jr., the Cold War, the civil rights and women's movements, the Vietnam War, and drug experimentations defined events for this generation and helped to shape the way Baby Boomers view the world (Beutell and Wittig-Berman, 2008; Wiedmer, 2015). Baby Boomers, born between 1946 and 1964, value a combination of family and work (Beutell and Wittig-Berman, 2008). This generation has an increased ability compared with past generations to manage work–family conflict because of corporate programs (Wiedmer, 2015). Boomers also have many things to balance, from jobs to grandchildren and aging parents, making a strong work–life balance important (Fishman, 2016). Mental health and job pressure are the two biggest factors for work–family conflict in this generation (Beutell and Wittig-Berman, 2008). Baby Boomers tend to be results oriented and monetarily driven and stay with organizations over the long term (Lampton, 2011; Wallace, 2006). Because of this, Boomers often prioritized work over family in the beginning of their careers to solidify their place in their organization. (Smola and Sutton, 2002; Twenge et al., 2010; Wiedmer, 2015). Boomers also have a reputation for being ultra-materialistic (Twenge et al., 2010). Boomers have lower leisure values than other generations, higher extrinsic rewards, and higher social reward values (Cennamo and Gardner, 2008; Twenge et al., 2010). This makes them value work and compensation and seek after status with their success. As Boomers have aged, concern over retirement, longer lives, and rising costs of healthcare have pushed many into an “encore career,” preventing high-paying jobs from passing to younger generations (Freedman, 2006).

Generation X

Generation X, born between 1965 and 1980, appears to be rather insular and to have a lack of affinity for working between generational cohorts (David et al., 2017). Researchers have claimed that Generation X is the “resilient generation, one whose members learned to rely on themselves” (David, 2017, p.77). Generation X's lack of affinity for working with Baby Boomers and Millennials could be caused by Generation X having fewer members when compared with other cohorts—with just 65 million Gen Xers, versus 77 million Baby Boomers and 85 million Millennials (Newman, 2019). Having fewer

members than Millennials and Baby boomers has led Generation X to believe that Millennials are getting more favorable treatment and promotions because of the large number of Millennials in the workplace (Newman, 2019). Studies also show that Baby Boomers reportedly had higher job satisfaction and organizational commitment scores than Generation X (Benson and Brown, 2011).

Research also shows a correlation between job satisfaction and the ability to utilize new technology in the workplace (Elias et al., 2012). This could potentially create a struggle for Generation X, who reportedly had less motivation to learn new technology (Elias et al., 2012; Townsend, 2000). Finally, in relation to general prosperity in the U.S., Generation X is the first generation to have a majority of workers that will not be wealthier than their parents, with about two-thirds of the generation being less wealthy than their parents at the same age, which shows the income differences between Baby Boomers and Generation X (Scotti, 2014).

Millennials

In a rapidly changing workplace environment, Millennials (born 1981–1996) tend to not so easily accept the “status quo,” and when compared with other generations, have moved from obedience to questioning (Singh et al., 2012); Millennials also “assess work in terms of its significance in human life and human nature” (Singh et al., 2012). Part of the reason Millennials differ from other generations in voicing their concerns and questioning authority figures in the workplace derives from their Baby Boomer parents; parents of Millennials tended to give their children “a voice,” and they have encouraged Millennials to make decisions and think critically. Some additional issues and stereotypes attached to Millennials depict them as lacking effort, lacking professionalism, being disrespectful and disloyal (Thompson and Thompson, 2017). Additionally, Baby Boomers and Generation X perceive that “Millennials do not do what it takes to get the job done as much as other generations” (Weeks et al., 2017). However, research on communication with Millennials shows that they possess more positive qualities, like the ability to work in a group, motivation to influence their organizations, and having open and frequent communication with their supervisors (Myers, 2010). Another positive attribute is that Baby Boomers and Generation X both perceive Millennials to be more competent at using technology in the workplace (Weeks et al., 2017).

Theoretical Framework and Model

Over the previous half century, thousands of research studies have examined job satisfaction as an outcome variable, as well as its determinants. As seen in Figure 1 below, we utilize the following job satisfaction theoretical and empirical model, which synthesizes much of the literature to date on job satisfaction and its determinants. As has been done in many previous research studies, we include work–life balance, work relations, and other important intrinsic and extrinsic rewards variables, as well as organizational and job characteristics control variables. Additionally, we have included an occupation variable to explore differences in the model based on the type of hospitality management job the respondent currently holds.

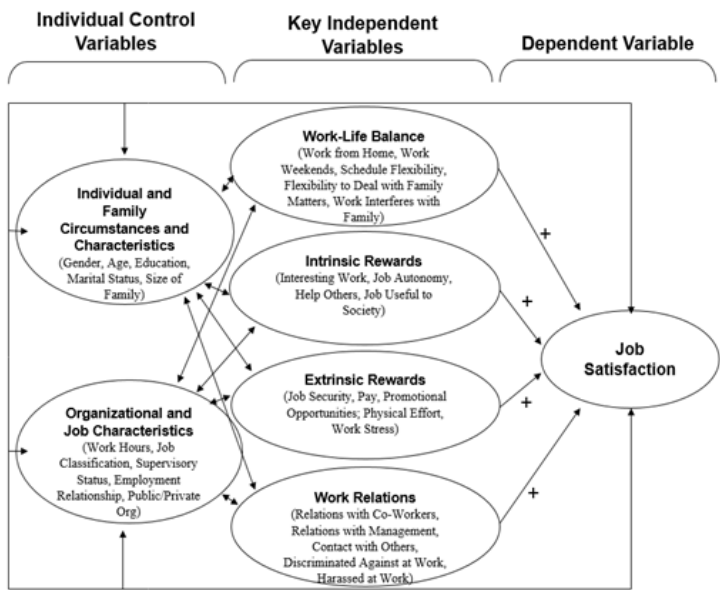


Figure 1: Factors influencing work characteristics and job satisfaction

Research Design and Methodology

This study examines differences in the saliency and impact of work–life balance variables on job satisfaction across generational cohorts. Specific hypotheses are as follows:

H1: There are statistically significant differences in mean scores for job satisfaction and work–life balance variables across generational cohorts.

Description of the data

Following the approach of Andrade and Westover (2018a; 2018b; see also Andrade et al., 2019a; Andrade et al., 2019b), this research utilizes cross-national comparative data from the International Social Survey Program (ISSP) 2015 Work Orientations Module IV, which uses multistage stratified probability samples in 37 individual countries around the globe. All ISSP Work Orientation variables are single-item indicators, and the unit of analysis is individuals across each participating country. We performed a variety of descriptive, multivariate, and regression analyses on work–life balance indicators of job satisfaction across four generational cohorts: The Silent Generation, Baby Boomers, Generation X, and Millennials.

Operationalization of variables

We use Andrade and Westover’s (2018a; 2018b; see also Andrade et al., 2019a; Andrade et al., 2019b) job satisfaction model (building on Handel’s (2005) and Kalleberg’s (1977) job satisfaction model, for comparing global differences in job satisfaction and its determinants across job types (see also Spector 1997). Following the approach of Andrade and Westover’s (2018a; 2018b; see also Andrade et al., 2019a; Andrade et al., 2019b), we focused on a range of intrinsic, extrinsic, workplace relationships, and work–life balance variables (in addition to a range of organization and individual control variables; Table 1 below).

Control variables

As indicated by Westover (2012b, 17) “the literature has identified many important individual control variables, due to limitations in data availability, control variables used for the quantitative piece of this study will be limited to the following individual characteristics: (1) Sex, (2) Age, (3) Years of Education, (4) Marital Status, and (5) Size of Family.” Additionally, control variables used in this analysis include: (1) Work Hours, (2) Supervisory Status, (3) Employment Relationship, and (4) Public/Private Organization.

Table 1: Key Work Characteristics Related to Job Satisfaction	
Dependent variable	Description
Job satisfaction	“How satisfied are you in your main job?”
Intrinsic rewards	
Interesting job	“My job is interesting.”
Job autonomy	“I can work independently.”
Help others	“In my job I can help other people.”
Job useful to society	“My job is useful to society.”
Extrinsic rewards	
Pay	“My income is high.”
Job security	“My job is secure.”
Promotional opportunities	“My opportunities for advancement are high.”
Physical effort	“How often do you have to do hard physical work?”
Work stress	“How often do you find your work stressful?”
Work relations	
Management–employee relations	“In general, how would you describe relations at your workplace between management and employees?”
Coworker relations	“In general, how would you describe relations at your workplace between workmates/colleagues?”
Contact with others	“In my job, I have personal contact with others.”
Discriminated against at work	“Over the past 5 years, have you been discriminated against with regard to work, for instance, when applying for a job, or when being considered for a pay increase or promotion?”
Harassed at work	“Over the past 5 years, have you been harassed by your supervisors or coworkers at your job, for example, have you experienced any bullying, physical, or psychological abuse?”

Table 1 continued	
Work–life balance	
Work from home	“How often do you work at home during your normal work hours?”
Work weekends	“How often does your job involve working weekends?”
Schedule flexibility	“Which of the following best describes how your working hours are decided (times you start and finish your work)?”
Flexibility to deal with family matters	“How difficult would it be for you to take an hour or two off during work hours, to take care of personal or family matters?”
Work interferes with family	“How often do you feel that the demands of your job interfere with your family?”

Statistical methodology

We analyzed ISSP Work Orientations data from individual respondents across 37 counties, first running appropriate bivariate and multivariate analyses on all key study variables to make comparisons. Next, we ran an Ordinary Least Squares Regression (OLS) model for all main study variables and respondents in all countries, followed by an OLS regression model specific for all jobs in all countries lumped together. Finally, we ran OLS regression models by each of the four generational cohorts.

Results

Descriptive statistics

Table 2 below shows the mean scores of main study variables by age cohort. We see that generational cohorts with the highest scores in the following categories also recorded a higher mean job satisfaction score: Interesting Work, Job Autonomy, Help Others, and Job Useful to Society. Generations who valued higher pay, such as Millennials and Generation X, have lower job satisfaction scores. The Work Stress category contains the greatest variance at .72 between generational cohorts, with the Silent Generation scoring the lowest at 2.53 and Generation X scoring the highest at 3.25. The Discriminated Against at Work category appears to be on a slight decline between generational cohorts. Harassed at Work follows a similar decline except for a slight

incline by .2 from Generation X to Millennials. It is worth noting that the sample size for the Silent Generation is only 97 respondents, whereas the samples for the other three generational cohorts were in the thousands.

Table 2: Mean Scores of Main Study Variables by Age Cohort, 2015*					
Variable	SG	BB	GX	M	All
Job satisfaction	5.69	5.39	5.28	5.26	5.32
Interesting work	3.84	3.86	3.82	3.78	3.83
Job autonomy	4.07	3.88	3.81	3.71	3.82
Help others	4.02	3.91	3.88	3.83	3.88
Job useful to society	4.06	4.01	3.95	3.86	3.94
Job security	3.89	3.77	3.75	3.81	3.77
Pay	2.63	2.73	2.83	2.87	2.82
Promotional opportunities	2.51	2.52	2.79	3.03	2.78
Physical effort	2.53	2.64	2.70	2.81	2.71
Work stress	2.53	3.07	3.25	3.16	3.17
Relations with coworkers	4.30	4.21	4.16	4.22	4.19
Relations with management	4.20	3.93	3.89	3.93	3.91
Contact with others	4.07	4.23	4.23	4.20	4.23
Discriminated against at work	1.89	1.83	1.81	1.81	1.82
Harassed at work	1.91	1.86	1.85	1.87	1.86
Work from home	3.30	3.93	3.95	4.17	4.00
Work weekends	3.10	3.21	3.14	3.05	3.14
Schedule flexibility	2.10	1.71	1.62	1.52	1.63
Flexibility to deal with family matters	1.81	2.15	2.26	2.36	2.25
Work interferes with family	4.00	3.79	3.55	3.71	3.66
Mean age	77.59	58.73	42.93	27.23	43.37
Mean years of education	11.07	12.73	13.40	13.76	13.34
Mean size of family	2.51	2.71	3.48	3.41	3.23
Mean number of work hours	32.35	39.85	41.87	41.10	40.96

* Job Satisfaction on 1–7 scale, all other variables on a 1–5 scale.

SG = Silent generation; BB = Baby boomers; GX = Generation X; M = Millennials.

Figure 2 shows that the younger the age cohort, the lower the mean job satisfaction score. The mean job satisfaction score for all generations is ~5.32. The highest mean job satisfaction score by age cohort is the Silent Generation, with a score of 5.69. The lowest job satisfaction score by age cohort is the Millennials, at 5.26.

Figure 3 shows that as employees have more opportunities to work from home during usual work hours, their job satisfaction increases. The Silent Generation trends differently, however. Satisfaction for all

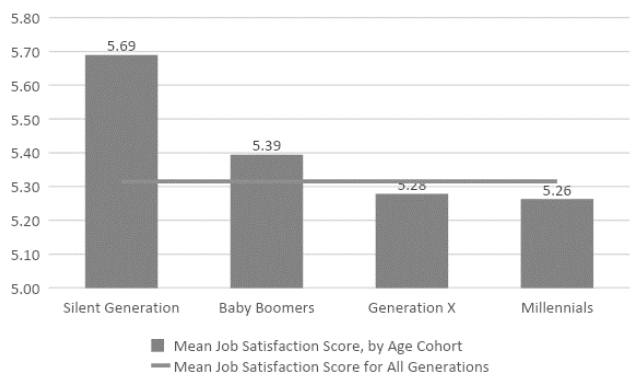


Figure 2: Mean job satisfaction score, by age cohort.

generations (except the Silent Generation) ranged from 5.4 to 5.5 when they had the ability to always work from home. As employees’ ability to work from home decreased, job satisfaction trended downwards to a range of 5.42 to 5.17.

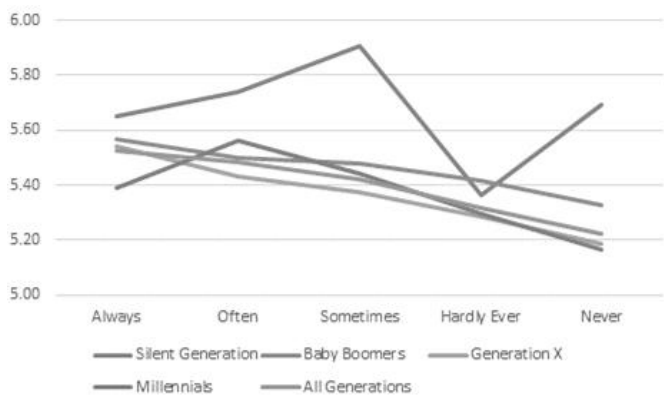


Figure 3: Job satisfaction mean score by work from home—how often do you work from home during usual working hours?

Figure 4 shows that as employees work on weekends less frequently, their work satisfaction grows. On average, all generations

increase by .2 (5.2–5.4) points from working every weekend to never having to work on weekends.

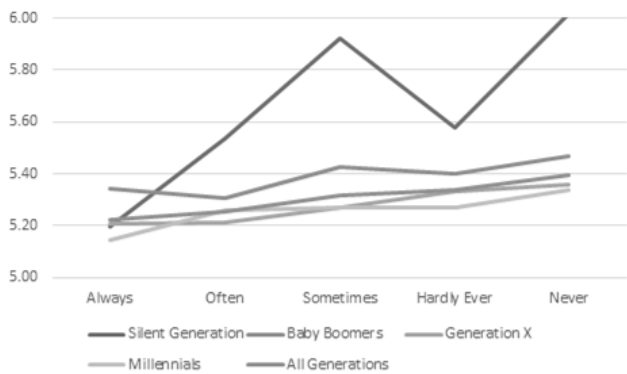


Figure 4: Job satisfaction mean score by work weekends—how often does your job involve working on weekends?

Figure 5 shows that the more flexibility employees have with their schedules, the higher their job satisfaction, with the exception of the Silent Generation. The Silent Generation had a slightly higher job satisfaction score of 5.75 when the starting and finishing times were decided by the employer and the employee could not change them. The freedom to decide one’s own start and finish work times for the Silent Generation ended with a slightly lower mean score of around 5.65. The Silent Generation still had an overall higher job satisfaction mean score among all the generations, despite this result.

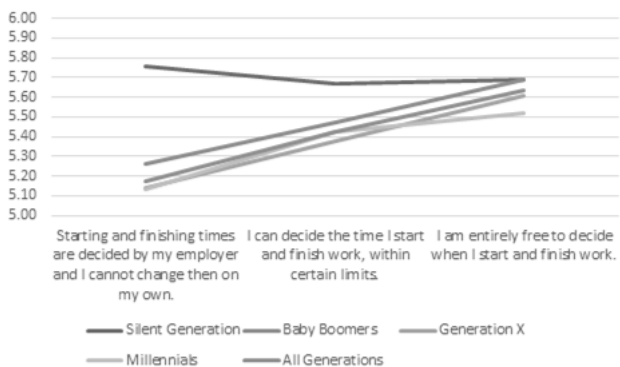


Figure 5: Job satisfaction mean score by schedule flexibility—which of the following statements best describes how your working hours are decided?

Figure 6 shows that the more difficult it is for an employee to take an hour or two off during work hours to take care of personal or family matters, the lower the job satisfaction mean score. The average score when it was very difficult to take that time was 5.00 and the average score when it was not difficult at all was around 5.65. However, the Silent Generation did not follow the same trend as the rest of the generations. The Silent Generation was slightly less satisfied when it was not too difficult to take time off than when it was very difficult or somewhat difficult. The mean job satisfaction score for the Silent Generation in comparison with the other generations was higher in each category.

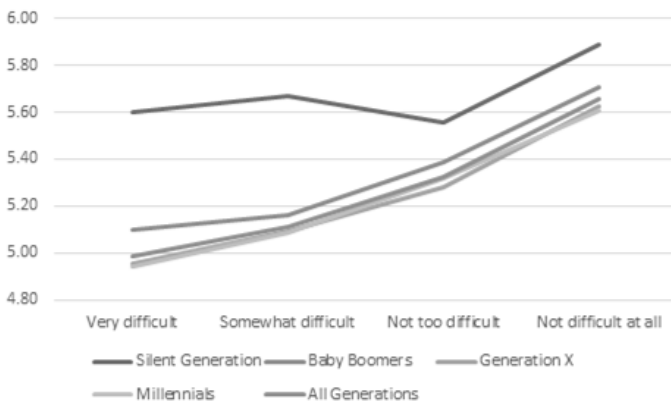


Figure 6: Job satisfaction mean score by flexibility to deal with family matters—how difficult would it be for you to take an hour or two off during working hours to take care of personal or family matters?

Figure 7 demonstrates that, with the exception of the Silent Generation, there is a clear, linear correlation between the extent to which one's work interferes with family life and the satisfaction one feels towards work. Workers who always feel that the demands of their job interfere with their family life have the lowest job satisfaction, whereas workers who feel that the demands of their job never interfere with family life have the highest job satisfaction.

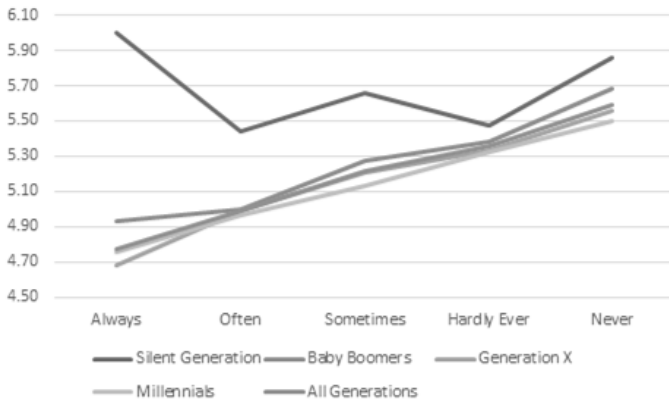


Figure 7: Job satisfaction mean score by work interferes with family—how often do you feel that the demands of your job interfere with your family life?

Regression results

Following the approach of Andrade and Westover (2018a, 2018b, see also Andrade et al. 2019a; Andrade et al. 2019b), we built our OLS models:

- Model 1—all control variables
- Model 2—all intrinsic rewards variables
- Model 3—all extrinsic rewards variables
- Model 4—all work relations variables
- Model 5—all work–life balance variables
- Model 6—combined model of all key independent variables (intrinsic, extrinsic, work relations, and work–life balance) and the control variables on job satisfaction.

Nearly all variables were statistically significant ($p < .001$) when the individual control model and models 2–5 were run, with the exception of size of family and working weekends. However, in the combined model, working weekends was significant, whereas physical effort, contact with others, working from home, and several individual control variables were not significant. Additionally, there were variations in adjusted r-squared values for the individual controls model and models 2–5 (with the separate intrinsic and extrinsic rewards models holding the strongest predictability), with the combined model (including all intrinsic, extrinsic, work relations, work–life balance, and control variables) accounting for nearly 43% of the variation in job satisfaction (adjusted r-squared = 0.428).

The above-specified combined model was then run for all workers across all job types and for each age cohort. As can be seen in Table 3, there is a great deal of variation among age cohorts in standardized beta coefficient statistical significance for each of the intrinsic, extrinsic, work relations, and work–life balance job characteristics and control variables in predicting job satisfaction. Of particular note is that many of the statistically significant independent variables in the model for all workers of any age cohort were not significant in each model for individual age cohorts. Additionally, as can be seen in Figure 8 below, the model fit was better for older age cohorts.

Table 3: OLS regression results of job satisfaction and main study variables by age cohort, 2015

Variable	SG	BB	GX	M	All
Interesting work	0.191	0.311***	0.275***	0.283***	0.287***
Job autonomy	-0.081	0.016	0.024**	0.019	0.019**
Help others	0.014	0.004	0.018	0.036**	0.022**
Job useful to society	-0.070	0.050***	0.030**	0.038**	0.037***
Job security	0.148	0.059***	0.055***	0.074***	0.063***
Pay	-0.009	0.077***	0.098***	0.119***	0.098***
Promotional opportunities	0.185	0.041**	0.062***	0.057***	0.057***
Physical effort	0.059	0.009	0.008	-0.004	0.005
Work stress	-0.232**	-0.090***	-0.086***	-0.072***	-0.086***
Relations with coworkers	0.236*	0.068***	0.094***	0.082***	0.085***
Relations with management	0.020	0.247***	0.228***	0.208***	0.225***
Contact with others	0.101	0.023	0.020*	-0.012	0.010
Discriminated against at work	0.039	0.082***	0.026**	0.026*	0.037***
Harassed at work	-0.021	0.015	0.023**	0.014	0.019***
Work from home	0.118	0.036**	-0.003	-0.010	0.005
Work weekends	-0.031	-0.019	-0.013	-0.040***	-0.023***
Schedule flexibility	0.033	0.041**	0.007	0.002	0.014*

Table 2 continued					
Flexibility to deal with family matters	-0.075	-0.024	-0.036***	-0.044***	-0.036***
Work interferes with family	0.004	0.114***	0.095***	0.091***	0.097***
Gender	-0.026	0.011	0.012	-0.016	0.005
Age	-0.028	0.037***	0.010	0.013	0.033***
Education	-0.187*	-0.030*	-0.042***	-0.055***	-0.045***
Marital status	-0.220*	-0.006	-0.013	-0.057***	-0.028***
Size of family	-0.338***	-0.003	0.006	-0.003	-0.007
Work hours	-0.348***	0.026*	0.008	-0.008	0.006
Job classification	-0.294**	0.000	-0.005	-0.025	-0.009
Supervisory status	0.093	-0.002	-0.003	-0.010	-0.004
Employment relationship	0.070	-0.027*	0.032***	-0.005	0.008
Public/private organization	-0.021	-0.025*	-0.030***	-0.025*	-0.028***
N	97	4,764	8,531	5,281	18,716
Adj. r-squared	0.499	0.451	0.424	0.418	0.428
F	4.30***	135.72***	217.90***	131.60***	483.58***

Beta values level of significance: * $p < .05$; ** $p < .01$; *** $p < .001$.

SG = Silent generation; BB = Baby boomers; GX = Generation X; M = Millennials.

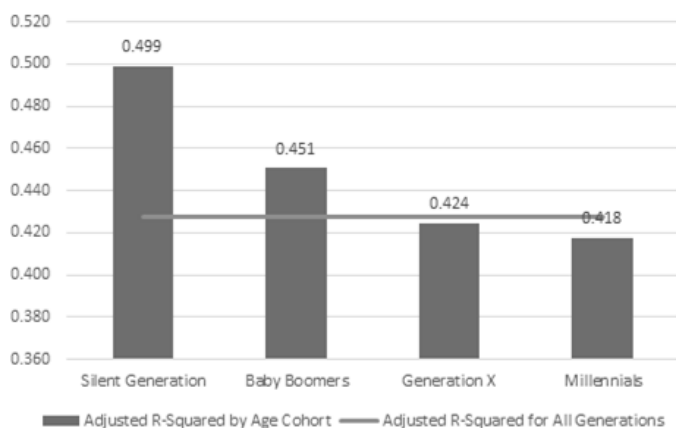


Figure 8: Adjusted r-squared, by age cohort

Below we can see the interpretation of results for each of the main study variables across each of the age cohorts.

Intrinsic Factors

There is a statistically significant positive standardized beta coefficient for the impact of interesting work on job satisfaction. It is worth noting that the coefficient strength for interesting work is the largest of any variable in the combined model and for each individual generational model, with the exception of the Silent Generation. For the combined model and for Generation X, there is a statistically significant positive standardized beta coefficient for the impact of job autonomy on job satisfaction.

There is a statistically significant positive standardized beta coefficient for the impact helping others on job satisfaction for the combined model and for Millennials. Similarly, the regression analysis shows that for all generations combined and individually except the Silent Generation, there is a positive effect from the impact of one's job being useful to society on job satisfaction.

Extrinsic Factors

All generations besides the Silent Generation have a statistically significant standardized beta coefficient, indicating that job security positively affects job satisfaction. Similar patterns were seen demonstrating that employee pay and promotional opportunities positively affect one's job satisfaction for all groups except the Silent Generation. The Silent Generation were also the only group to not show a negative impact of work stress on job satisfaction.

The impact of physical effort at work was different; regression analysis shows that physical effort does not affect job satisfaction in a statistically significant way.

Workplace Relations

All generations demonstrated a statistically significant positive effect of relations with coworkers on job satisfaction. Interestingly, the coefficient strength for relations with coworkers in the Silent Generation is much stronger than that in other three generations. Relations with management also had statistically significant positive effect on job satisfaction. Conversely, contact with others is not a statistically significant variable, except for Generation X.

Discrimination and harassment at work generally were negatively correlated with job satisfaction, with discrimination having a stronger effect, except for the Silent Generation. Although harassment at work

had a negative correlation when all generations were modeled together, it was only statistically significant for Generation X when modeled separately.

Work–Life Balance Factors

Analysis shows that as Boomers have the option to work from home, their satisfaction increases. No other generational cohort had a similar result. The results also showed that as schedule flexibility increases, job satisfaction also increases for the cohorts as a whole and for Baby Boomers as a group. Regression analysis shows a statistically significant negative standardized beta coefficient for working weekends in all age cohorts. This demonstrates that having a defined workweek that is reserved to Monday–Friday leads to higher work satisfaction. However, we can see that working weekends was only significant for Millennials when looking at the model for each specific age cohort.

Flexibility to deal with family matters appears to be more important for the younger generations and for the workers as a whole. This shows that as flexibility increased their job satisfaction increased. Furthermore, for all generations besides the Silent Generation having work that does not interfere with family yields higher work satisfaction.

Job satisfaction and work life balance

A company that ensures that the demands from work do not overstep into family life can help workers and employers understand boundaries related to work/family-life balance (Table 4). For example, all the generational cohort—with the exception of the Silent Generation—had a statistically significant indication that they felt like work interfered with their family time, or had poor work–life balance. Therefore, if a company wants to implement strategies that would increase job satisfaction among employees, they should find ways to limit or eliminate employees spending extra time away from their families.

Employees' work–life balance could be improved by employers recognizing the need for healthy boundaries between home and work. Some boundaries could be reducing tasks and communication on the weekends and after office hours. Our research shows that as employees reduce the time spent working on weekends, their job satisfaction increase. Being able to let employees have their weekends to themselves without work interfering would aid in creating a boundary between work and home life. Consistency in upholding these boundaries and schedules could help in increasing job satisfaction of employees.

Table 4: Summary mean scores and regression results of job satisfaction and WLB variables by age cohort, 2015

Variable	SG	BB	GX	M	All
Mean scores					
Job satisfaction	5.69	5.39	5.28	5.26	5.32
Work from home	3.30	3.93	3.95	4.17	4.00
Work weekends	3.10	3.21	3.14	3.05	3.14
Schedule flexibility	2.10	1.71	1.62	1.52	1.63
Flexibility to deal with family matters	1.81	2.15	2.26	2.36	2.25
Work interferes with family	4.00	3.79	3.55	3.71	3.66
Variable beta coefficients and significance in full model					
Work from home	0.118	0.036*	-0.003	-0.010	0.005
Work weekends	-0.031	-0.019	-0.013	-0.040***	-0.023***
Schedule flexibility	0.033	0.041**	0.007	0.002	0.014*
Flexibility to deal with family matters	-0.075	-0.024	-0.036***	-0.044***	-0.036***
Work interferes with family	0.004	0.114***	0.095***	0.091***	0.097***

Our research found that, as employees were able to work from home, their satisfaction increased. Reimagining employees' schedules could highlight specific tasks that could be completed outside of the office, thus giving employees the ability to work remotely for portions of their week. This could transition rigid schedules into flexible and modern schedules.

Limitations and Future Research

As noted previously, it is important to remember that the sample size for the Silent Generation is only 97 respondents in comparison to samples in the thousands for the other three generational cohorts. This is a result of fewer members in the Silent Generation age cohort still being in the labor force. However, despite the small sample size for this age cohort, there were still significant results in the regression model, and it is likely there would more consistency across age cohorts if the sample size was larger. Thus, we need to interpret the results for the Silent Generation with caution.

Additionally, the secondary data provided in the International Social Survey Program Work Orientations module does not always include the explanatory or control variables we would be most interested in and it utilizes single-item indicators, rather than scales. In addition, it

would be preferable to track the same employees over time, in a longitudinal study, to further examine the impact of age on the job satisfaction and its determinants.

Finally, given the limitations of the data and the limited scope of this specific study, there are opportunities for continued examination of the impact of work–life balance indicators and their impacts on job satisfaction across age cohorts. In particular, there is an opportunity to examine differences across the 37 countries that participated in the 2015 Work Orientations Module. Additionally, given the state of the current global pandemic, future research should focus on the significant increase of employees working from home because of COVID-19 and the potential positive and negative influences on job satisfaction.

Discussion and Implications

Because the ISSP 2015 Work Orientations data was collected from a wide variety of employees, cultures, and countries, we encourage all companies regardless of location and size to analyze these implications for the benefit of employee job satisfaction for their companies.

Working on weekends leads to lower job satisfaction. To combat this, employers could refine schedules to reduce hours worked on weekends for appropriate job types. A way to do this would be to foster a culture of leaving work at work and not taking it home for the weekend. Reliability of hours is a major benefit to many jobs; adding this consistency to some job positions could increase job satisfaction. Additionally, adding consistency of hours to employees' schedules could improve job satisfaction.

Based on the study findings, “Interesting Work” had the highest impact on job satisfaction. Additionally, workers tend to have higher job satisfaction if they have healthy relations with other employees at work and they feel safe in the work environment they are in. These results lead us to suggest that companies should teach employees how to build and maintain trusting, healthy relations with all employees. We also encourage employers to require trainings that teach employees about unhealthy discriminatory behaviors and sexual harassment behaviors. Having employees commit to not harming, discriminating, or harassing others keeps both the employee and the employer safe.

We found in our study that while there was not a strong correlation among all the generations to have contact with others in their job, there was a strong correlation to have good relations with others and job satisfaction. Articles and statistics support having a strong company culture to promote healthy relations between workers. This starts with management and goes beyond ping-pong and free food at work meetings.

It is important that employers create opportunities for employees to bond with workers and encourage relationship building through different activities, events, and meetings. It is also encouraged that employers create safe places for employees to openly communicate with each other and provide feedback to each other to be able to learn from their mistakes and progress. It is also important to reward hard work and positive actions.

Having an effective human resource department to responsibly and fairly deal with complaints could increase employee job satisfaction and lower the rates of discrimination in the workplace. Companies need to work diligently at creating a working environment and culture where employees feel safe, feel like they can speak up, and have the confidence to do so. Implementing effective human resource protocols, offering positive conflict resolution training, and providing appropriate resources would increase transparency to those who would like to know the process of how things are handled in human resource. Having an effective human resource department with appropriate policies and practices would give whistleblowers the confidence they need to bring issues to the attention of human resource, which will reduce discrimination at work and help to increase job satisfaction. Future research can examine what companies do to promote the effective human resource protocols and if these actions increase employee retention.

Our findings show that workers tend to have more job satisfaction and put forth a more concentrated effort to achieving company goals if their job is interesting to them. Because of this, we encourage companies to find opportunities to place employees where they can work on what interests them the most (e.g., through job rotation and job sharing programs).

We have evidence from our research to support that workers with more opportunities to make decisions within the company—or who have job autonomy—tend to have higher job satisfaction. Because of this, we encourage companies to appropriately enable employees to help make decisions within the scope of their job duties.

We have found through our research that workers with opportunities to benefit society through their work tend to have higher job satisfaction. For Millennials, our study found a statistically significant relationship between job satisfaction and helping others. Therefore, we would encourage companies to provide programs where employees can get involved with the community and offer services to increase the job satisfaction for Millennial workers.

Our research shows that interesting work, job autonomy, helping others, having a job useful to society, and job security are all more salient determinants of job satisfaction than pay for all generations. Based on

the findings of this study, we suggest that companies spend resources on job security, autonomy, jobs that are useful to society and helping others, rather than focusing on only pay. Note that we are not suggesting that a company pay employees less than market value for a position; rather, that once a company is paying a fair and equitable wage, it should then focus on these other factors.

Our research shows that companies who address employee complaints increase job satisfaction and retention rates. We suggest that companies implement strategies to ensure that employees' complaints are properly recorded and addressed. Our research shows work stress can have negative effects on employee job satisfaction and decreased retention. We would encourage, if possible, moderate employee workload and stress-reducing benefits, such as wellness programs, cafeteria programs, and game rooms.

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Housing and Autism Spectrum Disorder: Insights from Individuals and Families

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Abstract

Autism is one of the fastest growing disabilities in the country. Housing for autistic adults remains elusive for many, and access to funding and supports is often nonexistent. The aim of this project was to better understand the current and future housing needs of autistic adults in Utah, from the perspective of autistic individuals and their caregivers. Two surveys, one provided to autistic individuals and one to parents/guardians of autistic individuals, were developed and disseminated among a sample of convenience using social media and email. Descriptive analysis of the survey responses was undertaken for all respondents. The majority of respondents still live with their parents, and housing options are limited. The majority of autistic respondents stated that employment was funding their housing needs, and the majority of parents/guardians indicated that family funding was the primary source. The majority of autistic adults wanted to live

independently. A clear dichotomy was present between parent/guardian responses and autistic adult responses. The data received from the survey provides evidence that appropriate housing options for autistic individuals in Utah have been and continue to be an ongoing struggle. There are many individual organizations trying to offer solutions, but working together to synthesize research, outcomes, and lessons learned is imperative to finding optimal housing support for adults on the autism spectrum.

Introduction

Utah has the third highest rate of autism in the nation, with nearly 1 in 50 individuals on the autism spectrum¹. In Utah County, the number jumps to 1 in 40². Individuals with Autism Spectrum Disorders (ASD) experience unique challenges in the transition to adulthood and demonstrate the poorest transitional outcomes of any disability group. Research estimates that over 80% of autistic adults are unemployed or underemployed and that nearly 87% of individuals on the autism spectrum live with parents or other family members³. Supporting autistic individuals costs millions of dollars per year in both private and government funding, has been measured across multiple sectors, and affects the state of Utah both negatively and disproportionately⁴. Meanwhile the number of autism diagnoses nationwide continues to expand. The Center for Disease Control and Prevention (CDC) projects an increase of over 120% in individuals with ASD to age out of the secondary education system in the next decade¹. We face an overwhelming number of individuals with autism moving into and through adulthood in the coming years, all of whom will need a place to live.

Although residential independence may not be appropriate for all adults on the autism spectrum, prolonged caregiving is not sustainable, has adverse effects on parental well-being, and contributes to poor quality of life for autistic individuals^{3,5}. Research indicates that an individual's living situation is a strong predictor of their access to needed services⁵. Likewise, research also demonstrates the availability of financial resources as a determining factor in the proportion of autistic adults who have lived away from parents. Regardless of ability level, "adults with ASD from higher socioeconomic backgrounds [have] higher odds of living independently."³ This clearly implicates a shortage of needed resources, or the allotment thereof, as a determinant to the residential independence of autistic adults.

Prior to the 1980s, individuals on the autism spectrum were routinely institutionalized. It is important to recognize that the diagnostic criteria for autism were different in the Diagnostic and Statistical Manual (3rd Edition) at that time, with a diagnosis of autism primarily including individuals who were more impacted by their autism or considered “lower functioning.” In 1998, the U.S. Supreme Court ruled in *Olmstead v. L.C.* that “confinement in an institution severely diminishes the everyday life activities of individuals, including family relations, social contacts, work options, economic independence, educational advancement, and cultural enrichment.”⁶ *Olmstead* further deemed institutionalization without medical need to be a form of discrimination under the Americans With Disabilities Act of 1990⁶. However, the deinstitutionalization that followed *Olmstead*⁶ did not correspond with an adequate increase in support services, particularly given the recognition of autism as a spectrum including those who require significant amounts of support and those who require less support¹. The nationwide lack of community supports and basic services leaves service organizations oversaturated and overburdened families with few options.

Federal law guarantees education for children with developmental disabilities until the age of 21 years. At age 21, autistic young adults lose the specialized help and structure they’ve had for most of their lives, including Medicaid services, as autism-related services are not covered in Utah past the age of 21. Paradoxically, the high intellectual abilities that often accompany autism leave many adults with autism not “disabled enough” to qualify for support from Social Security or The Division of Services for People with Disabilities (DSPD)¹¹. This abrupt life change is colloquially referred to as falling off “the services cliff,” as there is no equivalent support at the state or federal level required to take over. “Children” with autism will spend the majority of their lives as adults, yet even when resources are available, services for autistic adults are sparse, difficult to find, and have long waiting lists³.

In Utah, this lack of services and resources for autistic adults coincides with a crisis in affordable housing. The Utah Department of Workforce Services’ Affordable Housing Assessment reports a statewide shortage of 45,000 affordable housing units⁷. Builders simply are not motivated to build low-income units because they are less profitable. Median sale prices for homes in Utah County have risen 277.5% and those in Salt Lake County have risen 303.9% since 1991⁷. The report also notes that Utah is concentrated in households with income below the median. A household with income below the median is 32 times more likely to have a severe housing cost burden than a household with income above the median. Since 2010, rental rates in Utah have increased 23.9%, and wages have not kept pace⁷. A minimum-

wage worker would need to work 129 hours a week to afford the average 1-bedroom unit in Utah County (a \$10-an-hour worker would need to work 94 hours a week). Vulnerable populations, such as those with disability, are disproportionately impacted by a lack of affordable housing and take more time to recover (if they do at all) from poor conditions⁷.

When compared with individuals living independently or with family members, autistic adults living in supported living situations are more likely to receive needed services⁵. Yet supported living opportunities are rare and often unaffordable. A new development in Phoenix, AZ, named “First Place” advertises 55 apartments (studio, 1-, 2-, and 4-bedroom units), a menu of supports and amenities, as well as a residential transition program for individuals on the spectrum.⁸ First Place’s location in the heart of the city provides access to public transportation, which supports community integration. However, a one-bedroom apartment at First Place rents for \$3800, and a two-bedroom rents for \$3400 per person with double-occupancy, which is nearly 300% of the market value in Phoenix where the average one-bedroom apartment rents at \$1216.⁸

The much smaller Sweetwater Spectrum in Sonoma, CA, consists of four single-story, 4-bedroom houses (3250 square feet).⁹ The community offers a pool, hot tub, community garden, exercise space, gathering area, chicken coop, and greenhouse. Families sign both a lease and a contract for care, as Sweetwater Spectrum does not provide services. Whether round-the-clock care is needed, or just a few hours a week, services are provided through the North Bay Regional Center, a state-funded government agency. The cost of residence at Sweetwater Spectrum is approximately \$3400 per month (\$40,000 per year).⁹ While more closely aligned to the local market value of \$2085 for a 1-bedroom apartment, this simplistic supported living environment still represents a severe if not impossible housing burden, particularly for those making the entry-level wages that are common for young adults (disabled or not) in the transition stage of life.⁹

Many supported living communities start with families coming together with a goal of mitigating housing and support costs by housing individuals with similar support needs in shared housing situations. Like Sweetwater Spectrum, these family-supported communities tend to be small, with rare openings and long waiting lists. Moreover, family-shared communities are typically out of reach for low- or middle-class families who lack contributory resources. Opponents argue that these congregate settings fall into discrimination territory under *Olmstead* as they segregate individuals from their community and restrict individual choice, control, and privacy.¹⁰

With so few individuals on the spectrum living independently and so little information available regarding the residential status of autistic adults, more research is needed in all areas. Moreover, the current oversaturation of adult service agencies indicates an urgency for better understanding of the service needs and obstacles for adults with autism. The aim of this project was to better understand the current and future housing needs of autistic adults in Utah, from the perspective of autistic individuals and their caregivers. For example, questions asked what types of housing would you consider living in or what living arrangements would you consider. Questions also inquired about specific supports needed to facilitate residential independence for adults on the autism spectrum.

Method

This project aimed to better understand the current and future housing needs of autistic adults in Utah County. After reviewing the literature and interviewing local professionals that research and work in the area of autism services, survey questions were designed to determine the need for housing and, if additional housing were available, what other factors would play into the individual being able to live on their own. Two separate surveys were developed and distributed via Qualtrics—one to autistic individuals and one to parents/guardians of autistic individuals (see Appendix 1). Specific questions addressed the current housing situation of the individual, their need for housing, when they needed the housing, what type of housing they would prefer, and what resources would they need assistance with, as well as the resources they have to be able to afford the housing.

Given the sensitive nature of the target population, convenience/snowball sampling was used, and a survey link was shared and promoted via social media platforms (Facebook, LinkedIn, and Twitter). Survey respondents were then encouraged to share the survey with their personal contacts who have connections with autistic individuals and the broader autistic community. Survey responses were collected for approximately six weeks, in the fall of 2018, with a total of 160 individuals completing the survey. All responses were anonymous. Descriptive analysis of the survey responses was undertaken for all respondents.

Additionally, efforts were taken to better understand what housing is already available for autistic individuals. Members of the research team contacted and interviewed local housing authorities and explored various publicly available publications. This step provided the research team with useful information on the current housing shortage as well as

the cost of housing in Utah, which is an important factor to consider when establishing housing for autistic adults.

Results

Participants

As shown in Table 1 below, a total of 160 responses were received; 45% from individuals on the autism spectrum and 55% from parents/guardians of autistic individuals. Additionally, as shown in Figure 1, the overwhelming majority of responses came from individuals 18–30 years of age. In addition, Table 2 shows the responses from across the various counties within Utah, with the vast majority of respondents residing in Utah County, the primary target demographic. Results of all survey questions are presented in Appendix 2.

Table 1: Survey respondents		
Parent/guardian	88	55%
Autistic individual	72	45%
Total	160	100%

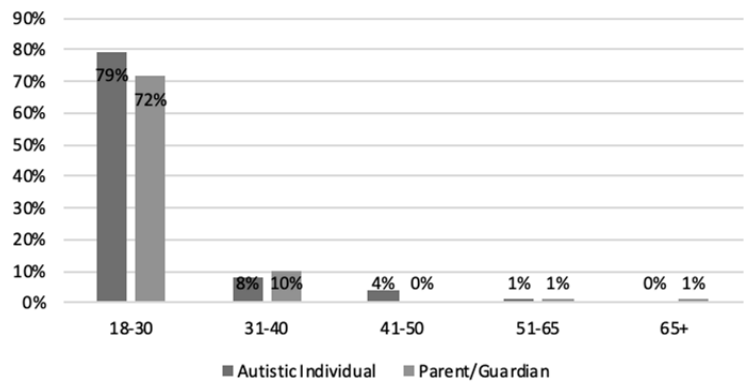


Figure 1: Age of autistic individual

Current circumstances

To determine current living circumstances (living with family, independently, etc.), respondents were asked to identify where they or their autistic child currently lives. As seen in Figure 2 below, the majority

of respondents (36% autistic individuals, 49% parent/guardians) stated the current living situation was the adult autistic child living *with their*

Table 2: Respondent county of residence			
County of residence	Autistic individuals	County of residence	Parents/guardians
Utah	50	Utah	50
Salt Lake	8	Salt Lake	13
Wasatch	2	Wasatch	4
Cache	1	Washington	9
Davis	1	Davis	2
Sanpete	1		
Summit	1		
Weber	1		
		Carbon	1
		Juab	1
Outside of Utah	1	Outside of Utah	1
Did not respond	6	Did not respond	7
Total	72	Total	88

parents. In addition, 22% of autistic individuals said they were currently at an *assisted living facility* followed by 18% *living independently*. Parents/guardians listed *independent living* second highest with 11% and *assisted living facility* third with 8%.

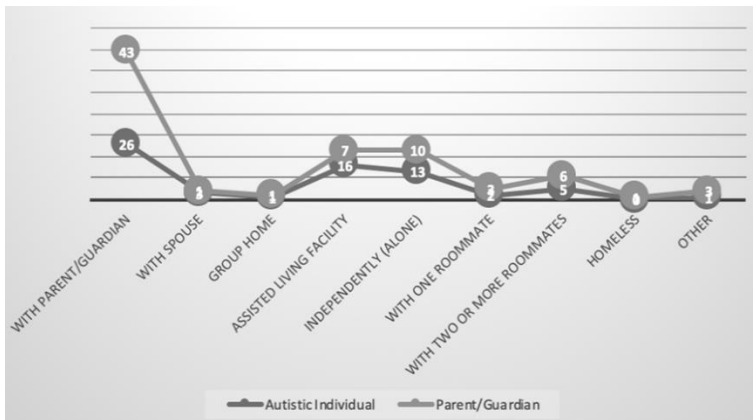


Figure 2: Current living situation of autistic individual (reported as %).

Future circumstances

As seen in Figures 3 and 4, when asked to assess the future housing needs and wants of the autistic individual, responses were highest in the *as soon as possible*, 1–2 years, and 3–5 years categories. However, it is interesting to note that while autistic individuals did not express a want or need for housing as late as 10+ years into the future, a comparatively high number of parents/guardians felt that 10+ years was when their child would need housing and when they would want housing for them. One possible reason to this response dichotomy could be that, as parents age, they believe they will no longer be able to care for their child and it is at this time when they will want/need to find a new housing scenario for their child. While a new housing situation is needed most

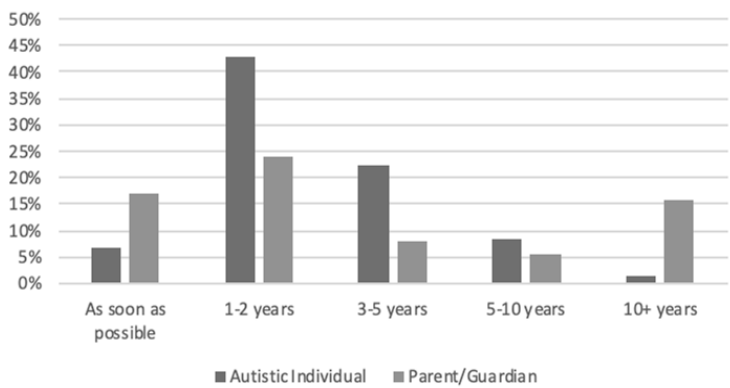


Figure 3: Future need for housing of autistic individual

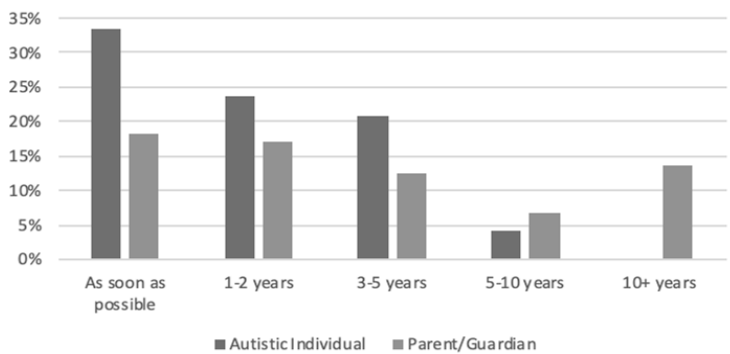


Figure 4: Future want for housing for autistic individual

commonly in 1–2 years, it is wanted as soon as possible. Three to five years was ranked third by both groups of respondents for both “need” and “want.” Therefore, the majority of respondents are seeking housing within the next 0–5 years.

In addition to ascertaining the timeframe in which housing is needed and wanted for autistic individuals, considerable types of housing and living arrangements (roommates, etc.) were also assessed. When answering these questions, respondents were asked to select all options they would consider as acceptable; therefore, multiple selections could be made by each respondent. As seen in Figures 5 and 6, the options of living in a *cooperative community* and *multi-family housing unit* were ranked highest by autistic individuals. Parents/guardians ranked *apartment community* first, followed by *cooperative community* and *multi-family housing unit*. Additionally, 60% of autistic individuals responded that they would prefer to live alone, with *no roommates*. *One roommate with autism*, the next highest response, dropped by nearly half. In addition, 29% of autistic individuals would consider living with *one neurotypical roommate*. Parents/guardians responses had less disparity among answers. There was only a 10% spread among all the options given. *No roommates* and *one autistic roommate* both received the most responses with 32%. Responses of *one neurotypical roommate* and *family member only* each received 26% with *two or more roommates with autism* just 1% lower at 25%.

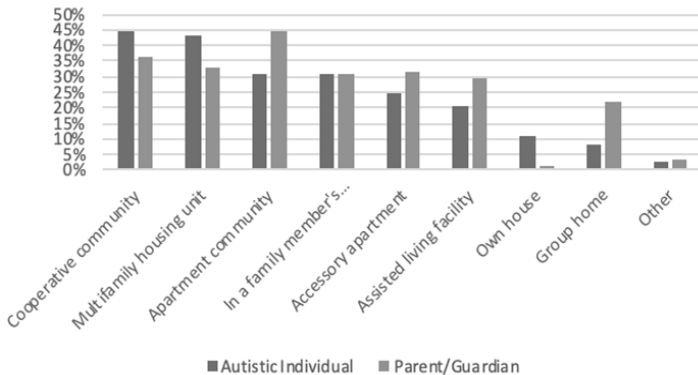


Figure 5: Housing options considered acceptable for autistic individual

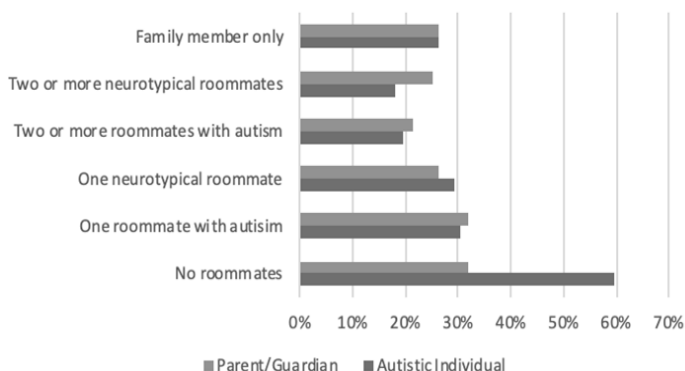


Figure 6: Living arrangements considered acceptable for autistic individual

Supportive services

With the understanding that a new housing option for autistic individuals would need to include some additional services, respondents were asked to select from a list of 15 services (including an “other” option) those that they currently receive. Interestingly, the total number of answers by autistic individuals was 185 while parents/guardians gave 473 answers. One possible explanation for the difference in total answers between the respondent groups is awareness. An autistic individual may not be aware that they are receiving assistance. For example, one respondent did not mark that they received assistance with grocery shopping because he/she did not personally go grocery shopping. There was no recognition that, by someone else doing the grocery shopping for him/her, he/she was in fact receiving assistance in that particular area. As such, parents/guardians responses might provide a more accurate view of currently received assistance. As seen in Figure 7, *transportation* and *managing money* were ranked in the top two by parents/guardians and individuals with autism. Additional services that ranked high for parent/guardians were *organizing daily schedule*, *grocery shopping*, and *personal hygiene reminders*.

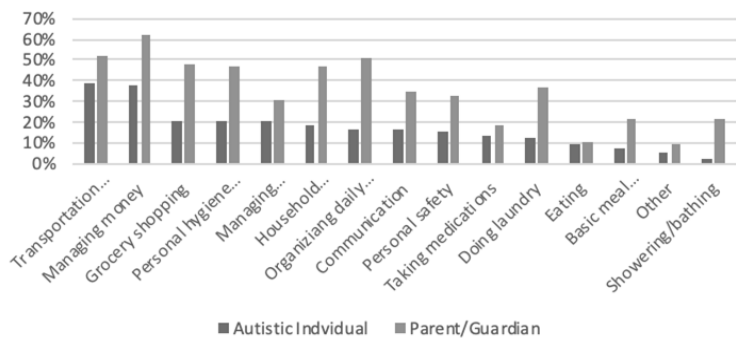


Figure 7: Services for which the autistic individual receives assistance

In conjunction with current services questioning, respondents were given a list of 14 additional services, some included in the previous question and others not, and were asked to prioritize, from 1 to 14, what supportive services they would like to receive. As seen in Tables 3 and 4 below, the priority levels did vary between autistic individuals and parent/guardians; however, when viewing the five highest ranking services within each group of respondents, three of the same services appeared on both lists. *Nutrition and exercise* was ranked first by autistic individuals, second by parents/guardians. *Social support* was ranked second by autistic individuals and third by parents/guardians. Lastly, *apartment life skills* was ranked fourth by autistic individuals but first by parents/guardians.

Table 3: Ranked support services	
Individuals with autism	Parents/guardians
Nutrition and exercise (grocery shopping, nutrition planning, and exercise)	Apartment life skills (maintaining living space, laundry, general living skills)
Social support (planned activities, social coaching)	Nutrition and exercise (grocery shopping, nutrition planning, and exercise)
Mental health counseling	Social support (planned activities, social coaching)
Apartment life skills (maintaining living space, laundry, general living skills)	Personal finance management
Transportation	Health & wellness (medical appts, managing health needs)

Table 4: Full listing of desired services ranked by mean		
Desired Services	Autistic Individual	Parent/Guardian
Nutrition & exercise (grocery shopping, individualized nutrition planning, and exercise)	5.22	4.84
Social support (planned social activities, social coaching)	5.49	5.09
Mental health counseling	5.82	7.10
Apartment life skills (maintaining living space, laundry, general living skills)	5.95	4.71
Transportation	6.84	8.24
Community involvement (community involvement programs, enrichment programs, educational programs)	6.85	6.79
Health & wellness (medical appointments, managing health needs)	6.85	6.28
Personal finance management	6.85	5.86
Therapy (occupational, speech, physical, etc)	6.96	9.91
Meal preparation	8.11	8.28
Executive functioning (organizing daily schedule, checking mail, checking email)	8.85	8.52
Personal hygiene	8.91	7.40
Personal safety	9.69	8.38
Other	12.60	13.60

Income factors

It is important to determine what income sources individuals with autism have available to cover the expenses that come with independent living. Thus, respondents were asked what sources of income they currently have. As seen in Figure 8, whereas 47% of autistic individuals listed employment as a source of income, ranking it first, it is important to note that this statistic does not differentiate between full-time/part-time, underemployed, wage level, etc. In contrast, parents/guardians ranked family support first (42%). One interpretation of this data could be that while nearly half of autistic individuals are employed, the income received is not enough to financially support the autistic individual’s needs, therefore, family support, or other means of assistance is required.

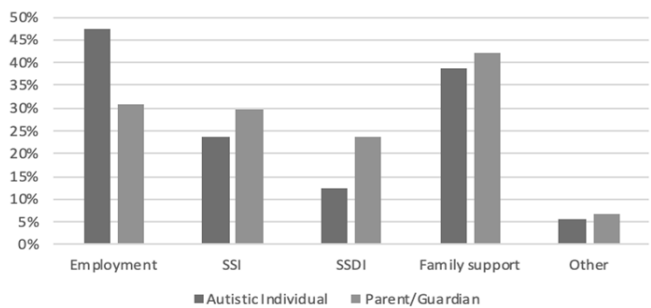


Figure 8: Income sources of autistic individual

Discussion and Recommendations

The goals of this survey were mainly to establish (1) the housing needs/wants of autistic individuals in Utah and (2) what supportive services are needed or wanted as part of the housing. The data received from the survey provides evidence that appropriate housing options for autistic individuals in Utah has been and continues to be an ongoing struggle. In response to the survey results, it can be surmised that autistic individuals desire independent living, and many are in need of housing options outside of their current situation, primarily living with family. At times, parents/guardians and autistic individuals expressed similar concerns with independent living skills, such as transportation and managing money; however, dichotomies between parents/guardians and autistic adults were evident. Financial concerns and acquiring skills to live independently are of primary concern to parents/guardians, but those same levels of concern are not expressed by the adults on the autism spectrum. This was evident in that the autistic adults didn't always realize that they were receiving some type of assistance be it government or familial. It is imperative that autistic adults gain an understanding of the skills necessary to live independently and then build an awareness as to where their own levels of competency are with regard to those skills.

In looking forward, any initiatives to improve housing options for autistic individuals looking to live more independently should include two crucial elements: inclusivity and empowerment. As such, the following initiatives are recommended as a call to action^{8,12}. Each addresses a potential roadblock to independent living for autistic individuals and many can and should be undertaken concurrently.

Awareness initiative

Create a "landlord" training program and campaign designed to educate and increase awareness regarding reasonable housing accommodations for individuals with autism. This would include best practices, processes, and protocols, as well as situational suggestions to assist landlords in better serving autistic residents. This initiative would also establish processes, procedures, and methods such as communication preferences and alternative solutions to traditional tenant issues for landlords and autistic tenants to utilize.

Transportation initiative

Among the *supportive services currently received*, out of the 15 options provided, autistic individuals ranked *transportation* first while parents/guardians ranked it second. Efforts to enable independent living

for autistic individuals would be best supported by increased public transportation accessibility. Therefore, an initiative to collaborate with public transportation entities, particularly Utah Transit Authority, to increase accessibility would be an important element to include. Suggestions for increased accessibility include extending bus routes into evening hours and adding stops at any future locations (apartment complexes, cooperative community) that house members of the autistic community.

Preparatory housing initiative

To facilitate the development of skills needed to live independently (cooking, cleaning, money management, etc.), the establishment of a transitional or “training” living center for autistic individuals is recommended. This housing community would function as a “test-run” location for autistic individuals preparing to live independently. Individual apartments would be available to rent on a short-term basis. While living there, residents would receive training in various skills needed for independent living. These classes would be purchased in a package, based on needed lessons, or a la carte. In addition, supportive staff would help in teaching the residents how to maintain the apartment, pay rent, etc. Residents would also receive assistance in locating and transitioning into an independent housing situation appropriate for the client. Employment opportunities for autistic individuals at the training community could also be provided.

Autism inclusivity initiative

As autistic individuals are ready to live independently, appropriate housing options need to be available to them. An initiative to partner with developers and builders of new and renovated communities to include autistic-friendly apartments into the design of these communities could greatly increase the available housing options for autistic individuals. The landlord of these communities could also undergo the landlord training described in the awareness initiative and be a partner with the preparatory housing training center. This would provide housing for autistic members of society within society as a whole, thus fostering inclusivity rather exclusivity.

In addition, each community or complex in which autistic individuals live would have a residential assistant responsible for monitoring and assisting the autistic residents on a scheduled basis. This could include bill-paying reminders, hygiene and housekeeping check-ups, daily schedule help, etc. The residential assistants could be college students, working on an applicable college degree, that could receive

college credit and/or reduced rent as payment. Additionally, as with the preparatory housing initiative, employment partnerships for the autistic residents at the communities could be explored.

Rent assistance initiative

As many autistic individuals do not have the financial means to live independently, a rental assistance program for autistic individuals could be established. This program could be needs based and donor funded. It would provide the gap funds so that autistic individuals would be able to afford independent living. This initiative could also be layered with the preparatory housing and autism inclusivity initiatives.

Limitations & Future Recommendations

It is recommended that the survey be readministered on an annual or biannual basis to continually monitor the status of the housing situation for autistic individuals, as it is bound to change and develop as more awareness and advocacy takes place. In addition, the survey was administered via Qualtrics, which limits responses to those who can respond to an online survey. Future iterations may want to consider alternative formats (e.g., reading the survey aloud, paper/pencil) to get a more representative sample of individuals with ASD and parents/guardians. At present, the survey was only given to individuals above the age of 18 but below the age of 30, which may disproportionately represent this age group. One recommended survey modification is to open the survey to those younger than 18 and over the age of 30 to expand the sample size of respondents from other age groups. This will provide a better understanding of what to expect within the autism community in the future. In addition, the survey could be modified to include additional questions regarding employment status and income sources. This would provide additional insight into whether or not the individual has been able to maintain employment, whether it is part time/full-time employment, at what wages they are receiving. Additionally, understanding not only income sources but also income levels would be valuable information. This would provide insight into what is affordable for an average autistic individual in Utah, what level of funding would be needed for housing assistance, and what government resources are already being utilized.

Conclusions

Housing for autistic adults continues to be a complex issue and one that will require collaboration and coordination among many state

agencies, funding sources, researchers, universities, caregivers, and autistic people to solve. It is past time when these concerns needed solutions, and the housing crisis needs creative solutions now. There are many individual organizations trying to offer solutions, but working together to synthesize research, outcomes, and lessons learned is imperative to finding optimal housing support for adults on the autism spectrum.

Acknowledgments

We would like to thank all of the individuals who took the time to fill out the survey and contribute their insights to this important work. We appreciate the Hurst Wood Education Foundation for requesting the initial inquiry that spawned this research. We also appreciate Dr. Westover's students who took on a service learning project and learned way more than they ever bargained for.

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Appendix 1: Survey Questions for Autistic Individuals

1. I am:

- A parent/guardian of an autistic individual
- An autistic individual

2. What county do you live in?/ In which county does the individual with autism live?

- Salt Lake County
- Utah County
- Cache County
- Weber County
- Davis County
- Other _____

3. How old are you?/ How old is the individual with autism?

- 18-30
- 31-40
- 41-50
- 51-65
- 65+

4. Where do you currently live?/ Where does the individual with autism currently live?

- With parent/guardian
- With spouse
- Group home
- Assisted Living Facility
- Independently (alone)
- With one roommate
- With two or more roommates
- Homeless
- Other _____

5. What types of housing would you consider living in?/ What types of housing would you consider for the individual?

- Multifamily housing unit (a building with multiple connected units such as an apartment with or without roommates)
- Accessory apartment (a self-contained living area within a single-family home)

- Group home (a home where a small number of unrelated people in need of care, support, or supervision live together, such as those who are elderly or mentally ill)
 - Assisted living facility (a building with multiple connected units such as an apartment with assistance with daily activities provided.)
 - Cooperative community (a neighborhood or cul de sac with individual houses designated specifically for autistic adults)
 - Apartment community (an apartment building or cluster of buildings designated specifically for autistic adults)
 - In a family member's home
 - Other_____
6. What living arrangements would you consider?/ What living arrangements would you consider for the individual?
- No roommates
 - One roommate with autism
 - One neurotypical roommate
 - Two or more roommates with autism
 - Two or more neurotypical roommates
 - Family member only
7. How soon do you need housing?/ How soon is housing needed for the individual?
- As soon as possible
 - 1-2 years
 - 3-5 years
 - 5-10 years
 - 10+ years
8. How soon do you want housing?/ How soon is housing wanted for the individual?
- As soon as possible
 - 1-2 years
 - 3-5 years
 - 5-10 years
 - 10+ years
9. Do you currently receive help with:/ The individual currently requires assistance with:
- Eating

- Managing money
 - Transportation (public or private)
 - Grocery shopping
 - Doing laundry
 - Organizing daily schedule
 - Personal hygiene “reminders”
 - Taking medications
 - Personal safety
 - Communication
 - Household chores/keeping room clean
 - Basic meal preparation (i.e. cannot use microwave)
 - Showering/bathing
 - Managing behaviors/anger issues
 - Other_____
10. In order of priority, what supportive living services would you like to receive? (1 being most important, 14 being least important)/ In order of priority, what supportive living services would you like the individual to receive? (1 being most important, 14 being least important)
- Nutrition & exercise (grocery shopping, individualized nutrition planning, and exercise)
 - Apartment life skills (maintaining living space, laundry, general living skills)
 - Social support (planned social activities, social coaching)
 - Community involvement (community involvement programs, enrichment programs, educational programs)
 - Health & wellness (medical appointments, managing health needs)
 - Personal finance management
 - Mental health counseling
 - Therapy (occupational, speech, physical, etc)
 - Personal hygiene
 - Meal preparation
 - Personal safety
 - Transportation
 - Executive functioning (organizing daily schedule, checking mail, checking email)
 - Other_____
11. How long are you comfortable being by yourself/alone?/ How long can the individual be left alone?

- Never
 - 1 to 3 hours
 - 4 to 6 hours
 - 7 to 12 hours
 - 13 to 16 hours
 - Several days
 - While sleeping only
12. What income source(s) do you currently have?/ What income source(s) does the individual currently have?
- Employment
 - SSI (Social Security Income)
 - SSDI (Social Security Disability Income)
 - Family support
 - Other_____
13. If money were no object, what would your ideal living situation look like?/ If money were no object, what would your ideal living situation for the individual look like?
14. Is there any other information/thoughts/concerns you would like us to know regarding your housing options?/
14. Are there any other information or concerns you would like us to know regarding housing for the individual?

Appendix 2: Autism Housing Survey Descriptive Data

	Autistic Individual		Parent/Guardian	
1) I am				
A parent/guardian of an autistic individual	88	55%		
An autistic individual	72	45%		
Total	160	100%		
2) What county do you currently live in?				
Salt Lake County	8	11%	13	15%
Utah County	50	69%	50	57%
Cache County	1	1%	0	0%
Weber County	1	1%	0	0%
Davis County	1	1%	2	2%
Wasatch County	2	3%	4	5%
Sanpete County	1	1%		0%
Summit County	1	1%		0%
Central Florida	1	1%		0%
Carbon County			1	1%
Juab County			1	1%
Washington County			9	10%
Oakland County, Michigan			1	1%
Total	66	92%	81	92%
3) How old are you?				
18-30	57	79%	63	72%
31-40	6	8%	9	10%
41-50	3	4%	0	0%
51-65	1	1%	1	1%
65+	0	0%	1	1%
Total	67	93%	74	84%
4) Where do you currently live?				
With parent/guardian	26	36%	43	49%
With spouse	3	4%	1	1%
Group home	1	1%	1	1%
Assisted living facility	16	22%	7	8%
Independently (alone)	13	18%	10	11%
With one roommate	2	3%	3	3%
With two or more roommates	5	7%	6	7%
Homeless	0	0%	1	1%
Other	1	1%	3	3%
Total	67	93%	75	85%
5) What types of housing would you consider living in? (Please select all that apply.)				
Cooperative community	32	44%	32	36%
Multifamily housing unit	31	43%	29	33%
Apartment community	22	31%	39	44%
In a family member's home	22	31%	27	31%
Accessory apartment	18	25%	28	32%
Assisted living facility	15	21%	26	30%
Own house	8	11%	1	1%
Group home	6	8%	19	22%
Other	2	3%	3	3%
Total	156	217%	204	232%

6) What living arrangements would you consider?

No roommates	43	60%	28	32%
One roommate with autism	22	31%	28	32%
One neurotypical roommate	21	29%	23	26%
Two or more roommates with autism	14	19%	19	22%
Two or more neurotypical roommates	13	18%	22	25%
Family member only	19	26%	23	26%
Total	132	183%	143	163%

7) How soon do you need housing?

As soon as possible	5	7%	15	17%
1-2 years	31	43%	21	24%
3-5 years	16	22%	7	8%
5-10 years	6	8%	5	6%
10+ years	1	1%	14	16%
Total	59	82%	62	70%

8) How soon do you want housing?

As soon as possible	24	33%	16	18%
1-2 years	17	24%	15	17%
3-5 years	15	21%	11	13%
5-10 years	3	4%	6	7%
10+ years	0	0%	12	14%
Total	59	82%	60	68%

9) Which of the following do you currently receive help with?

Transportation (public or private)	28	39%	46	52%
Managing money	27	38%	55	63%
Grocery shopping	15	21%	42	48%
Personal hygiene "reminders"	15	21%	41	47%
Managing behaviors/anger issues	15	21%	27	31%
Household chores/keeping room clean	13	18%	41	47%
Organizing daily schedule	12	17%	45	51%
Communication	12	17%	31	35%
Personal safety	11	15%	29	33%
Taking medications	10	14%	29	18%
Doing laundry	9	13%	32	36%
Eating	7	10%	9	10%
Basic meal preparation	5	7%	19	22%
Other	4	6%	8	9%
Showering/bathing	2	3%	19	22%
Total	185	257%	473	523%

10) In order of priority, what supportive services would you like to receive?

	Autistic individual	Parent/guardian
Nutrition & exercise (grocery shopping, individualized nutrition planning, and exercise)	5.22	4.84
Social support (planned social activities, social coaching)	5.49	5.09
Mental health counseling	5.82	7.1
Apartment life skills (maintaining living space, laundry, general living skills)	5.95	4.71
Transportation	6.84	8.24
Community involvement (community involvement programs, enrichment programs, educational programs)	6.85	6.79
Health & wellness (medical appointments, managing health needs)	6.85	6.28
Personal finance management	6.85	5.86
Therapy (occupational, speech, physical, etc)	6.96	9.91
Meal preparation	8.11	8.28
Executive functioning (organizing daily schedule, checking mail, checking email)	8.85	8.52
Personal hygiene	8.91	7.4
Personal safety	9.69	8.38
Other	12.6	13.6

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11) How long are you comfortable being by yourself/alone?

Never	2	3%	11	13%
1 to 3 hours	5	7%	10	11%
4 to 6 hours	8	11%	2	2%
7 to 12 hours	7	10%	4	5%
13 to 16 hours	9	13%	6	7%
Several days	24	33%	23	26%
While sleeping only	2	3%	3	3%
Total	57	79%	59	67%

12) What income source(s) do you currently have? (Select all that apply.)

Employment	34	47%	27	31%
SSI	17	24%	26	30%
SSDI	9	13%	21	24%
Family support	28	39%	37	42%
Other	4	6%	6	7%
Total	92	128%	117	133%

Tracking Professional Development through the Creation of Culturally Appropriate Educational Materials

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Abstract

Teacher candidates need to be provided with opportunities to develop their professional knowledge throughout their teacher education programs. This exploration and knowledge development do not necessarily need to happen in the university classroom but could occur in other authentic experiences. We used a phenomenological approach to examine the lived experiences of three pre-service teachers as they developed culturally authentic teaching materials in a culture different than their own. Our goal was to describe how, or if, their professional knowledge developed during the creation of the teaching materials. Using grounded theory to guide the analysis, as the researchers looked at journals, interviews, journal reflections, and philosophy statements, two predominant themes were identified. The results indicate that a materials development project provided fertile ground outside the traditional teacher education program for teacher candidates to consider how they will approach their future teaching situations.

Introduction

Teacher education programs provide teacher candidates tools to become professional educators. However, teacher candidates cannot learn all they need to know to become effective educators in the university classroom alone (Schulz, 2000). Because of the complexity of the teaching situation, teacher educators should provide opportunities in- and outside the university classroom. Most teacher candidates are expected to draw upon more than just their teacher education program experience to develop the skills needed to succeed in the classroom after graduation. Lortie (2002) suggests that teacher candidates can draw from several experiences, including what they have done in classrooms as students, tutoring, or working as a paraprofessional. These authentic experiences can vary greatly, but they should provide the teacher candidate with tasks that match actual classroom expectations. Therefore, it is important to keep in mind the experiences provided to teacher candidates should be nested in situations that are as authentic as possible (Tomlinson, 2014). Much has been written about authentic learning (Engström, 1987, 2001) and its benefit for teacher candidates. Teacher education programs can and should provide the opportunity for professional development in multiple spaces, which include outside coursework and practica (Zeichner et al. 2015). Professional development can take many forms, such as study abroad, hands-on experiences, or materials development.

Literature Review

Teacher development

As suggested above, teaching is a complex and multifaceted situation. But the preparation of teachers has not always been so complex or multifaceted. In earlier days, it only required local testing to demonstrate mastery in the subjects to be taught (Zeichner, 2016). In subsequent years, teachers' professional development slowly grew to include summer teacher institutes, then normal schools, until finally, teacher education was placed within departments and colleges of the university system with each step providing more support and differing requirements and allowing for research in teaching and learning to take place (Labaree, 2008; Zeichner, 2016).

Recently, teacher education programs have been in the public eye as a vehicle to improve teacher quality. The National Commission of Teaching and America's Future recommended that programs possess a clear vision of good teaching and a curriculum grounded in the various

aspects of pedagogical knowledge and theory (Darling-Hammond, 1997; Stürmer & Seidel, 2015). These recommendations were aimed at increasing proficiency in reading and mathematics (Wirt et al., 2002). Directly connected to these basic concepts, the Every Student Succeeds Act stressed the need for preparing teachers to work effectively with diverse learners (US Department of Education, 2015). Teacher education programs can help prospective teachers learn how to integrate these concepts and expand their instructional approaches in diverse ways. (Stürmer et al. 2016).

Clear Vision

Setting a clear vision of good teaching has played an important role in the development of teacher candidates (Darling-Hammond et al. 2005; Fairbanks et al., 2010; Hammerness, 2003, 2008). When teachers have a clear sense of their purpose as educators, they are much better positioned to do what is best for the students they teach. Clear vision reflects a personal viewpoint; can change over time; and is affected by experience and informs decisions for daily teaching (Duffy, 2002). Having vision is essential for the complexity of the teaching profession.

Curriculum Grounded in Pedagogical Knowledge and Theory

Darling-Hammond (1997) elucidated that this type of curriculum contains exposure to specific areas of teacher learning, namely, “child/adolescent development, learning theory, cognition, motivation and subject matter pedagogy” (p. 30). She also emphasized that these aspects of teaching should be presented to teacher candidates in a “context of practice” or, stated differently, authentic teaching situations (p. 30). Recently, Darling-Hammond (2017) has posited that part of this knowledge includes developing a teacher candidate’s ability to work with diverse learners as many nations are experiencing a multi-cultural influx. The diversity aspect of teacher development corresponds well with Grossman’s (1990) model of teacher knowledge discussed below.

Professional knowledge

Shulman (1986) examined the knowledge teachers need to possess in their subject areas and the concept of knowledge areas for teaching the subject. Later, Grossman’s model (1990) expanded on this work and developed a framework of teaching knowledge built on four cornerstones: 1) subject matter knowledge; 2) general pedagogical knowledge; 3) pedagogical content knowledge; and 4) knowledge of context. The four cornerstones of teaching knowledge provide the prospective teacher with a basis to frame the many and varied

experiences they have had, not only before entering their teacher education program but also the ones they encounter during their coursework and beyond in their professional lives.

Subject Matter Knowledge

Shulman (1987) defines subject matter knowledge as the comprehension of the subject as a subject matter specialist, which Grossman (1990) divided into three sub-areas: 1) knowledge of content (the central ideas within a given subject area and their relationship to each other); 2) substantive knowledge (the main concepts, theories, and terms of the subject area); and 3) syntactic knowledge (a given subject and the ideas and perspectives concerning the subject area). Together, the sub-areas give teachers an understanding of the subject area's main themes and how they are organized. Gess-Newsome et al. (2017) reframed subject matter knowledge as academic content knowledge or "the general factual knowledge that a teacher possesses about a specific topic" (p. 2).

General Pedagogical Knowledge

General pedagogical knowledge is awareness about learner's learning, general principles of instruction, and the aims and purposes of education; they are not subject-specific but are adjustable to subject-specific contexts (Gess-Newsome et al. 2017; König et al., 2016). Grossman (1990) breaks this type of knowledge down into three sub-components: 1) learners and learning (students as learners and how they will be taught); 2) classroom management (the way that the classroom is structured to promote learning); and 3) curriculum and instruction (how the course content is arranged for the instructional tasks) (see also König, 2014).

The apprenticeship of observation and teacher education programs both influence general pedagogical knowledge. The apprenticeship of observation is the knowledge of teaching and learning, including preconceived notions about teaching that prospective teachers bring with them from their own experiences as students (Lortie, 2002). These beliefs, in turn, affect to varying degrees how prospective teachers eventually teach. Teacher education programs' influence is derived from the core education courses required in teacher education programs.

Pedagogical Content Knowledge

The next component of Grossman's (1990) model is pedagogical content knowledge, which combines knowledge of the specific subject matter and knowledge of pedagogy to make content comprehensible for

students. Pedagogical content knowledge consists of four major interacting parts: 1) the teacher's conceptions of the purposes of teaching content (the teacher's beliefs about teaching a specific content area); 2) teacher's knowledge of the students' understanding of the subject (previous knowledge students have of the content); 3) teacher's curricular knowledge (knowledge of subject matter concepts and how they interrelate); and 4) knowledge of instructional strategies (strategies that the teacher uses while teaching the specific content) Gess-Newsome et al. (2017) parse pedagogical content knowledge into three similar constructs: content knowledge (connections within and between topics in the subject area); pedagogical knowledge (links teaching strategies to students learning); and contextual knowledge (how student variations impact decisions for instruction) (p. 7).

Knowledge of Context

In Grossman's (1990) model of teacher knowledge, context is mainly related to the students themselves. The teacher's understanding of students' educational, political, economic, social, and emotional lives will affect how the teacher will think about, plan, and carry out the instruction. Context also includes the school, the district, and the community. The importance of this concept is best captured by a famous quote by Ausubel (1968), "the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (p. vi). The teacher assesses student understanding and guides instruction based on assessment data. Similarly, Freeman and Johnson (1998) consider context as an important feature of the knowledge base. They separate context into two areas: 1) schools, which include the physical building, the social-cultural setting, and the everyday life in the place about which teachers learn and, subsequently, into which they are socialized; and 2) schooling or the social dynamics that are constructed over time, the hidden curriculum of a community, and society's expectations of the schools and students.

Materials development

Teaching materials are pedagogical aids, such as coursebooks or support that facilitate learning in the classroom (Bouckaert, 2019). Whereas teaching materials have been around as long as teaching has been happening, materials development in teaching has been a fairly new area of study (Tomlinson, 2020). Researchers (Bouckaert, 2019; Tomlinson, 2020) maintain that, by necessity, teachers are materials developers because no text is perfect and will fit every situation; rather, teachers must create, adapt, or modify existing materials to fit the needs

of their students, curriculum, or other educational situations or demand. Studies have shown that effective materials development by educators can be a complex and messy process that tends to be cyclical (Bouckaert, 2017; Hadfield, 2014; Timmis, 2014; Tomlinson, 2019).

Studies in materials development can benefit both pre- and in-service teachers. McGrath (2013) posits that materials development has benefits for teachers both in the process of creating materials, as well as the products that are produced, as “it stimulates the examination of beliefs and theories concerning teaching and learning,” (p. 95). Bouckaert’s (2019) research supports this position. She found that participants were able to articulate better their theories of teaching as they designed materials and that teachers developing materials displayed an interplay between tacit knowledge and self-conscious awareness. The knowledge of their content area served as an anchor in the creative process, while the awareness developed as they critiqued and made corrections over time. Popovici and Bolitho (2003) identified, in a textbook development project, the benefits of materials writing for teachers that included increased awareness, greater creativity, and confidence in their teaching. Similarly, Canniveng and Martinez (2003) found materials development can help teacher candidates transfer general knowledge into teaching realities. This was partly accomplished through a process of “inner exploration of self rather than a search for the outward characteristics of a good teacher” (p. 484). A significant finding is that the developer becomes aware of the needs of the learner (Masuhara, 2006) and, related to this realization, that the materials are made from learning, not teaching (Tomlinson, 2016). For the English as a foreign or second language (EFL/ESL) educator, research has shown an increased sense of linguistic awareness (Bouckaert, 2019; Timmis, 2014).

The Study

Background

The current study stemmed from a grant written by the authors to fund a project to create culturally appropriate stories for Thai orphans at a school in southern Thailand. These students receive enrichment in English language training from an independent foundation. The foundation had been gifted electronic tablets from the computer science department of the researchers’ university, and the stories were designed to use the capabilities of the devices. The study itself examined the professional development of three teacher candidates as they developed culturally appropriate materials for Thai students to study on the devices.

We examined initial and final philosophy statements, journals, journal reflection papers, and interviews to meet the following guiding principle of the study: How, if at all, do teacher candidates develop professional knowledge as they create materials in an experience outside their regular course of study?

Research design and data collection

Because of the nature of the data, a qualitative research methodology was deemed appropriate for the study. A phenomenological approach was used to analyze the data because the study recounted the background of a group of individuals and their lived experiences (Creswell, 2013). Phenomenology describes the commonality of the participants' experienced phenomenon to describe an overall consciousness for the group (Creswell, 2013, p. 76). Grounded theory provided the framework to find and structure the themes found within the texts being examined. Grounded theory assumes an inductive stance and strives to derive meaning from the data, where the result is a theory that emerges from, or is 'grounded' in, the data (Creswell, 2013; Merriam & Grenier, 2019). As a descriptive study, this work is an examination of the developing knowledge base of prospective teachers; therefore, it is grounded in the description of one of the potential situations that leads to the learning of this group.

Participants

The participants were selected from a large pool of applicants. The written application consisted of general information about the potential participant, including background, interest, and experience, as well as a creative writing sample. Each participant was then interviewed by a committee of four adjudicators who focused on specific skills needed to complete the task of the grant. None of the participants had ever developed material like the ones proposed for this project. The three selected participants in the study represent three distinct sub-areas of teacher education. Jodi (pseudonym) was an elementary education major in her last year of study with a minor in ESL. She had participated in a study abroad trip to Thailand the previous semester; while there she made significant contacts with the students at a Thai university and developed an appreciation for the Thai culture. It was also thought that her experience with working with ESL students through the work of her minor would help move the project forward. Lucy was a secondary English teaching major also with a minor in ESL. She possessed strong creative writing skills. She was new to ESL coursework and had limited experience with ESL students. Both Jodi and Lucy traveled to Thailand

to collect stories for the project before materials development. The third participant, Kam, was a graduate student and university-level academic advisor who was pursuing a degree to teach college-level courses. She was also a strong creative writer and had taught ESL courses twice before. The participants, throughout the summer and following academic year, collaborated to create short stories from the interview transcriptions of Thai student interviews. The participants wrote many versions of each story, as the stories were increasingly simplified because of feedback from the lead teacher at the foundation about how basic the language levels of the target audiences were. Throughout the entire story development process, the participants also received feedback from professors who were involved with the grant.

Data sources

Participants provided an initial teaching philosophy statement before the project began and submitted journals that focused on their experiences throughout the project. One face-to-face interview was conducted with each participant halfway through the process. Toward the end of the project, participants wrote a journal reflection paper, where they reviewed what they had previously written and reflected on the journal content. Finally, a revised teaching philosophy was submitted at the end of the study.

Data analysis

Typical of qualitative research using grounded theory methodology, all data gathered from each participant were open coded (using NVivo), resulting in 21 distinct categories. With these nominal categories, two of the researchers conducted the data analysis and implemented a constant comparison method (Creswell, 2013), which identified the underlying saturating concept of communicating processes. In the refinement of this category, the researchers again coded and sorted the data of communicating processes and found a relationship of 11 categories. Further analysis revealed two main categories: pedagogical knowledge and collaboration. From this analysis, the researchers together recognized an emerging theory about the participants' growth in their teacher preparation as being due to collaborative work and viewing their learning as a social experience.

Results

Following the data analysis procedures described in the previous section, patterns in the data allowed for an examination of the constructs

drawn from the guiding principle for this study to describe how, if at all, teacher candidates develop in their professional knowledge as they create materials in an experience outside their regular course of study. Through the process of coding the data collection, 11 overarching themes emerged with the two most frequently occurring themes being: 1) pedagogical knowledge and 2) learning as a social experience.

Pedagogical knowledge

This theme, as it emerged, aligned with Grossman's (1990) idea of general pedagogical knowledge defined above. As they developed materials, the participants examined several ideas that influenced two sub-areas of pedagogical knowledge, namely teacher practices and context.

Teacher Practices

This sub-theme is part of both general content knowledge and pedagogical content knowledge, addressing how instruction in and out of the classroom takes place in general and in the content area classroom specifically. The back-and-forth process of working as a team led the participants to think of direct teaching ideas in a new light. First, related to this sub-theme, general references were made, such as "I really never thought about feedback before" or "I learned to appreciate the feedback." Most directly, Lucy, a secondary English major, pondered in her journals that the process of materials development and the feedback that she received from her colleagues mirrored how she will approach her writing classes in the future:

This is something that I have been thinking about in my *how to teach writing* classes but noticed the benefits of when we sat down to edit our story. We had a hard time knowing what to change and what to leave the same. Many of my students may feel that same way when they sit down with their papers. I think that this can be avoided by giving very clear and explanatory feedback.

The next idea connected to pedagogical knowledge is the approach to teaching. Jodi considered the idea of approaches when she recalled the process of gathering the stories that she later developed for the same the students and talked about having "found other successful strategies in building vocabulary and speech." She continued with a description of a pattern of introducing a new word, reminding the speaker that they had learned the word and providing a synonym. She further noted, "I found

this interesting as some students would then use the second word in their vocabulary. This way their knowledge was scaffolded in such a way that they were able to learn two or more words and add them to their vocabulary.” As a final statement in describing the process, she emphasized, “This [process] will be helpful to use in the future.”

The last aspect of pedagogical knowledge that the participants pondered was what thoughts and ideas influence teaching and teachers. Kam realized as she thought about her approach to developing materials and what was expected that teaching “depends on the strengths and weaknesses of the individual teacher.” In her final philosophy statement, Lucy discussed some broad, yet vital influences on being a teacher and how they relate directly to her situation:

My first principle is that I study myself. To me, this means that I am constantly aware of what I am doing and that I stay mindful of why I am doing things the way that I am. Many things influence the way that a teacher teaches: past experiences, educational training, colleagues, teaching situation, materials available, students, and legislation. Although none of these influences are strictly bad, doing things without realizing why I am doing them can be. I could end up teaching as I was taught, even if that is not the best way to teach.

Realizing that these ideas are in place, Lucy continued by examining how they could potentially affect her classroom:

Because I am aware of these influences, I can choose how much these influences affect me. I plan to evaluate myself regularly and ask myself why I am doing things the way that I am. By remaining self-aware, I believe that I will be able to avoid negative influences on my teaching and avoid having a negative attitude toward my students. The only thing I can control is my attitude.

Context

This sub-theme addresses the space (school, community) where teaching takes place, the students themselves, and the dynamic of the social situation where learning takes place. The other area of pedagogical knowledge that came to the fore was the context of teaching. In the present study, the participants wrote about being aware of the students for whom they were developing the materials. During her interview, Kam expounded on needing to know the students who will learn from the materials and that relying on her knowledge and experience were not

sufficient, “It’s not just to say, oh, I’m going to cook up something cool to teach these people English. It’s critical to have a direction of who am I teaching and what is the aim that I’m going for.” In a later journal, she revisits this issue as she tries to decide what level of language she can use for the stories, particularly verb tenses and idioms.

Learning as a social experience

The other major theme that manifested from the data deals with the interactions among the education community. Three distinct sub-themes came out of the data related to this theme: 1) self-realization; 2) collaboration; and 3) culture.

Self-realization

In taking part in the group project, the participants discovered that they were actively taking part in learning as a social experience and made connections to their future careers. Two of the participants discussed outright that they socially approach their learning. In her interview, Jodi explicitly stated that “I am a social learner.” Similarly, Lucy stated in her interview that “I learn a lot more socially, and I think it’s because I have this perception and I try to have an open perspective but when I work with a group it’s like: ‘oh, I would have never thought of that’ or ‘oh, that’s a really good idea,’ and then because I get little bits and pieces of other people’s opinions or ideas then I’m better able to expand or form my own opinion or ideas.” These comments suggest that they are well aware that learning is not accomplished in a vacuum but must include others.

Collaboration

The participants narrowed their social learning experience to the concept of collaboration or working in pairs (or small groups) on writing, editing, and creating pedagogical materials that helped to develop greater knowledge. For this sub-theme, the participants frequently considered the idea of sharing previous knowledge that helped move the project forward. Speaking generally, they wrote about abilities or other materials that would enhance the project’s development. Lucy’s journal entry summed up the ideas conveyed by “a lot of really cool materials that we use” in conjunction with writing the stories and creating pedagogical activities. The participants also discussed active collaboration as they interacted and co-constructed knowledge throughout the project. About writing the stories, Lucy pointed out that “[i]t is nice to be able to collaborate and bounce ideas back and forth off of each other.” Further attention is directly linked to the needs of students and how they can be

aided in learning with ideas such as “[I realized] how important it is to give students specific feedback. When I tell them that something is good, I want to make sure to explain what is good about it.” Similarly, Kam wrote in her journals about the importance of using rubrics in teaching.

The participants also considered the target audience of the project or the students who would be reading and learning from the materials. On one level, they considered learners in general and referred to the experience that their partner had working with and how it potentially helps. Lucy commented, “She works with kids, which also helps because, like, little things that we need to use a specific font and stuff like that.” More directly to the Thai students, Kam stated,

Anyway—writing the more advanced version was fun, but tricky as I kept looking at it through the eyes of a student. How many verb tenses can they handle? Idioms? I have the kids saying things like “Wow!” or “Great!” Maybe P [a Thai speaker, connected to the project] can help out here? What would a Thai kid say? Also, the kids are thanking their uncle. Is that a lot more formal in Thailand? Should the uncle have an honorific?

Finally, the teacher candidates commented on the task of collaboration itself and how it can be experienced for better and/or for worse. Jess stated, “I don’t think group work is always good. I am sure that we all have our own group work project horror stories.” Kam pointed out some similar feelings but also suggested that not all is a challenge when she wrote that she “[will] never love working in a group but coordinating with computer science seems to be the best of both worlds or teamwork and individual creativity.” Overall, these ideas seemed to lead to the realities of the teaching workplace. The following journal entry statement from Lucy sums up how collaboration ideally works for educators,

But when everyone is committed, working as a group can be very productive and fulfilling. I think that when I am a teacher I am going to be very grateful if I am in a school where the department collaborates at times.

Culture

Culture relates to both pedagogical content knowledge and knowledge of context as these constructs deal with the learner and how they comprehend materials, specifically how their culture is key in accessing the concepts presented through instruction. Lucy and Jodi traveled to Thailand at the beginning of the project to collect stories from

native Thai students and found that they learned through this process. Jodi wrote in her journals what she took away from this step in the process, “That was one of my favorite parts about being in Thailand is just talking to the different people; have them tell me stories, like why do they have this in front of their yard and stuff. It’s cool.” Lucy had a similar point-of-view about such interactions, but connected it more explicitly to herself as a learner and, potentially, a teacher, “it’s been really cool to learn so much from that but just realizing from that every culture has so much going on and that I do not know and I feel like it’s made me more comfortable asking questions to people about their culture and background.”

Discussion

The results of the present study align well with the previous research on teacher education, teacher knowledge, and materials development and how the various areas interact to increase pre-service professional knowledge development. The participants were placed in a unique situation that allowed them to consider ideas about their future profession. The results of the present study tended to focus more on the students who would receive the materials, rather than on the approaches the teacher candidates would use themselves. As the research data also tended to focus on writing the stories and less on pedagogical materials, this finding is not surprising.

The participants were taking part in a project where the creation of the materials occurred in an environment that mirrored the social nature of learning, which provided them the opportunity to see how collaborative actions are part of their future teaching and are vital to the success of teachers in the classroom. Both Grossman (1990) and Freeman and Johnson (1998) discuss the importance of collaboration in schools, where teachers need to be aware of the social nature of the school environment that includes working with administrators, counselors, and para-professionals, among others. The participants made meaningful connections to their future teaching situations and explored ideas related to the social nature of learning, which manifested frequently as they considered their students. The participants often made direct references to their thoughts about the social experience of learning, including the benefits of group work along with considering ideas about important daily teacher tasks, such as providing effective feedback to their future students and establishing a classroom environment where the students can feel safe to express themselves. These ideas support Popovici and Bolitho’s (2003) findings that pre-service teachers grew more generally aware of teaching, as well as Masuhara’s (2006) ideas

that material developers are more cognizant of learners' needs for instruction. This project put participants into a position to examine their beliefs and theories of teaching and to articulate the same (Bouckaert, 2019; Canniveng & Martinez, 2003). Directly connected to these ideas were the findings of considering how teaching and learning happen.

The results also showed clearly that the project allowed the teacher candidates the opportunity to examine their beliefs and theories about teaching, which give credence to McGrath's (2013) and Bouckaert's (2019) results. The current findings stemmed largely from the consideration of the Thai recipients of the materials. In creating the materials, the participants often referred to the students who would be using the stories. They were guided by making certain that the materials were at appropriate levels for skills that the students possessed. Likewise, they had to consider ideas of culture and whether the recipients would be able to relate to the stories. These findings support several aspects of Shulman's (1986) and Grossman's (1990) early work and how that work connects to dealing with students. The participants discussed several parts of pedagogical content knowledge in the data sources. They explored the need to take the subject matter and make it comprehensible to students. The data showed that they considered ideas such as vocabulary (including idioms) and culture (honorifics). This also supports Gess-Newsome et al.'s (2017) idea of contextual knowledge or how student variations impact decisions for instruction (p. 7). These findings also support the Teacher's Commission on Teaching and America's Future's concept of clear vision in teaching. Examining how their decisions influence their students' learning better positions them to do what is best for the students. Concerning students, the participants pondered ideas related to culture, supporting Darling-Hammond's (2017) assertion that developing pre-service teacher's knowledge about diverse students is a crucial part of pedagogical knowledge and theory. All these considerations about students and their learning correspond well with Ausubel's (1968) assertion that teachers need to "learn what the learner already knows" to make learning successful for them.

The results further support the idea that the collaborative environment of a space outside of a teacher education program can be a move in the right direction to have teacher candidates experience what they will eventually experience in a classroom, school, or district setting. Historically, the space for teacher education has changed as the demands of more effective teacher preparation has been called for (Labaree, 2008; Zeichner, 2016). The research has generated findings that support the idea of creating new and different learning spaces for these changes to happen (Stürmer et al., 2016). Such a project is an authentic forum for teacher candidates to further their path to becoming professional

educators (Schulz, 2000; Tomlinson, 2014). As seen through the lived experiences of participants in the present study, a materials development project accomplished outside the main curriculum of the teacher education program provided fertile ground to consider ideas directly connected to their professional development.

Lastly, the study supports Tomlinson's (2020) assertion that materials development is an area that needs more study. The results indicated that the development of authentically appropriate stories for a specific audience provided ample opportunities for pre-service teachers to consider the various aspects of teaching (Bouckaert, 2019; McGrath, 2013). The experience proved to be complex and messy at times, supporting the findings by Bouckaert (2017), Hadfield (2014), and Tomlinson (2019). The participants spoke frequently about having to revisit ideas and approaches in creating the stories. They indicated that they often did so with the aid of others taking part in the process as well.

Conclusion

Lucy's journal entry, stating that "I study myself. To me this means that I am constantly aware of what I am doing and that I stay mindful of why I am doing things the way that I am," seems to sum up the process that all the participants went through while creating culturally appropriate materials and connecting it to their professional development. The themes manifested throughout all the data suggested that the participants recognized professional knowledge growth in their teacher preparations and also came to new knowledge through collaborative work and that for both teachers and learners, learning is a social experience. By going through the process of creating materials, they had the opportunity to explore their preferences or biases in learning, which they considered with their teaching such as recognizing that they are social learners or that their past experiences could influence their future practices (Lortie, 2002). The reflective self-analysis intertwined throughout the expression of the lived experiences of the participants, allowed them to consider the demands of teaching and gave them pause to think about how their actions will potentially influence their future students, classrooms, and schools.

Application

The context of the present study was situated in connection with a foundation in Thailand, but the idea of materials development within the arena of authentic learning can happen anywhere. As teacher candidates are taught about the use of materials for any classroom or other learning situations, the same principles can be applied. First, in a classroom

situation, teacher educators can start by emphasizing the need to look at the contextual factors, such as gender and/or the ethnic makeup of the classroom, the culture of the school and its surrounding community, and socioeconomic status, affecting the field experience location throughout a program. As teacher candidates prepare to practice teach, they can and should be encouraged to adapt and develop materials to meet the needs of their students. Second, outside of the classroom situation, the same ideas can be applied to service opportunities, like before- or after-school programs, tutoring in the community being served, and so on. As teacher candidates consider and implement pedagogical concepts, even as basic as the vocabulary used in the materials or cultural issues presented by authors and how they can (and should) change them, that directly influence their classroom of students, they can challenge or support their belief systems (Byrd, 2013). Teacher educators, in turn, can help them via journaling and other forms of reflective practice, examine their beliefs, and how they change and develop through the process.

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Heat Transfer Analysis of Eicosane in a Vertical Cylinder During Freezing Phase Change

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Abstract

To better understand the heat transfer through materials undergoing a phase change, experiments were conducted using eicosane as it went through the freezing process. Liquid eicosane at 50°C was placed in a cylindrical test vessel and cooled from the outer surface of the vessel by using a counterflow heat exchanger. The heat exchanger provided constant temperature cooling by means of a constant temperature bath system. An initial analysis of the data showed that a steady fusion temperature of ~35.6°C was achieved before the eicosane solidified. By analyzing the temperatures recorded by the thermocouples, we obtained detailed quantitative time-dependent volumetric temperature distributions, freeze-front motion, and shape. Under idealized conditions, the phase-changing material (PCM) behaves as a thermal lumped capacitance, providing cooling (or heating) for a wide range of heat transfer rates at a single temperature corresponding to its melting-point (fusion) temperature. In practice, this temperature exists only at the solid/liquid interface. As the PCM freezes, the interface moves away

from the surface of the heat source, and a thermal resistance layer is built up, resulting in a reduced heat transfer rate and/or increased temperature difference between the system to be cooled and the PCM. Results have been generalized to apply to any low-Stefan number PCM. By examining the data collected from this experiment, the phase change behavior of eicosane was characterized.

Introduction

During the phase change from liquid to gas, a phenomenon occurs in which the temperature of liquid does not exceed its boiling temperature. As heat is added to the liquid, any excess thermal energy is consumed in the breaking of intermolecular bonds. This added heat is called the latent heat of vaporization. The temperature of the liquid can only continue to increase after all of the bonds are broken and the liquid is completely transformed into vapor.

This constant temperature phenomenon also happens when a liquid changes to a solid. As heat is removed from a liquid, crystal structures form and release heat. This process keeps the temperature constant until all the liquid has turned into a solid. When completely solid, the temperature drops below the freezing temperature of the material. The total energy removed from a material to change it from a liquid to a solid is the latent heat of fusion.

As interest grows in finding cleaner and more efficient ways to utilize energy, so does the interest in using the passive thermal energy released or absorbed when material changes phase. Because temperature remains constant during a phase change, phase-changing materials (PCMs) can be used as heat capacitors to maintain a specific temperature (fusion or vaporization temperature) without requiring any additional energy. Possible uses of these phase-changing properties include the cooling of organs for medical use, passive heating/cooling devices for satellites, higher efficiency HVAC systems, and constant temperature heat sinks for delicate laboratory equipment. A review of the experimental literature [11-18] shows the active and ongoing process of understanding the behavior of melting or freezing of a PCM in externally heated or cooled cylinders.

To better understand PCMs, a detailed experimental study was performed to evaluate the heat transfer performance of a liquid-to-solid phase-change energy storage system. The PCM was contained in a vertically oriented test cylinder that was cooled radially inward from its outside boundary (circumference). Cooling was provided by the fluid flow of a constant temperature bath (CTB) system with a counterflow

heat exchanger wrapped tightly around the cylindrical test vessel. As the PCM froze, it was predicted that the solid/liquid interface inside the vessel would move radially inward from the inner surface of the vessel. At the same time, the frozen PCM would build up a thermal resistance layer. This was expected because the solid phase of a PCM has a lower thermal conductivity than the liquid phase. Accordingly, this ever-thickening solid layer would reduce the heat transfer rate between the CTB and the liquid PCM.

In this undergraduate research experiment, a copper test vessel was filled with liquid eicosane and cooled from 50°C to 10°C. During this process, the eicosane completed a phase change from liquid to solid. These tests were performed to evaluate the total heat transfer required to complete the phase change and to perform a detailed system operations test. In the freezing case study, a one-dimensional mathematical model was developed to display the rate of freezing in the radial direction, which considered conduction as the only mode of heat transfer. Additionally, a comparison of experimental data with analytical predictions of the solid/liquid interface position and temperature distribution was performed.

Test System and Procedure

The cylindrical copper vessel in Figure 1 contained the eicosane for the experiment. Also shown in Figure 1 are the copper cooling tubes in contact with the vessel.



Figure 1. Copper vessel with copper tubing wrapped in a helical arrangement.

The cooling tubes allowed the coolant to flow around the vessel and cool the PCM inside. They are tightly wrapped in parallel, providing a counterflow heat exchanger that uniformly cooled the vessel. The temperature of the eicosane in the vessel was monitored using the thermocouple (TC) tree shown in Figure 2.



Figure 2. Thermocouple tree used to measure water temperature.

Figure 2 does not show the complete arrays of TCs in place. The TC tree was placed inside the test vessel such that the center of the tree was aligned with the vertical central axis of the vessel. Ten thermocouples were used on each row, and there were nine rows. The outer two columns of TCs are attached to a printed circuit board (PCB) board referred to as “chip A,” the next two columns (moving inward) are attached to “chip B,” the next to “chip C,” and so forth. Chip F is used for the component TCs and other miscellaneous reference points. The temperature at each point was recorded at 60-second intervals using the data acquisition system. An illustration of the TC tree showing the relative location of each TC in the cylinder is presented in Figure 3.

The vessel, coolant tubes, TC tree, piping, and CTB were assembled as shown in Figure 4. In this figure, the insulation is removed to present the system clearly.

To evaluate the heat transfer performance of a liquid-to-solid phase change energy storage system, the CTB and coolant were used to bring the eicosane from 50°C to 10°C while the data acquisition system recorded the temperature via the TC tree. It should be noted that data collection began and ended only when the system was at a steady state.

A 2	A 3	B 2	B 3	C 2	C 3	D 2	D 3	E 2	E 3	C E N T E R O F C Y L I N D E R
A 4	A 5	B 4	B 5	C 4	C 5	D 4	D 5	E 4	E 5	
A 6	A 7	B 6	B 7	C 6	C 7	D 6	D 7	E 6	E 7	
A 8	A 9	B 8	B 9	C 8	C 9	D 8	D 9	E 8	E 9	
A 10	A 11	B 10	B 11	C 10	C 11	D 10	D 11	E 10	E 11	
A 12	A 13	B 12	B 13	C 12	C 13	D 12	D 13	E 12	E 13	
A 14	A 15	B 14	B 15	C 14	C 15	D 14	D 15	E 14	E 15	
A 16	A 17	B 16	B 17	C 16	C 17	D 16	D 17	E 16	E 17	
A 18	A 19	B 18	B 19	C 18	C 19	D 18	D 19	E 18	E 19	

Figure 3. Representation of the location of each thermocouple in the cylinder.

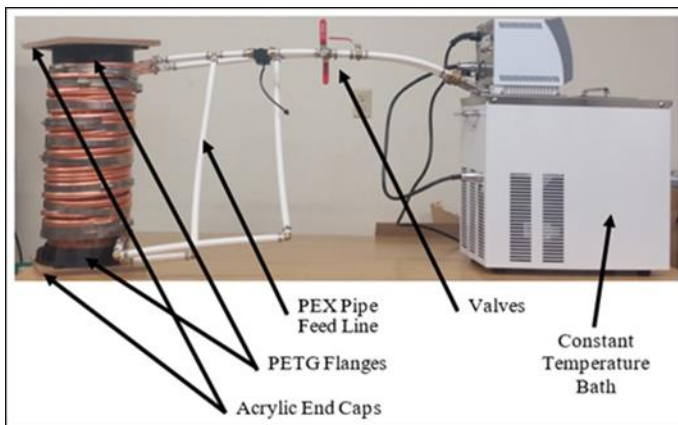


Figure 4. Experimental setup.

Heat Transfer Analysis

To simplify the analysis of the freezing process, the following assumptions were made:

1. No convection or radiation heat transfer in the solid and liquid.
2. One-dimensional heat transfer in the radial (r) direction.
3. Physical properties are independent of temperature but different for each phase.
4. Overall volume change due to phase change is negligible.
5. The solid–liquid interface is clearly defined (i.e., the PCM has a well-defined fusion temperature).
6. No heat source or generation.

During a freezing experiment, there are three contributors to the total heat transfer at any time: the (I) latent heat released by freezing, Q_{fus} ; (II) sensible heat released by subcooling of the frozen solid below the fusion temperature, Q_{fus-s} ; and (III) sensible heat released from the liquid as it cools to the fusion temperature, Q_{l-fus} . These three contributors are described in detail below.

If m_s (kg) is the mass of eicosane wax at any time and Δh_{fus} (kJ/kg) is the latent heat of fusion released by the freezing process, then the total heat of fusion (kJ) released is given by [1]:

$$Q_{fus} = m_s \Delta h_{fus} \quad (1)$$

The second component of energy is the sensible heat released by subcooling of the frozen solid below the fusion temperature, Q_{fus-s} . It is expressed as [1]:

$$Q_{fus-s} = m_s c_{ps} (T_{fus} - T_m) \quad (2)$$

where c_{ps} (kJ/(kgK)) is the specific heat constants of the solid, T_{fus} (°C) is the fusion temperature, and T_m (°C) is the mean temperature of the frozen mass at the end of the test. The mean temperature is then defined as [2]:

$$T_m = \frac{\int_{r_{fus}}^{r_w} T(r) \rho_s 2\pi r \, dr}{\int_{r_{fus}}^{r_w} \rho_s 2\pi r \, dr} = \frac{\int_{r_{fus}}^{r_w} r T(r) \, dr}{\frac{1}{2} (r_w^2 - r_{fus}^2)} \quad (3)$$

where the bounds of integration are from the solid–liquid interface radius, r_{fus} (m), to the outer tank radius (wall), r_w (m), and ρ_s (kg/m³) is the density of the solid.

The local radial temperature in the solid, $T(r)$, was evaluated by postulating a quasi-steady state model and solving the energy equation [2]:

$$d\left(k_s r \frac{dT}{dr}\right) = 0 \quad (4)$$

where k_s (kJ/(kgK)) is the solid thermal conductivity. This equation is subjected to the boundary conditions

$$T = T_{fus} \text{ at } r = r_{fus}$$

$$T = T_w \text{ at } r = r_w$$

where w denotes the location of the wall (the outer tank rank). Solving Eq. (4) for $T(r)$ yields

$$T(r) = \frac{T_w - T_{fus}}{\ln(r_w) - \ln(r_{fus})} \ln\left(\frac{r}{r_{fus}}\right) + T_{fus}. \quad (5)$$

Substituting Eq. (5) into Eq. (3) and then integrating Eq. (3) yields T_m for solid eicosane, given as

$$T_m = \frac{(T_w - T_{fus})r_w^2}{r_w^2 - r_{fus}^2} - \frac{T_w - T_{fus}}{2(\ln(r_w) - \ln(r_{fus}))} + T_{fus}. \quad (6)$$

The temperature-dependent specific heat of liquid eicosane, c_{pl} (kJ/kg.K), is based on the correlation [3] given as

$$c_{pl} = 2.0395 + 0.004539T. \quad (7)$$

The final energy component, Q_{sen} , is the sensible heat released from the liquid, which remains unfrozen at the time of interest [3]. It is defined as

$$Q_{sen} = m_l \int_{T_b}^{T_i} c_{pl} dT \quad (8)$$

where m_l (kg) is the unfrozen eicosane left at end of the test and T_b (°C) is the bulk temperature of residual liquid. For sufficiently long times, T_b becomes equal to the T_{fus} . In this case,

$$Q_{l-fus} + Q_{sen} = m_{tot} \int_{T_{fus}}^{T_i} c_{pl} dT \quad (9)$$

where m_{tot} (kg) is the total eicosane mass in the tank. From Eqs. (1), (2), and (9), the total heat transfer from eicosane, $Q_{eicosane}$, is defined as

$$Q_{eicosane} = Q_{fusion} + Q_{fus-s} + Q_{l-fus} + Q_{sen}. \quad (10)$$

Using the technique mentioned earlier, the heat extracted from the system components could be estimated from the thermocouple data at any time. The total heat transfer for each component may be expressed as

$$Q_2 = m_{comp} c_{p,comp} (T_{f,comp} - T_{i,comp}) \quad (11)$$

where Q_2 (J) is the heat transfer to/from a component, m_{comp} (kg) is the mass of the component, c_p (kJ/(kgK)) is the specific heat of the component, $T_{f,comp}$ (°C) is the temperature of the given component at the time in question, and T_i (°C) is the initial temperature of the component.

The amount of heat removed from the system by each component was determined by monitoring the temperature of each component using thermocouples. The initial temperature remained constant whereas T_f varied as time proceeded. This indicated the total amount of heat removed by the component at that moment.

The heat removed from the system by the CTB fluid was based on the temperature difference between the inlet and outlet of CTB. The heat removed from the eicosane and components was based on the temperature reported by the thermocouples.

The incremental heat transfer (Q_2) from the cooling system was determined by finding the inlet and outlet temperatures of the CTB fluid for a given time step. The incremental heat transfer (Q_2) from the system to the CTB fluid for a given time step is given by the product of the instantaneous heat transfer and change in the time:

$$Q_1 = \sum \dot{m} c_p (\Delta T) \Delta t \quad (12)$$

where Q_1 is heat transfer to CTB (kJ), $\dot{m}$ (kg/s) is the mass flow rate of CTB fluid in the tubes, c_p (kJ/(kgK)) is the specific heat of the CTB fluid, ΔT (°C) is the instantaneous temperature difference between the inlet and outlet flow, and Δt (s) is the time step. At every time step, the heat transfer from the CTB flow was calculated. At the end of the test run, they were added up to evaluate the cumulative integral heat transfer.

If there is no parasitic heat loss to environment, the energy added to the CTB fluid, Q_1 , is equal to the energy removed from components, Q_2 , plus the energy removed from eicosane, $Q_{eicosane}$.

Results and Discussion

Table 1 shows the mass and specific heat of the components of the system. The mass of each component was measured before the experiment. All values shown were used in the evaluation of the final heat transfer results. Table 2 shows the specific heat, density, mass, and heat of fusion for the working fluid of the CTB, liquid eicosane, and

eicosane wax. The mass of each component was measured several times before the experiment and the average masses were used in the analysis.

Table 1. Mass and specific heat of components		
Components	Specific heat (kJ/(kgK))	Mass (kg)
Acrylic [4]	1.460	1.280
PETG flanges [5]	1.300	0.480
Copper vessel [6]	0.377	3.230
Copper tubing [6]	0.377	4.820
PEX tube [7]	2.300	0.241

According to the manufacturer, the fusion temperature of 99% eicosane is 35–37°C [10]. To experimentally evaluate the fusion temperature of eicosane, data from 69–99 minutes, when freezing occurred, was analyzed. The temperatures are consistent in this region and the average fusion temperature was determined to be 35.6°C. From now on, the freezing temperature of eicosane will be considered as 35.6°C.

Table 2. Thermal properties of working fluid and liquid eicosane				
Components	Specific heat (kJ/(kgK))	Density (kg/m³)	Mass (kg)	Heat of fusion (kJ/kg)
CTB fluid	1.46 [8]	9.70 [8]	N/A	N/A
Liquid eicosane	4.81 [5]	788.6 [9]	6.8	239.94 [6]
Eicosane wax	2.108 [5]	788.6 [9]	6.8	239.94 [6]

Figure 10 shows the temperature of eicosane decreases at a very high rate until it reaches the steady fusion temperature of approximately 35.6°C, where it undergoes a liquid/solid phase change. The time required for each column to reach freezing temperature increases slightly, and the time spent at freezing temperature increases significantly as the distance between the TC column and the outer wall increases. This behavior was expected because of the insulative nature of the solid eicosane phase that builds up on the inside wall of the vessel. This built-up layer of eicosane proceeds to thicken in the inward radial direction as energy is removed from the system.

Figure 11 shows the average radius from the center of the vessel at 37 different points in time over a 459-minute interval. Inspection of the chart shows that the progression of the freeze-front is not linear. This occurs as a result of the increasing insulative effect of the freeze-front as it progresses. Each new layer takes longer to freeze than the last.

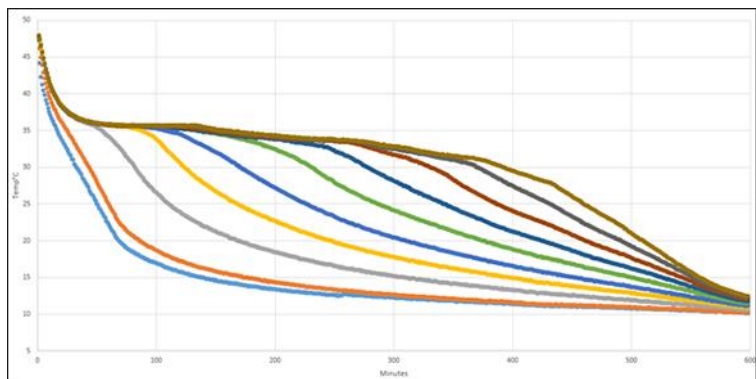


Figure 10. Average temperature of each individual column.

Using linear regression, a third-order polynomial equation was found that represented the freeze-front progression with an appropriate level of accuracy. This equation (presented in Fig. 11), was used in Eq. (6) to predict the latent heat of fusion transferred during the phase change process.

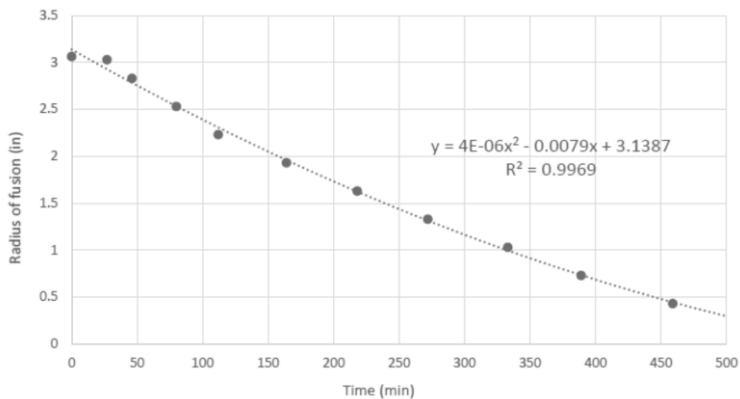


Figure 11. Radius of fusion.

Figure 12 shows the cumulative heat removed from components and heat gained by the CTB. This figure shows how quickly components reach the steady-state conditions. Studying this figure shows that the CTB does not reach the steady-state condition. This behavior indicates the presence of parasitic (wasted) heat transfer to the environment

(room). The heat removed by the CTB fluid was significantly higher than the heat removed from the eicosane.

Because of this discrepancy in reported energy transfer, a correction factor was necessary to correct the error due to parasitic heat transfer. The correction factor was found by noting the difference between the cumulative heat transfer change of the working fluid and the heat transfer from components. The difference was plotted over time and given a trend line. This trend line equation was then added to the heat transfer change of the working fluid to produce the corrected $\dot{m}$ plot on Figure 12. By considering the parasitic heat, the heat transfer to the CTB fluid becomes flat and parallel to the heat transfer from the components. It can be seen that this correction produced a very similar trend to the calculated heat change of the system and the CTB fluid reaches the steady-state condition. It also should be mentioned that in Figure 12, the difference between the corrected CTB heat transfer and the heat transfer from components is the heat removed from eicosane.

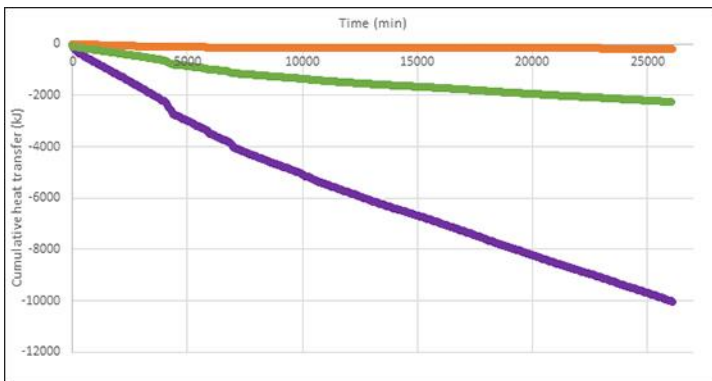


Figure 12. Cumulative heat transfer from components and CTB fluid.

The heat removed by $\dot{m}$ in Figure 12 also shows a steep slope, indicating that the initial amount of energy removed was large in the first part of the experiment. Later, the slope flattens out as the system approaches steady state. During the heat transfer calculations of the working fluid, a $\dot{m}$ value of 0.4675 kg/s [8] was used. This value was calculated using the expected output of 30 lpm from the CTB.

Figure 13 shows the cumulative energy removed from eicosane and components with respect to time. The heat of fusion is not taken directly from TC data but is calculated in a two-step process by Eq. (12).

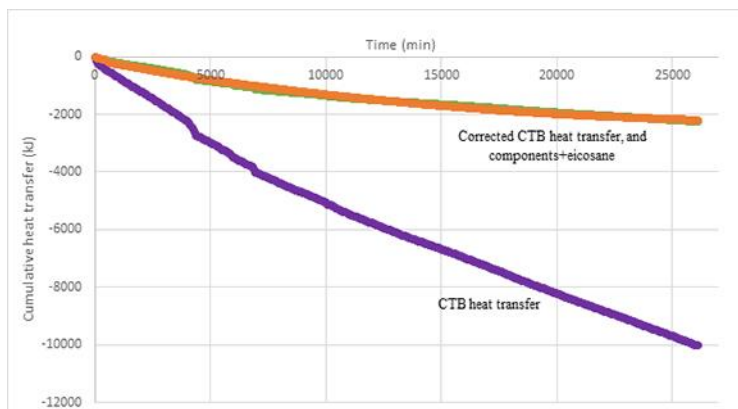


Figure 13. Cumulative energy removed from eicosane with respect to time.

The mass of the frozen eicosane at any given time was evaluated by substituting the value for time into the equation found in Figure 11. With the mass of frozen eicosane at that time, it was substituted into Eq. (1) to find the total heat of fusion released by the eicosane at the time in question. The sensible heat removed from liquid eicosane is evaluated by using Eq. (8). In this evaluation, it is assumed that the specific heat of liquid eicosane is constant.

Recommendations

In an effort to obtain more accurate results in future testing, holes should be drilled into the system, with the thermocouples being placed directly into the fluid flow stream. Doing so will allow researchers to obtain the most accurate temperature readings. Furthermore, adding an insulating enclosure around the test vessel may reduce the amount of parasitic heat loss and aid in the collection of more accurate data. Additional recommendations to improve the accuracy of the experiment include:

- Improving the heat shield design
- Improving the pipe insulation
- Adding insulation to the top lid
- Adding a fan and possible ductwork to redirect waste heat from CTB
- Relocating the temp in/out thermocouples

A borescope can also be purchased to observe the interior of the test vessel without disassembling the lid and thermocouple tree.

Conclusion

A detailed experiment was conducted to evaluate the performance of a thermal energy storage system utilizing eicosane as a PCM. These tests were performed to evaluate the total heat transfer required to complete the phase change and to perform additional systems operational testing.

In the freezing case study, a one-dimensional mathematical model was developed to display the freezing rate of eicosane in the radial direction. This model considered conduction as the only mode of heat transfer. Additionally, a comparison of experimental data with analytical predictions of the solid/liquid interface position and temperature distribution was performed. The temperature analysis revealed that, similar to the water experiment, the top surface of the eicosane froze first, indicating heat transfer in the vertical direction. Once the layer of solid eicosane wax on top of the liquid column reached sufficient thickness, the insulating properties of the wax became great enough to calculate the remaining thermocouple data as though freezing only occurred in the radial direction. As such, the experiment was considered to have one dimensional heat transfer in the radial direction.

The results of the analysis also revealed that an approximate steady temperature of 35.6°C was achieved before the eicosane froze. By characterizing the liquid/solid phase change process of eicosane, the groundwork has been laid for further eicosane testing using metal foam as a heat transfer matrix to circumvent the insulation effects of the solid-state buildup around the outer wall.

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Analytical Solutions for Inward Solidification of a Phase Change Material in a Cylindrical Coordinate System: Part I

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Abstract

In this paper, we analytically predict the inward freezing of a phase-change material (PCM) system, eicosane ($C_{20}H_{42}$), in a cylindrical enclosure. A quasi-steady-state heat transfer analysis was conducted, and the experimental results were compared with theoretical predictions. The heat transfer analysis consisted of (I) implementing a calorimetric heat transfer measurement with eicosane to ensure that the system was functioning properly; (II) conducting an incremental heat transfer analysis using data from thermocouples; and (III) using mathematical models such as the Heat Diffusion Energy Conservation and Conduction Model to present a detailed quantitative analysis. We also discuss how the analytical and experimental results support one another by presenting mathematical models that yielded time-dependent volumetric temperature distribution and freeze-front motion distribution

plots. Predictions from previous experimentation are also presented to further validate the results of this work. This work is accompanied by two other papers in this issue.

Introduction

We are motivated by the opportunity to do hands-on research in an engineering discipline that goes beyond what we learn in our heat transfer course, especially as undergraduate students. In conducting this research and writing this paper, we anticipated growing in our presentation, writing, and general skills, which are important as future engineers. Much of this mindset was influenced by our professors who emphasize the importance of proper communication in the workplace as an engineer, and the development of those necessary skills occur beyond the classroom walls.

To better understand the behavior and importance of the freezing of a phase-change material (PCM) in externally heated or cooled cylinders, a literature review was conducted. The latent heat thermal energy storage is a passive and effective approach to increase energy efficiency of a thermal system [1] and also it is passive with no mechanical parts to introduce vibration [2]. The high storage density is advantageous, because PCMs have the potential to increase the energy density of small and medium-sized tanks [3]. The eicosane PCM is used in this experiment. Because of its thermal properties, it has been used in many experiments [4].

To minimize the wasted (parasitic) heat, eicosane with a melting temperature of approximately 36.5°C was selected as the PCM. Eicosane also has the following characteristics that make it a satisfactory PCM:

7. High heat of fusion per unit of mass and volume;
8. Proper melting point and reversible solid-to-liquid transition;
9. Relatively high thermal conductivity, density, and specific heat;
10. Low vapor pressure;
11. Noncorrosive and nontoxic;
12. Low coefficient of thermal expansion;
13. High flash point;
14. Good wetting characteristics; and
15. Stable and pure.

Previous Work

This project expanded on the research conducted by previous students for over a period of two years. The previous students designed and constructed a test system to be used to research the thermal behavior of the solid–liquid PCMs. The system consisted of a vertical copper test cylinder that was heated and cooled inwardly by using copper tubing wrapped in a counter-flow arrangement around the outside of the test cylinder. The tubing was connected to a constant temperature bath (CTB) that provided fluid to heat or cool the copper cylinder in the range of -20°C to 100°C . The solidification progress of the phase change was monitored using an array of more than 100 thermocouples. The experimental setup (without the system insulation) is shown in Figure 1.

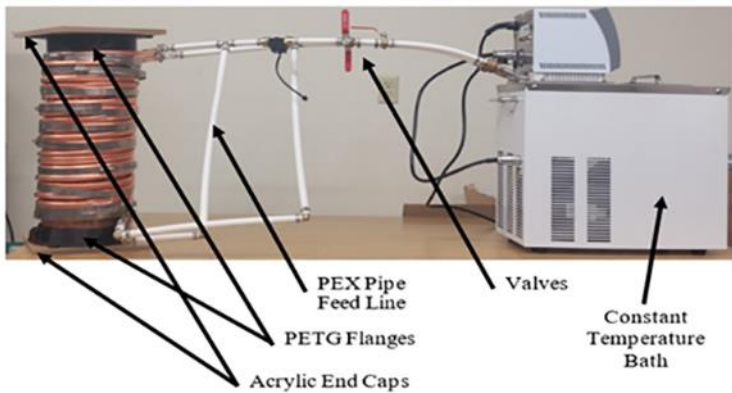


Figure 1. Setup of the test system.

Prior to our analysis, a copper test cylinder was filled with liquid eicosane in a vertically oriented test cylinder that was radially cooled inward from its outer circumference. Cooling of the eicosane from 50°C to 10°C was provided by the fluid flow of a CTB system with a counterflow heat exchanger wrapped tightly around the test cylinder. As the eicosane changed phase and solidified, it was expected that the solid/liquid interface inside the cylinder would move radially inward from the inner surface of the cylinder, and a thermal resistance layer would be built up by the frozen eicosane [5].

Heat Diffusion Analysis

In this section, a mathematical model is presented to determine the one-dimensional temperature distribution. The following assumptions were made to simplify the heat transfer analysis:

1. No convection or radiation heat transfer in the solid and liquid.
2. One-dimensional conduction heat transfer in the radial r direction.
3. Physical properties are independent of temperature but different for each phase.
4. Overall volume change due to phase change is negligible.
5. The solid–liquid interface is clearly defined.
6. No heat source or heat generation.

The initial and boundary conditions for freezing are:

$$\begin{aligned}
 T_l &= T_i \text{ for } t \leq 0 \\
 T_s &= T_w \text{ at } r = r_w \\
 T_s &= T_l = T_{fus} \text{ at } r = r_{fus} \\
 \frac{\partial T}{\partial r} &= 0 \text{ at } r = 0
 \end{aligned} \tag{1}$$

where T is temperature ($^{\circ}\text{C}$) and subscripts i , w , s , l , and fus refer to states at the initial position, wall, solid, liquid, and fusion, respectively. The last boundary condition in Eq. (1) describes the symmetry with respect to the centerline.

To analyze the temperature distribution, an energy balance at the interface is performed. Figure 2 depicts a cross-section of the test cylinder with liquid freezing inwardly. On the left side of the freeze front, there is a liquid of density ρ_l and velocity U_l , and on the right side is a solid of density ρ_s and velocity U_s .

The resulting equation for mass conservation is

$$\rho_l U_l A = \rho_s U_s A \tag{2}$$

where A (m^2) is the cross-sectional area of the control volume.

The resulting energy balance on the control volume (within the dotted line on Fig. 2) is expressed as

$$Q_{in,cond} + Q_{in,conv} = Q_{out,cond} + Q_{out,conv} \tag{3}$$

where q (W) is the heat transfer rate. The subscripts attached to each term indicate the direction of the heat transfer (in or out) and the method by which they transfer (conduction or convection).

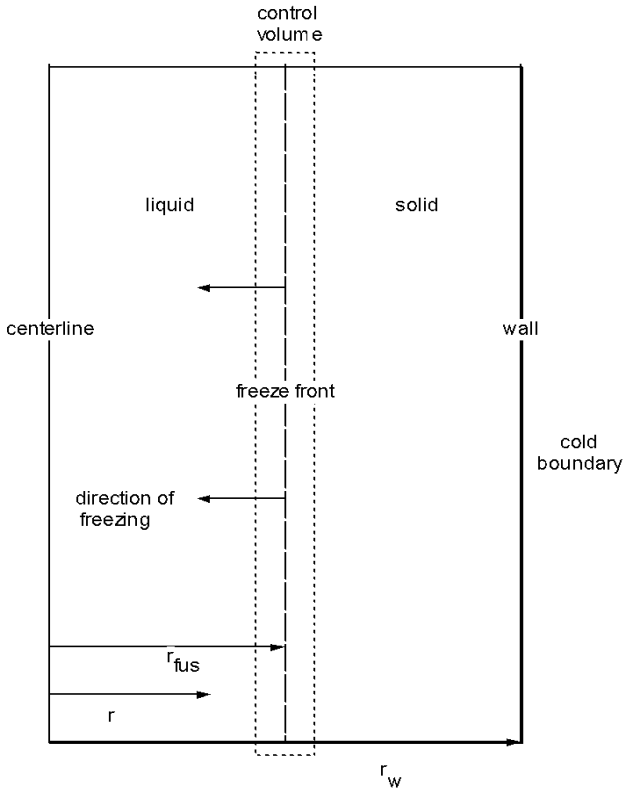


Figure 2. Inward freezing [6].

From Fourier's law, radial conduction heat transfer may be expressed as

$$Q_{in,cond} = -k_1 A \left(\frac{dT_1}{dr} \right) \bigg|_{r=r_{fus}} \quad (4)$$

$$Q_{out,cond} = -k_s A \left(\frac{dT_s}{dr} \right) \bigg|_{r=r_{fus}}$$

where k ($\text{W/m}^2\text{K}$) is the thermal conductivity. The convection in and out of the control volume is presented as

$$Q_{in,conv} = \rho_1 U_1 A h_1$$

$$Q_{out,conv} = \rho_s U_s A h_s \quad (5)$$

where h_l and h_s are the specific enthalpy of the liquid and solid sections (kJ/kg), respectively.

The convection energy balance at the control volume is:

$$\begin{aligned} q_{in,conv} &= q_{out,conv} \\ \rho_l U_l h_l &= \rho_s U_s h_s \end{aligned} \quad (6)$$

From the conservation of mass, the heat of fusion Δh_{fus} (kJ/kg) and the interface velocity U_s (m/s) are given by

$$\begin{aligned} \Delta h_{fus} &= h_l - h_s \\ U_s &= \frac{dr_{fus}}{dt} \end{aligned} \quad (7)$$

Making use of the mass conservation principle yields

$$\rho_s \Delta h_{fus} \left(\frac{\partial T}{\partial r} \right)_{fus} + k_l \left(\frac{\partial T}{\partial r} \right)_1 - k_s \left(\frac{\partial T}{\partial r} \right)_s = 0 \quad \text{at} \quad r = r_{fus} \quad (8)$$

In the special case where the liquid is isothermal at the fusion temperature, there is no heat transfer in the liquid region, reducing the energy balance equation to:

$$\rho_s \Delta h_{fus} \left(\frac{\partial T}{\partial r} \right)_{fus} - k_s \left(\frac{\partial T}{\partial r} \right)_s = 0 \quad \text{at} \quad r = r_{fus} \quad (9)$$

Equation (9) combined with the radial heat conduction equation, Eq. (10), presented later, provides a complete solution for the freezing problem.

Conduction Model

After approximately 50 minutes, the temperature of the liquid inside the cylinder decreased to the fusion temperature, as presented in Figure 3. This figure presents the typical behavior of all thermocouples embedded in eicosane. The vertical black line in the figure represents the time at which the average temperature of the inner columns reached the fusion temperature of 36.5°C, where the eicosane undergoes a liquid/solid phase change. The time required for each column to reach freezing temperature increases slightly, and the time spent at freezing temperature increases significantly as the distance between the thermocouple column and the outer wall increases. Because of the insulative nature of the solid eicosane phase that builds up on the inside wall of the cylinder, this behavior was expected. This built-up layer proceeds to thicken in the inward radial direction as energy is removed from the system [5]. Moreover, because the cylinder's height of 45.36

cm is much greater than its 7.62-cm radius [5], it is assumed that the heat transfer is one-dimensional.

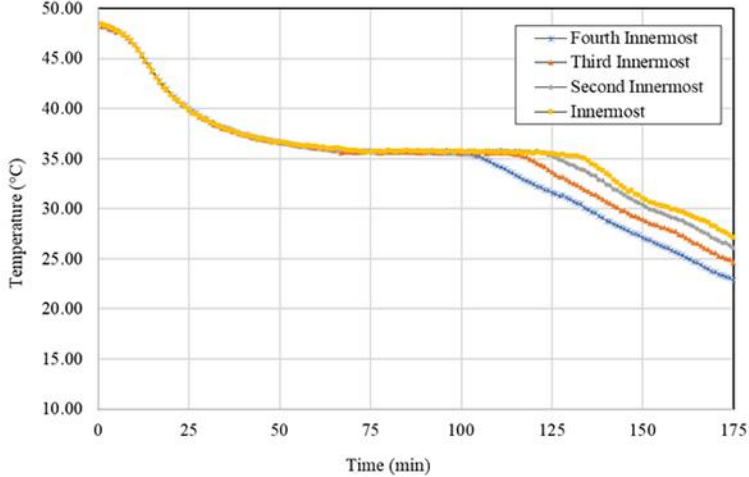


Figure 3. Typical average temperature of thermocouples at the top of the cylinder [6].

The insulative layer of ice began to form approximately 75 minutes into testing. As mentioned earlier, because the liquid eicosane was at the fusion temperature, there was no convection heat transfer, and because the interface temperature was fixed by thermodynamic considerations at the fusion temperature, the problem became a moving-boundary conduction problem. The freezing front moved inward with respect to the fusion temperature [6]. Therefore, the inward freezing front of the eicosane can be analytically modeled with the pure conduction assumption and because the total experiment period was greater than 600 minutes, a quasi-steady-state assumption is valid.

A one-dimensional quasi-steady-state condition with no heat generation or thermal energy storage in the solid region is assumed in this paper. The radial heat conduction equation in the solid region simplifies to:

$$\frac{d}{dr} \left(r \cdot \frac{dT}{dr} \right) = 0 \quad (10)$$

By integration and separation of variables, we were able to derive a general equation for the temperature T at any radius r , and it is expressed as

$$T(r) = C_1 \cdot \ln(r) + C_2 \quad (11)$$

Using the boundary conditions defined in Eq. (1) to solve for constants C_1 and C_2 yields

$$T(r) = T_w + \frac{T_{fus} - T_w}{\ln(r_{fus}) - \ln(r_w)} \cdot \ln\left(\frac{r}{r_w}\right) \quad (12)$$

To predict the phase-change location, it was necessary to define the thermal diffusivity α_s , Fourier number, Fo_s , and Stefan number, St_s , of the solid eicosane. This Fourier number is a dimensionless time parameter that represents the ratio of the heat conduction rate to the rate of thermal energy storage in a solid, and the Stefan numbers represents the ratio of sensible heat to latent heat during solidification. The three variables, where T_w is the wall temperature, are expressed as

$$\alpha_s = \frac{k_s}{\rho_s \cdot c_{p_s}} \quad (13)$$

$$Fo_s = \frac{\alpha_s \cdot t}{r_w^2} \quad (14)$$

$$St_s = \frac{c_{p_s} \cdot (T_{fus} - T_w)}{\Delta h_{fus}} \quad (15)$$

Assuming at this stage that the only mode of heat transfer inside the copper cylinder is conduction, Eq. (10) is presented as

$$k_s \cdot \frac{dT}{dr} = \rho_s \cdot \Delta h_{fus} \cdot \frac{dr_{fus}}{dt} \quad (16)$$

Equation (12) was differentiated and combined with Eqs. (13), (14), and (16) to yield Eq. (17). This equation allowed us to analytically predict the radius of the freezing front of the eicosane. It is expressed as

$$2 \left(\frac{r_{fus}}{r_w} \right)^2 \ln \left(\frac{r_{fus}}{r_w} \right) - \left(\frac{r_{fus}}{r_w} \right)^2 + 1 = 4Fo_s St_s \quad (17)$$

Using Eq. (17), at any time, the radius of fusion may be predicted. With the analytical equation generated, we were able to compare the conduction model freeze front with the experimental freeze front. The physical and thermal properties of the eicosane and measurements from the experiment are presented in Table 1. They are used in further calculations.

Table 1. Properties from the eicosane experiment [6]	
$k_{\text{eicosane-solid}}$	0.423 W/m·K
$C_{p\text{-eicosane-solid}}$	2.108 kJ/kg·K
ρ_{eicosane}	788.6 kg/m ³
$Q_{\text{fus-eicosane}}$	239.94 kJ
m_{eicosane}	6.8 kg
$T_{\text{fus-eicosane}}$	36.5°C
r_w	0.0777875 m
T_w	10°C

The Stefan number St_s was calculated using Eqs. (15) and (17) along with material properties presented in Table 1. The unitless Stefan number is 1.5294, indicating a slow-moving freeze front. The Fourier number was numerically calculated using MATLAB (Mathworks, <https://www.mathworks.com/products/matlab.html>).

Figure 4 compares the inward progression of the freeze front for the conduction model and the experimental radius of fusion, determined using Eq. (17). The PCM did not begin freezing until approximately 75 minutes, and as such, the model shows progression from 100 minutes and beyond. The experimental radius of fusion was determined using the thermocouples in the test cylinder. As the freezing progressed, the thermocouples collected data to calculate the average temperature of eicosane at each location. When the average temperature recorded at a thermocouple was equivalent to the fusion temperature $T_{\text{fus-eicosane}}$, the distance of that thermocouple was evaluated and that indicates the

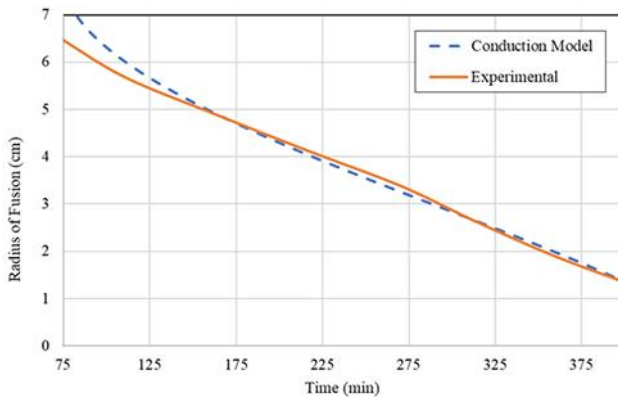


Figure 4. Inward progression of the freeze front.

location of r_{fus} at the time t . For this reason, our results vary by 45 minutes; if we consider the time for the liquid to reach the $T_{fus-eicosane}$, then we are close. We plotted the data until approximately 400 minutes, at that point the PCM is completely solid.

When an equation for the experimental line in Fig. 4 is determined, the experimental time at which the radius of fusion is zero is 475 minutes, using properties of shown in Table 1. When compared with the results of the Conduction Model, we found that the two are close. Equation (18) was derived from Eqs. (14), (15), and (17), to determine the time at which the radius of fusion would become 0 for the Conduction Model. The radius of fusion is 0 when time is approximately 430 minutes.

$$1 = 4 \left(\frac{k_s}{\rho_s \cdot c_{p_s}} \right) \left(\frac{t}{r_w^2} \right) \frac{c_{p_s} \cdot (T_{fus} - T_w)}{\Delta h_{fus}} \quad (18)$$

Presented in Figure 5 is the same information as that of Figure 4, but it was produced by Siahpush [6]. Overall, the plots are very similar, and discrepancies are expected due to cylinder size, number of thermocouples, type of insulation, flow rate, parasitic heat, and technical information provided by the manufacturer.

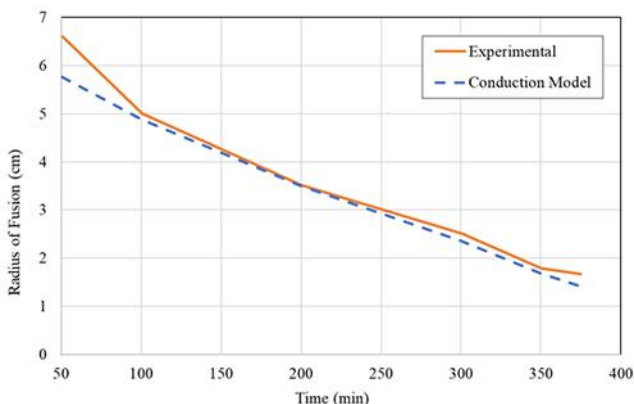


Figure 5. Nominal inward progress of freeze front with respect to time [6].

Conclusion

In conducting this experiment, we were able to successfully predict the inward freezing of a PCM system, eicosane, in a cylindrical enclosure. This analysis had two primary parts: (I) a heat diffusion analysis, and (II) a Conduction Model. After conducting these analyses, we generated theoretical values for the radius of fusion at any time and

were able to compare it with experimental values acquired in prior experimentation. Both the theoretical and experimental results followed the same downward trend. The variation between the two, though minimal, was assumed to be a result of our negligence of natural convection.

Following this work, our team intends to use another mathematical model called the Integral Method to predict the inward freezing of eicosane in the same conditions. Once we have the results of the Integral Method, we will plot it alongside the Conduction Model and experimental results to verify that our work is accurate and correct.

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Analytical Solutions for Inward Solidification of a Phase-Change Material in a Cylindrical Coordinate System: Part II

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Abstract

In our previous research, we investigated the inward freezing of eicosane in a cylindrical coordinate system. Experimentally, we determined the location of the radius of fusion and performed a calorimetric heat transfer analysis to confirm the location of the freeze front. As in the accompanying two papers, in this paper, we analytically predict the inward freezing of a phase-change material (PCM) system, eicosane ($C_{20}H_{42}$), in a cylindrical enclosure via a quasi-steady-state heat transfer analysis, and the experimental results are compared with theoretical predictions. As in the related work, the heat transfer analysis began with implementing a calorimetric heat transfer measurement with eicosane to ensure that the system was functioning properly. Subsequently, in this work, we used a mathematical heat balance integral method to present a detailed quantitative heat transfer analysis

and radius of fusion location; and predicted the eicosane thermal conductivity. We also discuss how the analytical and experimental results support one another by presenting mathematical models that yielded time-dependent volumetric temperature distribution and freeze-front motion distribution plots. Predictions from previous experimentation are also presented to further validate the results of this work.

Introduction

According to a report by Training Magazine [1], companies in the U.S. spend an average of \$4.5 billion (2015) on training and development programs for employees. Some of the training budget is for teaching ethics and communication skills. As an educator, the instructor's duty is to prepare students to perform well in their future jobs. The lack of readiness of students inspired the senior author to include undergraduate research in the mechanical engineering program courses at Southern Utah University (SUU). One of the focuses of this undergraduate research has been in the use of phase-changing materials (PCMs).

As concerns about efficient energy use grow, so does interest in more efficiently using energy, especially the thermal energy that is released or absorbed when a material undergoes a phase change. Possible uses of these phase-changing properties include the cooling of organs for medical use, more efficient HVAC systems, and constant temperature heat sinks for delicate laboratory equipment. Additionally, there are potential applications in space; these properties can be used with multi-layer insulation blanket to protect spacecraft from excessive heating or cooling, as passive heating/cooling devices for satellites, and more.

Many researchers have recognized that latent heat thermal energy storage is an effective approach to increase energy efficiency [2], and this method is becoming more appealing for its passiveness with no vibration (cryocooler), compactness, high storage density, and higher efficiency [3]. The advantage of high storage density is especially important in this case because that storage density changes depending on the PCM used, and PCMs have the potential to increase the energy density of small tanks [4]. The ideal PCM is one with a low-to-medium phase-change temperature, and eicosane, used in this experiment, fulfills that requirement. Eicosane has also been used as a base in many experiments that have successfully expanded the thermal conductivity of the PCM [5], so it is an adequate PCM choice.

Previous Work

This project continues the research performed at SUU over a period of two years. In previous years, students team-designed and constructed a thermal system to perform research in the field of the solid–liquid PCMs (Fig. 1). The constant temperature bath (CTB) provided fluid to cool the cylinder in the range of -20°C to 100°C . Over 100 thermocouples (TCs) are used to monitor the solidification progress of the PCM.

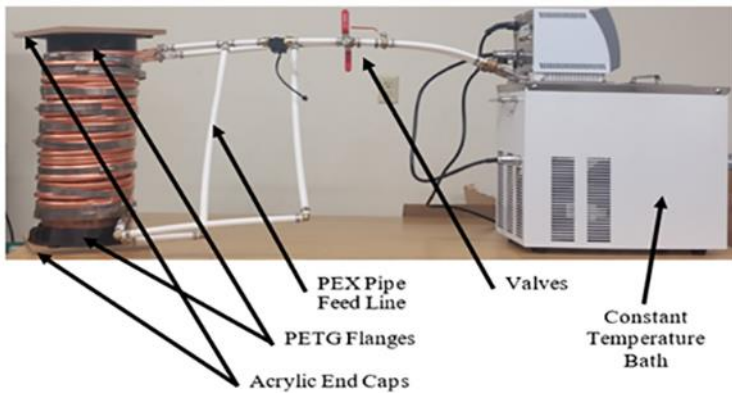


Figure 1. Setup of the test system (shown without system insulation).

In the previous testing, the thermal system was radially cooled. The system was cooled from 50°C to 10°C . In the thermal system, eicosane changed phase and solidified. The solid/liquid interface moved inwardly. As eicosane freezes inwardly, the progress of the freeze front slowed down significantly because of the higher thermal resistance of solid eicosane [6].

We built on this work in our accompanying paper [7] by conducting a heat diffusion analysis and creating a conduction model. In the heat diffusion analysis, we determined a complete solution for one-dimensional solidification of eicosane. With that, we were able to derive an equation to predict the radius of fusion at any given time during freezing. This radius of fusion from the conduction model was plotted alongside the data collected in experimentation. Figure 2 (from previous study) presents the plot of the inward progression of the radius of fusion, and thus freeze front, for both the conduction model and experimental data. Both behaved the same, and any discrepancies between the two are expected because we assumed an instant freezing process (ignoring the

sensible heat removed from liquid), pure conduction, and neglected any convection heat transfer.

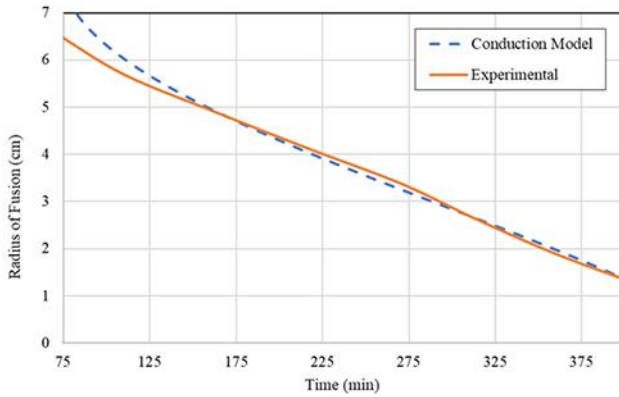


Figure 2. Inward progression of freeze front of conduction model and experimental data.

Integral Method

In this section, we provide another method to analytically predict the radius of fusion at any given time. The assumptions and the initial and boundary conditions made to simplify the heat transfer analysis in our previous paper still stand [7]. The boundary conditions are

$$\begin{aligned}
 T_l &= T_i \text{ for } t \leq 0 \\
 T_s &= T_w \text{ at } r = r_w \\
 T_s &= T_l = T_{fus} \text{ at } r = r_{fus} \\
 \frac{\partial T}{\partial r} &= 0 \text{ at } r = 0
 \end{aligned} \tag{1}$$

where T is temperature ($^{\circ}\text{C}$) and subscripts i , w , s , l , and fus refer to states at the initial position, wall, solid, liquid, and fusion, respectively. The last boundary condition in Eq. (1) describes the symmetry with respect to the centerline.

If there is no convection heat transfer, the interface energy equation is defined as [8]:

$$\rho_s \Delta h_{fus} \left(\frac{\partial T}{\partial r} \right)_{fus} - k_s \left(\frac{\partial T}{\partial r} \right)_s = 0 \quad \text{at} \quad r = r_{fus} \tag{2}$$

where ρ_s (kg/m³) is the density of the solid eicosane, Δh_{fus} (kJ/kg) is the heat of fusion, r (cm) is the radius at a corresponding time t (s), and k_s (W/mK) is thermal conductivity.

For a solid, the energy balance equation is expressed as:

$$\alpha_s \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) = r \frac{\partial T}{\partial t} \quad (3)$$

where α_s (m²/s) is the thermal diffusivity of solid eicosane, given as:

$$\alpha_s = \frac{k_s}{\rho_s c_{p_s}} \quad (4)$$

For a long period of time, Eq. (3) becomes

$$\alpha_s \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) = \frac{\partial}{\partial t} (rT) \quad (5)$$

However, in this experiment, modifications need to be made to the equation because the volume in which the heat diffuses is not the same for equal increments of radius r , as in a planar case. This modified equation is defined as:

$$\int_{r_w}^{r_{fus}} \left[\alpha \frac{\partial}{\partial r} \left(r \frac{\partial T}{\partial r} \right) = \frac{\partial}{\partial t} (rT) \right] \partial r \quad (6)$$

Ψ_s is the heat balance integral of the product of the radius and temperature of the solid (at r), from the radius of the phase change radius to the cylinder [9]. It is expressed as:

$$\Psi_s = \int_{T_w}^{T_{fus}} rT \, dT \quad (7)$$

Leibniz' Rule [8] provides a method to differentiate a definite integral whose limits are functions of the differential variable. It is defined as:

$$\int_{r_w}^{r_{fus}} \frac{\partial}{\partial t} (rT_s) \, dr = (r_w T_s) \frac{dr_w}{dt} - (r_{fus} T_s) \frac{dr_{fus}}{dt} + \frac{d}{dt} \int_{r_w}^{r_{fus}} rT_s \, dr \quad (8)$$

Combined with Eq. (7), it yields an equation for temperature as a function of the radius, which was derived in our previous paper [7, Eq. (12)]. It is

$$T(r) = T_w - (T_w - T_{fus}) \frac{\ln \left(\frac{r}{r_w} \right)}{\ln \left(\frac{r_{fus}}{r_w} \right)} \quad (9)$$

Equation (9) can be simplified further to yield the dimensionless time as a function of the dimensionless radius of fusion, defined as:

$$\tau = \frac{St_s}{4} [\beta_r^2 - 1 - 2\ln\beta_r - (\ln\beta_r)^2 - \dots - \frac{2^n (\ln\beta_r)^2}{n!}] + \frac{\beta_r^2}{2} \ln\beta_r - \frac{\beta_r^2}{4} + \frac{1}{4} \quad (10)$$

where St_s is the Stefan number and represents the ratio of sensible heat to latent heat during solidification, β_r is a dimensionless radius of fusion, and τ is a dimensionless time. Respectively, they are expressed as:

$$\beta_r = \frac{r_{fus}}{r_w} \quad (11)$$

$$\tau = \frac{\alpha_s t St_s}{r_w^2} \quad (12)$$

We used the physical and thermal properties of eicosane, as well as necessary measurements, and they are presented in Table 1.

Table 1. Properties from the eicosane experiment [6]	
$k_{\text{eicosane-solid}}$	0.423 W/m·K
$C_{p\text{-eicosane-solid}}$	2.108 kJ/kg·K
ρ_{eicosane}	788.6 kg/m ³
$Q_{\text{fus-eicosane}}$	239.94 kJ
m_{eicosane}	6.8 kg
$T_{\text{fus-eicosane}}$	36.5°C
r_w	0.0777875 m
T_w	10°C

Using Eq. (10) at any time, the radius of fusion may be analytically predicted. In Figure 3, we compared these results from the Integral Method with experimental data and Conduction Model results, which were explained in the accompanying paper [7].

Although the thermocouples record temperature of the eicosane beginning at 0 minutes, freezing begins at approximately 75 minutes. For this reason, Figure 3 displays presents the solidification at this time. Estimations of the radius of fusion via the Integral Method are similar to the experimental and Conduction Model Data, further verifying the validity of the latter.

Between the three sets of data, the most obvious deviation occurs within the first 150 minutes—primarily the result of the gradual freezing at the beginning and the natural convection that was neglected in our analysis.

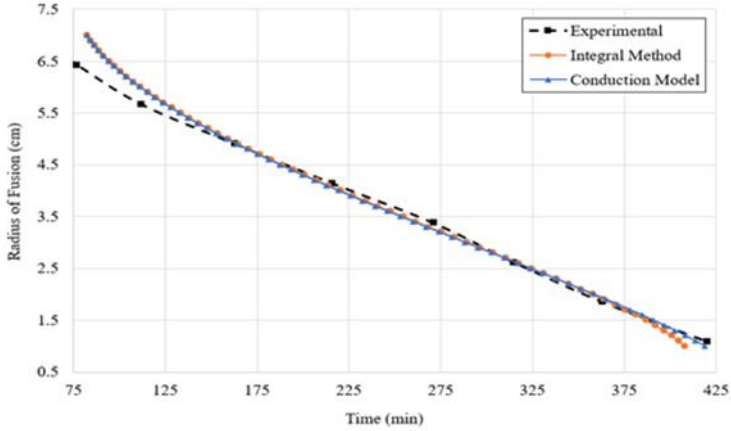


Figure 3. Inward progression of freeze front of all methods.

Thermal Conductivity of Solid Eicosane

In this section, the thermal conductivity, k , is estimated from the time-dependent location of the radius of fusion.

The heat transferred from eicosane, Q_3 (J), at any time is the difference between the cumulative heat transferred to the coolant, Q_1 (J), and the heat transferred from system components, Q_2 (J). This is expressed as

$$Q_1 = Q_2 + Q_3 \quad (13)$$

The cumulative heat transferred from eicosane has 3 main components:

1. sensible heat extracted from liquid eicosane to lower it to the fusion temperature (Q_{l-fus});
2. heat of fusion released from eicosane at fusion temperature (Q_{fus});
3. cumulative sensible heat extracted from the frozen eicosane to bring it from fusion temperature to wall temperature (Q_{fus-s}).

The sensible heat extracted from eicosane to lower it to the fusion temperature is expressed as

$$Q_{l-fus} = m_{tot} c_{pl} (T_i - T_{fus}) \quad (14)$$

where m_{tot} (kg) is the total mass of eicosane and c_{pl} (kJ/kgK) is the specific heat capacity for liquid eicosane. Generally, this equation would

be included in analysis, but because we are trying to eliminate the error from the sensible heat of the liquid and solid, we eliminate Eq. (14). We start the experiment by considering the liquid is at the fusion temperature.

The heat of fusion released from eicosane at T_{fus} is

$$Q_{fus} = m_s \Delta h_{fus} = \rho_s \pi (r_w^2 - r_{fus}^2) H \Delta h_{fus} \quad (15)$$

where H (m) denotes the height of the copper cylinder and m_s (kg) is the mass of the solid eicosane, which is time-dependent and a function of the fusion radius.

Finally, the cumulative sensible heat extracted from the frozen eicosane to bring it from fusion temperature to wall temperature is defined as

$$Q_{fus-s} = m_s c_{ps} (T_{fus} - T_m) = \rho_s \pi (r_w^2 - r_{fus}^2) H c_{ps} (T_{fus} - T_m) \quad (16)$$

When Eqs. (15) and (16) are substituted into Eq. (13) and solved for r_{fus} , the result is

$$r_{fus} = \sqrt{r_w^2 - \frac{Q_1 - Q_2}{\rho_s \pi H [c_{ps} (T_{fus} - T_m) + \Delta h_{fus}]}} \quad (17)$$

Equation (17) may be applied to determine the radius of fusion at any time from the initial position to the center, when completely solid. It is presented in Figure 4, alongside a linear, curve-fitted line.

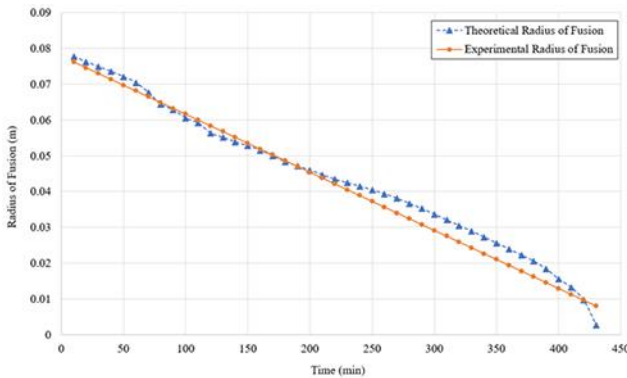


Figure 4. Estimated radius of fusion based on cumulative heat transfer.

The values from the linear radius of fusion line will be used for further analysis because, ideally, the radius of fusion should be linear.

Nonlinearity of the radius of fusion estimated using Eq. (17) is a result of the assumptions stated at the beginning of this paper.

The radius of fusion from Figure 4 is used in Eq. (10) to solve for the thermal conductivity, k . Results are presented alongside experimental values in Fig. 5.

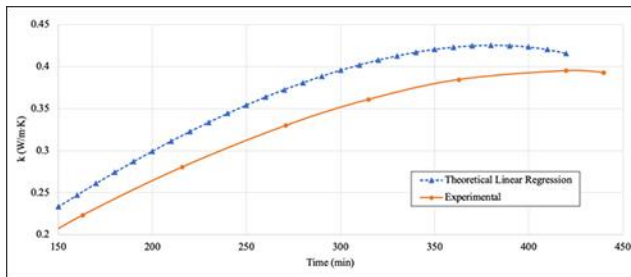


Figure 5. Comparison of theoretical and experimental radius of fusion.

Because we are concerned about the thermal conductivity of solid eicosane, we focused on the time that eicosane is solid and disregarded the behavior below 150 minutes. As shown in Figure 5, both lines follow that same upward trend and plateau directly below a thermal conductivity of 0.4. The predicted thermal conductivities at 0°C and 36.5°C are presented in Table 2.

Table 2. Predictions for k at 0°C and 36.5°C	
T (°C)	k (W/mK)
0	0.4154
36.5	0.0324

The predicted value for thermal conductivity at 36.5°C was found by using the time in which the average temperature inside the cylinder was 36.5°C. Similarly, the prediction for 0°C was found by calculating the thermal conductivity at the time of freezing, which was around 430 minutes. The predicted values in Table 2 are in agreement with published results of Stryker and Sparrow [10] and Hale et al. [11]. Both parties conducted similar experiments but had different parameters such as measurements of the test cylinder. Stryker and Sparrow reported a constant thermal conductivity of 0.423 W/mK for solid eicosane. Hale et al. measured the thermal conductivity, and then expressed a least-squares fit of data as a quadratic function of temperature. It is defined as

$$k = 0.4037 + 1.594 \cdot 10^{-4}T - 7.82 \cdot 10^{-5}T^2 \quad (18)$$

At 0°C and 36.5°C, Eq. (18) predicts the thermal conductivity to be 0.4037 and 0.308 W/mK, respectively.

Conclusion

In our previous research, we investigated the inward freezing of eicosane in a cylindrical coordinate system. Experimentally, we determined the location of the radius of fusion and performed a calorimetric heat transfer analysis to confirm the location of the freeze front.

In conducting this experiment, we successfully (I) completed our analysis to predict the inward freezing of a PCM system, eicosane ($C_{20}H_{42}$), in a cylindrical enclosure and (II) predicted the thermal conductivity of solid eicosane. The analysis to predict the radius of fusion for eicosane at any time consisted of using a mathematical heat balance integral method. The Integral Method yielded results that were identical with those produced by the Conduction Model in our accompanying paper [7], verifying that our work is correct and accurate. With known values for the radius of fusion, we estimated the thermal conductivity of eicosane. We did so by using the same equations, solving for k instead of r_{fus} . This theoretical thermal conductivity followed the same upward trend as experimental data but still deviates slightly.

We also discussed how the analytical and experimental results support one another by presenting mathematical models that yielded time-dependent volumetric temperature distribution and freeze-front motion distribution plots. Predictions from previous experimentation are also presented to further validate the results of this work.

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Solar Flux Evaluation and Thermal Radiation Absorptivity of a Metallic Plate

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ABSTRACT

The first objective of this paper is to evaluate the solar flux in Cedar City, Utah, by conducting radiation heat transfer experiments with aluminum and steel sheets. Results are then utilized to calculate the thermal absorptivity of the two metals. The thermal absorptivities are compared with published values. The solar flux values calculated using the aluminum and steel sheets are within 4.23% and 4.48% of the values reported by a solar field approximately 10 miles west of the Southern Utah University Engineering Building. From these solar flux values, the thermal absorptivity of each material was determined using explicit numerical methods in MATLAB. The calculated absorptivity of each material fell within the published values.

Nomenclature		
Symbol	Name (Unit)	Value
α_{Al}	Solar absorptivity of aluminum plate	0.40–0.65 [1]
α_{Black}	Solar absorptivity of carbon black paint	0.96 [2]
α_{St}	Solar absorptivity of steel plate	0.80–0.90 [1]
A_S	Surface area (m^2)	
$C_{p,Al}$	Specific heat of aluminum plate ($J/kg \cdot K$)	903 [1]
$C_{p,St}$	Specific heat of steel plate ($J/kg \cdot K$)	434 [1]
$C_{p,Ins}$	Specific heat of insulation ($J/kg \cdot K$)	1600 [2]
ΔT	Change in temperature (K)	
Δt	Change in time (s)	
Δx_{Al}	Thickness of aluminum plate (m)	0.0032
Δx_{St}	Thickness of steel plate (m)	0.003
Δx_{Ins}	Thickness of single node of insulation (m)	0.00254
ε_{Al}	Emissivity of aluminum plate	0.40–0.65 [1]
ε_{Black}	Emissivity of carbon black plate	0.88 [2]
ε_{St}	Emissivity of steel plate	0.80–0.90 [1]
q''_{Solar}	Solar flux (W/m^2)	
$\dot{Q}$	Heat transfer rate (W)	
ρ_{Al}	Density of aluminum (kg/m^3)	2702 [1]
ρ_{St}	Density of steel (kg/m^3)	7870 [1]
ρ_{Ins}	Density of insulation (kg/m^3)	20.8 [3]
k_{ins}	Thermal conductivity of insulation ($W/m \cdot K$)	0.0334 [3]
σ	Stefan-Boltzman Constant ($W/m^2 K$)	5.67×10^{-8}
τ_G	Transmissivity of glass pane	0.88 [1]
T_{Al}	Temperature of aluminum plate (K)	
T_{Sky}	Effective temperature of the sky (K)	270
T_{St}	Temperature of steel plate (K)	

Introduction

During his decades of experience hiring young engineers, it was apparent to the senior author (AS) that many of them did not possess the required skills to solve real-world engineering problems. As a result, extensive training for new employees was required to ensure the new engineer could perform the required tasks. This training was performed by an experienced engineer and was extremely time-intensive, taking up to a year from hiring in some cases. The resulting investment of time added additional costs to the hiring process.

Because the purpose of university education is to prepare students for the workplace, the lack of ability displayed by many graduates

inspired the senior author to develop undergraduate research programs for his students. These undergraduate research programs are intended to expose students to “real-world” work environments to better prepare them for future careers. This research aims to prepare students to work in a diverse group, learn problem-solving with minimal guidance, and perform real-world engineering research.

In the past, students at Southern Utah University (SUU) have done studies to measure the solar flux and the absorptivities of metal sheets. However, they have not considered heat loss through the insulation placed on the back of the metal. This experiment is designed to first measure the solar irradiance in Cedar City, Utah, by performing an analysis assuming perfect insulation, and second, compare it to an analysis that accounts for the heat loss through the insulation.

The temperature change of the plate is modeled using explicit numerical methods in MATLAB. When the painted black side of the plate is facing the sun, the only unknown in the analysis is the solar flux. By adjusting this value until the experimental and theoretical temperature profile match as closely as possible, the solar flux can be evaluated. Once the solar flux is determined, that value is used to find the material’s thermal radiation absorptivity.

Experiment

The setup consisted of a metal sheet placed in a picture frame (12×12 in) with glass facing the sun and two inches of Styrofoam insulation applied to the backside. First, one side of the material was painted with Liquitex Carbon Black Paint, which has a known absorptivity, to simulate a black body and maximize solar absorptivity. The ‘black body’ was important to use to establish a correct solar flux, which was required to evaluate the absorptivity of the unpainted metal sheets. The space between the metal and the glass is ~1 mm. Therefore, the glass covering the metal in the picture frame prevented natural convection from occurring at the surface. The back of the plate was insulated to minimize the heat loss from environment. The test was conducted at solar noon when the sun is at its highest point in the sky and the solar flux is maximum.

The experiment has two purposes:

1. First, determine the solar flux, both assuming perfect insulation and accounting for heat loss through the insulation, by using the known absorptivity of the applied paint.
2. Second, evaluate the absorptivity of steel and aluminum using the calculated solar flux evaluated from the blackbody trials.

Procedure

Before testing, a suitable day was chosen based on minimal cloud coverage. The time of solar noon was determined to provide the most direct sunlight and therefore the greatest solar flux possible [4]. An even coating of carbon black paint was applied to one side of the steel and aluminum sheets and allowed to dry completely for over 24 hours. The aluminum and steel sheets were placed in the cooler until the temperature reached about 35°F. A representative of the Utah Red Hills Renewable Energy Park, located within 10 miles of the experiment location, was notified to record the solar flux data during the time of the experiment.

The test procedure was conducted as follows.

1. Attach a thermocouple, using Kapton tape, to the unpainted side of the aluminum plate.
2. Remove metal plates when it reaches about 35°F from the cooler filled with ice packs as shown in Fig. 1.
3. Place the plate in the picture frame with the black painted side facing towards the sun, and secure the insulation on the back using duct tape as shown in Fig. 2.
4. Point the frame perpendicular to the sun by ensuring that the dowel does not cast a shadow as shown in Fig. 2.
5. Record the temperature of the plate until the temperature reaches approximately 90°F (305 K).
6. Repeat steps 1–6 for the steel plate.
7. Cool down the two materials again by placing them in the cooler until the temperature reaches approximately 35°F (274 K).
8. Repeat steps 1–9 with the unpainted side facing the sun instead of the black painted side.



Figure 1. Test plates stored in the cooler with ice packs.



Figure 2. Test setup.

Results

Figures 3–6 show the results obtained from the experiments performed on October 10, 2019, for the aluminum and steel plates. Because the experiment was conducted in the fall, the solar flux was not high enough to change the plate’s temperature immediately. The data were collected every second, and as it can be observed from Figures 3–6, the measured temperature was not as sensitive. For future study of the radiation heat transfer, a 10-second interval to record temperature is recommended to eliminate the plateau seen in these figures.

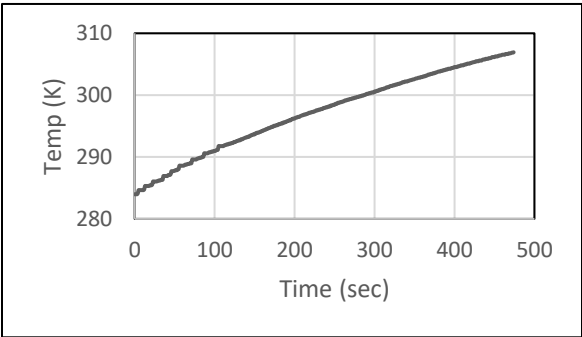


Figure 3. Results for the black side of the aluminum.

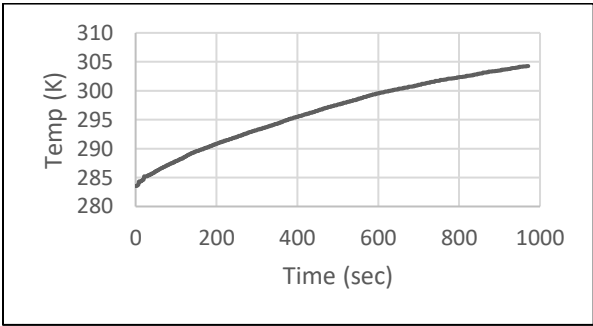


Figure 4. Results for the unpainted side of the aluminum.

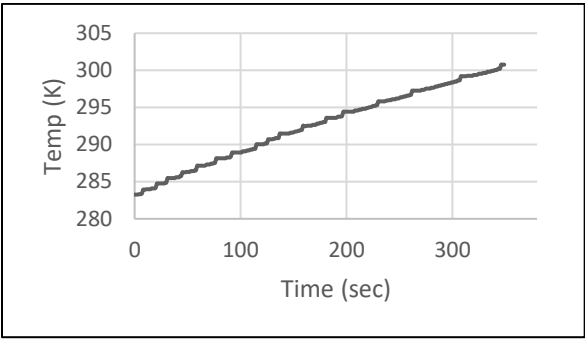


Figure 5. Results for the painted side of the steel.

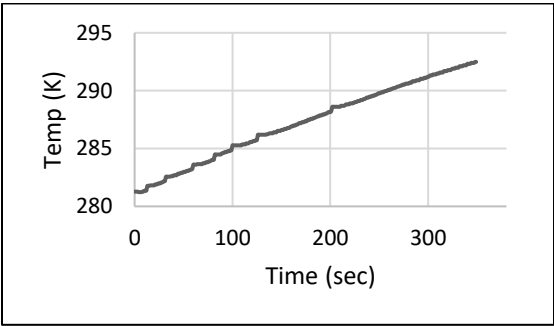


Figure 6. Results for the unpainted side of the steel.

Heat transfer analysis

A transient analysis will be performed assuming no heat is lost through the insulation. Figure 7 shows a representation of the system.

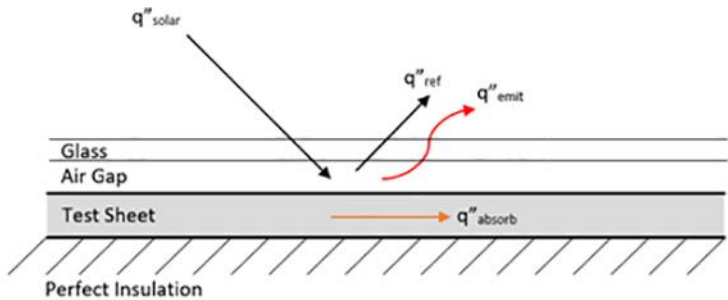


Figure 7. Representation of heat transfer in the system.

The energy balance of the system may be presented as

$$\dot{Q}_{\text{net}} = \dot{Q}_{\text{in}} - \dot{Q}_{\text{out}} \quad (1)$$

where $\dot{Q}_{\text{net}}$ is the net energy absorbed by the material (W), $\dot{Q}_{\text{in}}$ is the heat transfer rate to the system (W), and $\dot{Q}_{\text{out}}$ is the energy lost from the system (W). $\dot{Q}_{\text{net}}$ is proportional to the change in temperature of the system and can be described as

$$\dot{Q}_{\text{net}} = \frac{mC_p(T_{\text{final}} - T_{\text{initial}})}{\Delta t} \quad (2)$$

where m is the mass of the plate (kg), c_p is the specific heat capacity of the plate (J/K·kg), T_{final} is the final temperature of the material (K), and T_{initial} is the initial temperature of the material (K).

The amount of heat transferred to the material from the solar flux depended on the transmissivity of the glass, the surface area of the plate, and the absorptivity of the material. The relationship may be expressed as

$$\dot{Q}_{\text{in}} = A_{\text{plate}}\tau_{\text{glass}}\alpha_{\text{plate}}q''_{\text{solar}} \quad (3)$$

where A_{plate} is the surface area of the plate (m^2), τ_{glass} is the transmissivity of the glass, α_{plate} is the absorptivity of the surface of the plate, and q''_{solar} is the solar flux introduced to the system from the sun (W/m^2).

The radiation heat transfer away from the metal plate may be presented as.

$$\dot{Q}_{\text{out}} = \varepsilon_{\text{plate}}\sigma A_{\text{plate}}(T_{\text{plate}}^4 - T_{\text{sky}}^4) \quad (4)$$

where $\varepsilon_{\text{plate}}$ is the emissivity of the plate, σ is Boltzmann's constant ($5.67 \times 10^{-8} \text{ W}/\text{m}^2 \cdot \text{K}^4$), A_{plate} is the surface area of the plate (m^2), T_{plate} is the temperature of the plate (K), and T_{sky} [1] is the effective temperature of the sky (K).

In this case, conduction through the insulation is ignored and Eqs. (2–4) may be substituted into Eq. (1) to yield

$$\frac{mC_p(T_{\text{final}} - T_{\text{initial}})}{\Delta t} = A_{\text{plate}}\tau_{\text{glass}}\alpha_{\text{plate}}q''_{\text{solar}} - \varepsilon_{\text{plate}}\sigma A_{\text{plate}}(T_{\text{plate}}^4 - T_{\text{sky}}^4) \quad (5)$$

Equation (5) can be solved for plate temperature change over time (dT/dt). The rate of temperature change of the plate as is

$$\left(\frac{dT}{dt}\right) = \frac{\alpha_{\text{plate}}q''_{\text{solar}}\tau_{\text{glass}}}{\rho C_p \Delta x_{\text{plate}}} - \frac{\varepsilon_{\text{plate}}\sigma(T_{\text{plate}}^4 - T_{\text{sky}}^4)}{\rho C_p \Delta x_{\text{plate}}} \quad (6)$$

where ρ is the density of the plate (kg/m^3), and Δx_{plate} is the thickness of the plate (m).

To utilize Eq. (6) for numerical analysis, the explicit finite difference method is employed. This method of approximation uses information about the system at the current time to predict the temperature at the next time-step as

$$T_n^{i+1} = \left[\frac{\alpha q''_{\text{solar}} \tau_{\text{glass}}}{\rho C_p \Delta x_{\text{plate}}} - \frac{\varepsilon_{\text{plate}} \sigma (T_{\text{plate}}^4 - T_{\text{sky}}^4)}{\rho C_p \Delta x_{\text{plate}}} \right] dt + T_n^i \quad (7)$$

where T_n^i is the current temperature of a given node (K), T_n^{i+1} is the temperature of the node at a later time (K), and dt is the time differential (sec). Figures 8–11 were produced in MATLAB by applying Eq. (7). The solar flux was calculated by adjusting q''_{solar} until the theoretical line (bottom) matched the profile of the experimental line (top). That solar flux was then used to find the absorptivity. The value for thermal absorptivity was calculated by changing α_{plate} until the theoretical value resulted in a similar curve to the experimental data. The value that most closely approximates the data was then compared with a published value for the absorptivity of the plate.

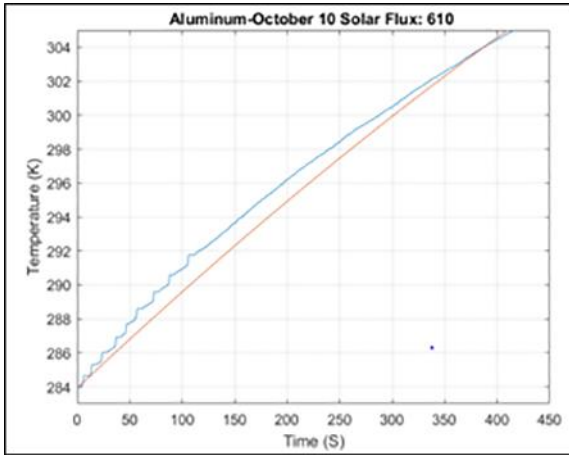


Figure 8. Evaluating the solar flux with the aluminum plate.

From Figures 8–11, the data and trendline behave differently from each other. This difference is best seen in Figures 8 and 9. The slope of the curves does not approximate the behavior of the data. In all of the graphs, each dataset is intercepted by the approximated trendline at the beginning and end of the curve. The curves are most similar in this condition, but the slopes are dissimilar. The trend lines are more linear than the data, resulting in error. The discrepancy was determined to be

from the initial assumption of perfect insulation. For a small range of data, this approach would appear to be accurate, but over a longer period, it becomes inaccurate.

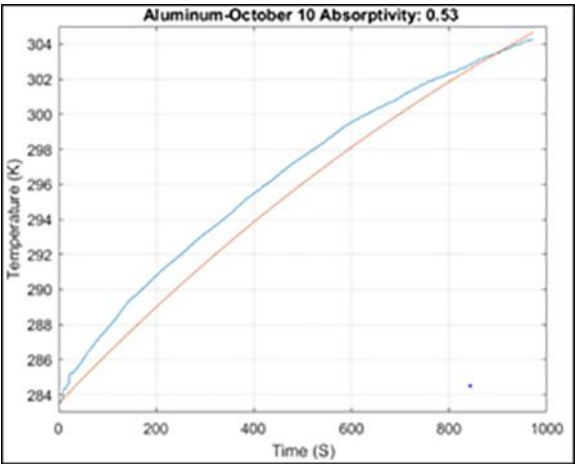


Figure 9. Evaluating the absorptivity of the aluminum plate.

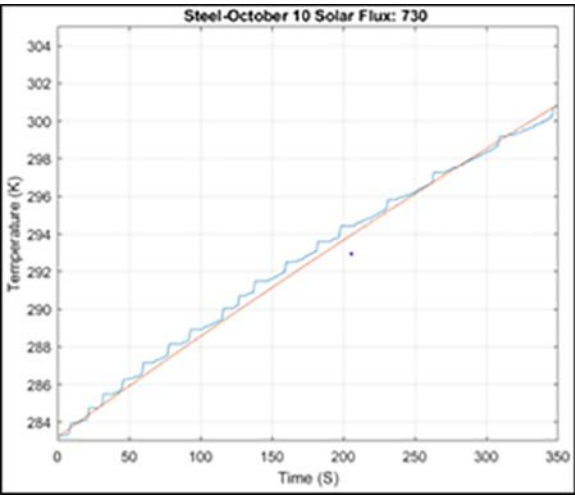


Figure 10. Evaluating the solar flux with the steel plate.

Next, to increase the accuracy of the results, the system was analyzed again by taking into consideration the heat loss through the

insulation. The insulation is divided into 20 nodes. The first node is in intimate contact with the plate and was assumed to be at the same temperature as the plate. Each node is equally spaced and has a specific initial condition and predictable behavior.

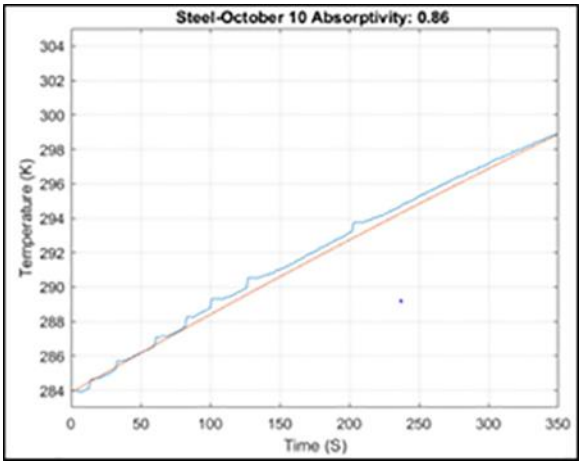


Figure 11. Evaluating the absorptivity of the steel plate.

Figure 12 is a model of the system accounting for heat loss through the insulation. It should be noted that the reflected radiation (q''_{ref}) shown in Figure 12 is ignored only when the black painted side is facing the sun. Therefore, it is assumed that q''_{ref} of a black body is zero.

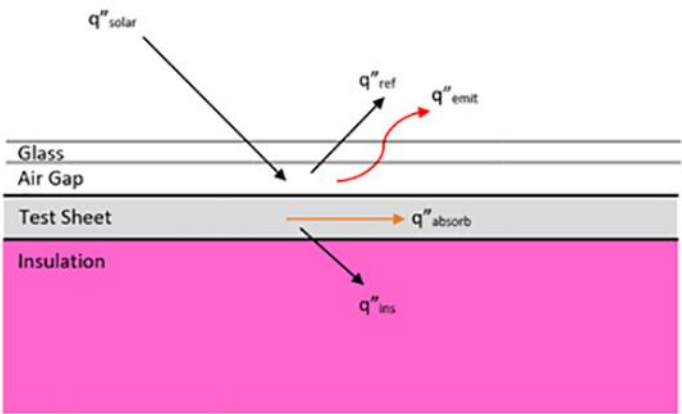


Figure 12. Representation of heat transfer in the system.

The heat loss from the plate can then be defined as

$$\dot{Q}_{\text{out}} = \epsilon_{\text{plate}} \sigma A_{\text{plate}} (T_{\text{plate}}^4 - T_{\text{sky}}^4) - k_{\text{ins}} A_{\text{plate}} (T_2 - T_1) \quad (8)$$

where k_{ins} is the thermal conductivity of the insulation, A_{plate} is the surface area of the metal sheet, T_1 is the temperature on the surface of the insulation and T_2 is the temperature of the first internal node of the insulation.

The rate of temperature change of the plate is given by

$$\left(\frac{dT}{dt} \right) = \frac{\alpha_{\text{plate}} q''_{\text{solar}} \tau_{\text{glass}}}{\rho C_p \Delta x_{\text{plate}}} - \frac{\epsilon_{\text{plate}} \sigma (T_{\text{plate}}^4 - T_{\text{sky}}^4)}{\rho C_p \Delta x_{\text{plate}}} + \frac{k_{\text{ins}} (T_2 - T_1)}{\rho C_p \Delta x_{\text{plate}} \Delta x_{\text{ins}}} \quad (9)$$

Expanding the left-hand side of Eq. (7) and solving explicitly for T_n^{i+1} , Eq. (9) can be rewritten as

$$T_n^{i+1} = \left[\frac{\alpha_{\text{plate}} q''_{\text{solar}} \tau_{\text{glass}}}{\rho C_p \Delta x_{\text{plate}}} - \frac{\epsilon_{\text{plate}} \sigma (T_{\text{plate}}^4 - T_{\text{sky}}^4)}{\rho C_p \Delta x_{\text{plate}}} + \frac{k_{\text{ins}} (T_2 - T_1)}{\rho C_p \Delta x_{\text{plate}} \Delta x_{\text{ins}}} \right] dt + T_n^{i+1} \quad (10)$$

When the explicit method is used, the stability of the system must be considered. If the time step is too large, the system will become unstable and the predicted temperature will fluctuate. The needed time step was evaluated as

$$\Delta T \leq \frac{\rho_{\text{ins}} C_{p,\text{ins}}}{2k_{\text{ins}}} (\Delta x_{\text{ins}})^2 \quad (11)$$

With the space between nodes of approximately 3 mm, the time step for the explicit analysis of the insulation had to be equal to or less than 3.2 seconds. A time step of one second was chosen because that is the same frequency as the temperature was recorded during the experiment.

Figures 13–16 were created in MATLAB by applying Eq. (10). As in the previous evaluation, the solar flux was calculated by adjusting q''_{solar} until the theoretical rate of temperature change matched the experimental data. This could be seen by the lines overlapping. The value for the thermal absorptivity was calculated by changing α_{plate} until the theoretical value resulted in a similar curve to the experimental data.

Figure 13 shows the calculated solar flux evaluated with the aluminum plate to be 770 W/m². Figure 14 shows the evaluated absorptivity of aluminum to be 0.58. Figure 15 shows the calculated solar flux evaluated with the steel plate to be 840 W/m². Figure 16 shows the evaluated absorptivity of steel to be 0.91.

Tables 1 and 2 summarize the results of both analyses. The results for the analysis with assumed perfect insulation are presented in Table

1. The analysis results with heat loss through insulation follow in Table 2.

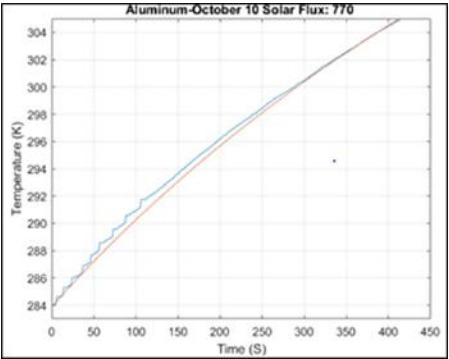


Figure 13. Evaluating the solar flux with the aluminum plate.

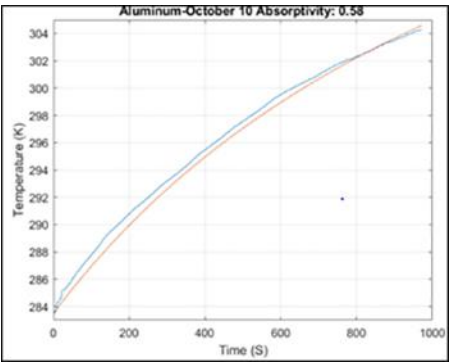


Figure 14. Evaluating the absorptivity of the aluminum plate.

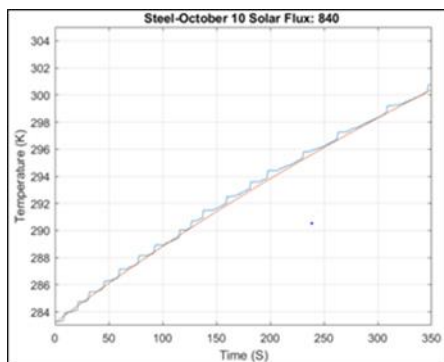


Figure 15. Evaluating the solar flux with the steel plate.

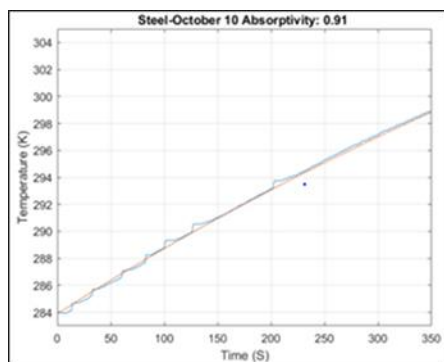


Figure 16. Evaluating the absorptivity of the steel plate.

Accurate results for the solar irradiance and absorptivity of the plates tested were obtained by performing this heat transfer experiment. The temperature data recorded by the thermocouples on the plate established the correct curve to determine the analytical q''_{solar} . This q''_{solar} was compared with the value obtained from the solar field in Cedar City. For the October 10, 2019, the solar flux was an average of 804 W/m^2 . This value is calculated using the provided data between 11:30 am and 12:30 pm. These times approximately coincide with the beginning of the testing and should reflect the actual value associated with solar noon. Because the error for the steel and aluminum plates were both under 5%, the experiment was considered to be a success.

Table 1. Summary of results assuming perfect insulation

	Calculated	Published	Percent error
Solar flux (Al)	610	805	24.2%
Solar flux (St)	730	805	9.32%
α_{Aluminum}	0.53	0.40-0.65	0%
α_{Steel}	0.86	0.80-0.90	0%

Table 2. Summary of results accounting for heat loss through insulation

	Calculated	Published	Percent error
Solar flux (Al)	770	805	4.35%
Solar flux (St)	840	805	4.35%
α_{Aluminum}	0.58	0.40-0.65	0%
α_{Steel}	0.91	0.80-0.90	1.1%

The solar flux and absorptivity were evaluated using two variations of the same method. The first approach assumed the backside of the plate is perfectly insulated with no heat transfer through it. This method only evaluated the heat emitted from the plate through radiation, ignoring the losses through the backside. Using this first method of solving for solar flux, values for the q''_{solar} were approximated. The aluminum and steel sheets yielded different flux values of 610 W/m² and 730 W/m², respectively. The percent differences for q''_{solar} are 24.13% for the aluminum sheet and 9.20% for the steel. These values are much less than nominal and required more accuracy than this first method provides. This conclusion can be supported by the curves found in Figs. 7-10. The theoretical lines are much more linear than the experimental values. This large difference requires a more correct approximation of the solutions previously presented.

The second approach considered the heat transfer through the insulation, in addition to the radiation. Using the second method, the analysis agreed with the experimental data more closely than before. Using the same value for solar flux as before, the percent differences can be calculated. The q''_{solar} value for the steel sheet was found to be 840 W/m² while the aluminum sheet gave a value of 770 W/m². These values differ from the provided solar flux by 4.48% and 4.23%, respectively.

With a much more acceptable margin of error, the absorptivity of each material was found using the same numerical methods. The absorptivity of the metal plates was evaluated using a range of tabulated values. The experiment was performed using the median of the range. Because the plates experienced various levels of oxidation, a precise absorptivity was unavailable for the experimental metal plates. When researching materials absorptivity values, many resources provide a

range of values. The aluminum values are between 0.4 and 0.65. Steel values fall within the range of 0.8 to 0.9. From Fig. 12, the aluminum absorptivity was estimated to be 0.58. This is within the range referenced previously and is an acceptable result. For the steel, the absorptivity from Fig. 14 is 0.91. Although this value is outside of the range discussed, the difference can be accounted for in material impurities (every metal sheet has a slightly different composition), surface finish and oxidation, and data acquisition system. These effects are discussed further in the Error Analysis. For this reason, the absorptivity found for steel is still acceptable.

The explicit finite difference methods provided numerical solutions to ordinary differential equations with known boundary and initial conditions value. In the case of the insulation, the geometry of the material was divided up into nodes. The nodes allowed a better and more accurate understanding of the transient temperature distribution of the insulation. This problem-solving approach was necessary to calculate the heat transfer through the back of the plate into the insulation. The transient temperature of the insulation was best understood by applying the finite element method. Knowing this quantity, a more accurate theoretical model for the temperature change of the metal plate was achieved.

Sources of Error

Several sources of error could have contributed to the 4.23% and 4.48% error in solar flux measurements. First, the assumption was made that the first node of the insulation was at the same temperature as the plate. This is not entirely accurate and is just an approximation. A thin layer of cardboard existed between the plate and insulation. The properties of the cardboard, which are not accounted for in the analysis, differ from the insulation and the plates. Although the difference is minute, it may explain some of the errors in the experimental setup. If a thermocouple was added to the first node, the surface temperature of the insulation could be more accurately modeled. The insulation was also assumed to be at ambient temperature. However, it is likely that it was higher because it was also subject to solar flux. For a more accurate initial temperature of the insulation, it should be left in a shaded area until the test begins. Measuring the temperature of both sides of the insulation helps determine the boundary conditions for the numerical analysis.

The second area of error relates to the instrumentation used to measure the temperature of the plates. The data logger used could not accurately measure small differences in the plate temperature. Although

the measured data has the correct shape over time, jumps appeared in the temperature that is not precise. The data logger was limited by its resolution, the number of bits it divides the supplied voltage into. An instrument with higher resolution could have produced more accurate results.

The absorptivity of a surface depends on the color and surface finish of the material. The tabulated values for the absorptivity of aluminum and steel were general values. For aluminum, the values range from 0.40 to 0.65. The mean value of 0.525, was used in the analysis. For steel, the values ranged from 0.80 to 0.90. All of the calculated values appeared to be either in the range or within 1% of the range. So, the values of absorptivity could have appeared to have a higher error than they do because of the range of values that a plate may have.

Any errors found in the values for absorptivity can likely be attributed to the percent error found when estimating the value for solar flux. Because the solar flux was not an exact match, any error from that result will affect any results later dependent upon it.

Conclusion

The experiment to measure the solar flux in Cedar City, Utah, and the absorptivity of two different types of metal plates can be considered as a success. The solar flux evaluated using each of the two materials was within 5% of the average value reported from the solar plant. This low difference can be attributed to a more exact method of solving for a temperature profile. The first solution method did not account for the loss of heat through the insulation. The second method accounts for this heat transfer and is thus more accurate. This heat transfer analysis affirms the need for proper control of assumptions made and numerical solutions in evaluating theoretical values that cannot be properly approximated otherwise.

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Material Properties of Photopolymer Resin, Polylactic Acid, and Other 3D Printing Materials

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Abstract

In this experiment, we tested and studied the mechanical and physical properties of thermoplastic polylactic acid (PLA) filament and thermoset photopolymer resins by investigating the material bonds in the form of tensile stress evaluations. The three-dimensional (3D) filament used in the primary dogbone tests were all PLA material. For comparison, secondary tests were run on PLA, acrylonitrile butadiene styrene, polyethylene terephthalate glycol, and carbon-fiber PLA strands of unprinted 1.75-mm-diameter wire. For additional comparison, tie wire and braided steel cable were also used in the secondary test. These secondary tests were conducted to study the difference between unprinted and printed materials and how the bonds change the mechanical properties of the sample materials.

Introduction

In any type of manufacturing, knowing the physical and mechanical properties of the material used is critical. Tensile properties are just a small portion of material properties when analyzed as a whole, but they are arguably among the most important when studying the strength of the material. Tensile properties are important because how well a material performs under load can often determine what it is best utilized for.

Plastic three-dimensional (3D) filaments are a material type that is easily procured and can be printed into any desired shape when using a proper 3D printer. For example, to investigate and test the tensile strength of several different 3D printing materials, Tanikella et al. [1] printed specimens for acrylonitrile butadiene styrene (ABS), high-impact polystyrene sheet, polycarbonate, T-Glase, nylon, SemiFlex, and Ninjaflex following ASTM D638 standards [2]. The specimens were tested using an Instron 4206, and the study concluded that the tensile strength of a 3D-printed specimen depends mostly on the mass of the specimen for any given material.

Similarly, a study by Torrado Perez et al. [3] tested the differences in tensile strength of multiple versions of ABS filament, specifically pure ABS, 2 ABS composites, and an ABS/elastomer blend. The specimens for their study were also printed to ASTM D638 standards [2] and were printed both vertically and horizontally. Tensile tests were conducted using an Instron 5866 equipped with a 10-kN load cell. It was found that the ABS composite reinforced with titanium dioxide performed the best on the tensile tests, when printed both vertically and horizontally.

Further evaluation of research found a third study that varied the infill density and metal additives/reinforcements. These methods are beyond the capabilities for the resources for this study and were not considered when deciding how to conduct the study [4].

To the best of authors' knowledge, there are very limited studies that have been conducted to compare the tensile properties of PLA with those of photopolymer resin. Each print has drastically different manufacturing and printing processes. Therefore, it was decided to study, explore, and compare the tensile properties of PLA and photopolymer resin. It was also decided to replicate some of the above studies by comparing the tensile properties of several different wire strand materials, namely polylactic acid (PLA), ABS, carbon-fiber PLA, polyethylene terephthalate glycol (PETG), tie wire, and braided steel cable. This secondary test will provide a comparison to the printed specimen testing, in addition to being a replication of the above studies.

Theory

Testing of PLA thermoplastic filament and thermoset photopolymer resin consisted of samples of identical shape and dimensions. From the material properties data sheet of the Form Labs standard photopolymer resin and Hatchbox PLA filament [5, 6], theoretical values can be collected and then other properties calculated. For the standard resin, the tensile modulus of a post-cured sample is 402 ksi, and the ultimate tensile strength (UTS) is 9.38 ksi. For PLA, the modulus of elasticity is 507 ksi and the UTS is 4.79 ksi. The modulus of elasticity of the resin material is substantially lower than that of the PLA. From these properties, the assumption can be made that the PLA sample will be more ductile and able to elongate and retain its original shape better, while the resin sample will be more brittle and develop permanent defects at a much lower force. However, the UTS of the resin is much higher than that of the polylactic material, giving it the ability to withstand a much larger force than the PLA.

It should be noted that the values listed were obtained using post-cured ASTM D638-10 standards [2], which are different from the ASTM D368 standards used in this study [7]. Likewise, comparing the values obtained in the study with the theoretical values above produced some discrepancies because of the difference in ASTM standards. However, the pattern of the specimens remains consistent between the two standards, making it an acceptable and justified comparison.

The PLA and resin printed specimens were made with an equivalent rectangular cross-sectional area (A) of 0.06 in^2 . Using Eq. (1) and UTS ($\sigma_{\max}$), the theoretical maximum force (F) before fracture occurs can be calculated.

$$\sigma_{\max} = \frac{F}{A} \quad (1)$$

where A is the cross-section area (m^2). Theoretical maximum forces for the standard resin and PLA samples were calculated to be 556 and 282 lbf, respectively. Applying the theoretical forces to a Solidworks tensile simulation gives a visual representation of the stress concentration within the sample, as shown in Figure 1.

To find the Modulus of Elasticity (E) of material, the equation developed by the 18th-century English physician and physicist Thomas Young [8] is used.

$$E = \frac{\Delta\sigma}{\Delta\epsilon} \quad (2)$$

where $\Delta\sigma$ represents the change in stress (ksi), and $\Delta\epsilon$ is the change in strain.

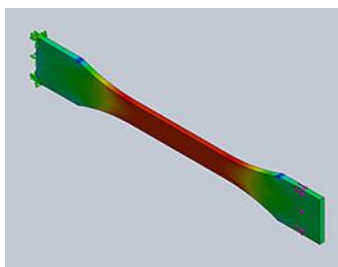


Figure 1. Stress concentrations for standardized dogbone shape in Solidworks. Red showing the high stress area.

Equipment/Materials

- Creality Ender 3-3D filament printer
- PLA filament
- Formlabs Form 2 resin printer
- Photopolymer resin
- Safety glasses
- Tape measure
- Pliers
- Tensile testing apparatus (TTA)
- Instron 5582 testing machine
- Bluehill program for Instron
- Cool Term Data Collection for TTA
- Wire strands (1.75-mm diameter) of:
 - PLA, ABS, PETG, and carbon-fiber PLA serial data logger
 - Braided steel cable (1.6 mm), tie wire (1.4 mm)

Primary Procedure

1. The dogbone design of the materials being tested was created in Solidworks as closely to the 1964 ASTM Standards for Testing Plastics [7] as possible, with only a few minor modifications necessary for printing & testing, shown in Figure 2.

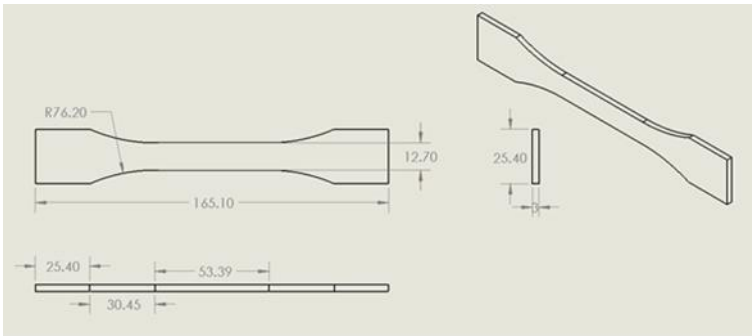


Figure 2. PLA and resin dogbone sample piece dimensions (mm) [7].

2. Print the dogbone design on both the Ender 3 filament printer and the Formlabs 2 resin printer shown in Figure 3.

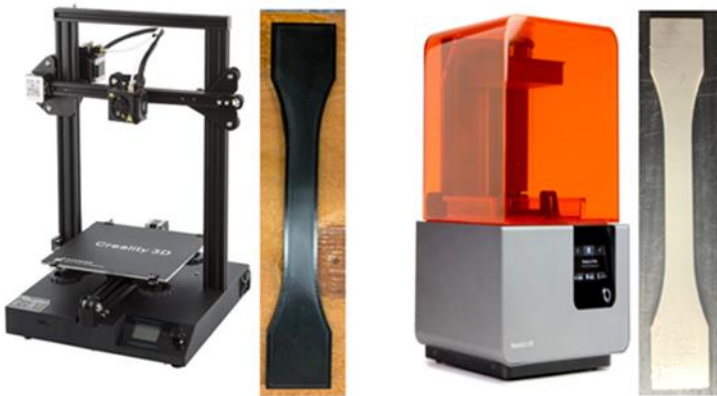


Figure 3. (Left) Creality Ender 3-3D Filament Printer and PLA dogbone sample. Reproduced with permission from Matter Hackers (<https://www.matterhackers.com/store/l/creality3d-cr-20-3d-printer/sk/MN6SPN76>). (Right) Formlabs 2 Resin Printer and photopolymer resin dogbone sample. Reproduced with permission from Atlas Resell https://www.atlasresell.com/used-dental-equipment/cadcam-dental-restoration/formlabs-form-2-3d-sla-laser-printer-desktop?gclid=Cj0KCQiAiZPvBRDZARIsAORkq7eFsLNzdzASfDMAZb4b3MAuB13OztSzfnGkAnuBiE8a4UTuTer3OsaAj6vEALw_wcB.

3. Turn on the Instron 5582 Test machine and initiate the Bluehill program.

4. After setting up the method and sample specifications, secure the bottom end of the specimen in the lower clamp of the testing apparatus and “jog” the upper half down to be in the proper position to clamp the upper end.
5. Reset the transducer before clamping the upper end of the dogbone. Clamp the upper end of the specimen and attach the extensometer (Fig. 4). Reset the extensometer and gauge length.



Figure 4. PLA sample in Instron 5582 testing machine.

6. After the specimen is secured and the program is set up, initiate the test.
7. Remove the broken test sample and save the data to a .txt file.
8. Repeat steps 4–6 for all PLA and photopolymer resin dogbone test samples.
9. Complete the data analysis in Excel.

Secondary Procedure

1. Acquire three 18” samples of PLA, ABS, PETG, carbon-fiber PLA, braided steel cable, and tie wire.

2. Using the TTA, set the wire grips 5" apart from center to center as seen in Figure 5.



Figure 5. Setting initial length of the PLA wire sample test to 5".

3. Launch the Cool Term Data Collection system to begin collecting the data.
4. Set the first wire sample in the grips (some trimming required) as shown in Figure 6.



Figure 6. PLA wire sample set up for testing in grips.

5. Initiate data collection on Cool Term by clicking Connect, Connections > Capture to text file > Start > Save as .csv.
6. Begin test by using the crank on top of the TTA (slowly).
7. Once the sample breaks, go to Connection > Capture to text file > Stop, and it will save the data.
8. Disconnect from the TTA.
9. Repeat steps 1–8 for every sample.
10. Complete data analysis in Excel.

PLA and Resin Dogbone Trials

The PLA and photopolymer resin test samples were designed using 1964 ASTM Plastic Standards for Testing [7]. This is kept constant over the course of the dogbone tests to keep consistency and to help control the testing and environment. All of the tested samples were printed at the same time in the same pattern/manner, in the same batch of samples respective to the material. Three consistent and controlled tests were completed as outlined in the primary procedure for each material with the results listed below.

Results

Results from two successful and identical PLA dogbone tensile tests were further examined in an Excel file. Using Eq. (1), stress values were evaluated to create stress vs. strain plots of the PLA data. The maximum failure force for each PLA sample was gathered and averaged to be 371 lbf. Using Eqs. (1) and (2), and by substituting in the maximum force and the rectangular cross-sectional area values, respectively, the average ultimate strength was calculated to be 6.3 ksi. From the stress–strain diagram, the linear portion (elastic region) can be used to approximate the modulus of elasticity. The slope of the linear line from the diagram in Figure 7 represents the modulus of elasticity and can be determined by evaluating Eq. (2). The average modulus of elasticity from the tests was found to be 455 ksi. In Figure 7, the results from the two tests are plotted on a stress–strain diagram. The tests follow the same trend and behave in the same manner with slight differences in stress and strain values. The changes in slope from the tests are due to the ductile behavior of the PLA material. As the material gets closer to its fracture point, the specimen elongates, increasing the strain while decreasing the stress.

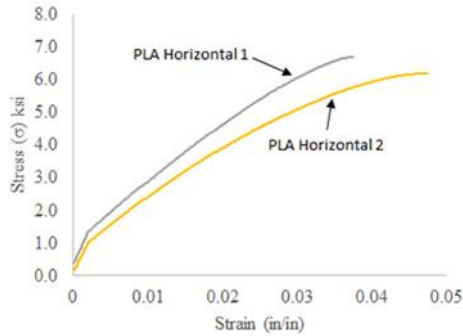


Figure 7. Stress vs. strain line chart of PLA dogbone tests.

The results of two successful resin tests were used to find important experimental mechanical properties of the material. The results were put into a stress–strain diagram in the same manner as the PLA samples, as shown in Figure 8. Using an approximation of the slope and evaluating Eq. (2), the average modulus of elasticity of the resin samples was calculated to be 443 ksi. From the data, the average maximum force and UTS were found to be 430 lbf and 6.8 ksi, respectively. The results from the two experiments are shown in Figure 8. The slope and stress vs. strain values with the exception of the maximum force or in this case, the force at which the fracture occurred, were almost identical in behavior. As shown in Figure 8, the slope of the resin samples remains mostly constant because the resin samples show a brittle behavior. The specimens are subjected to continuous loading until fracture.

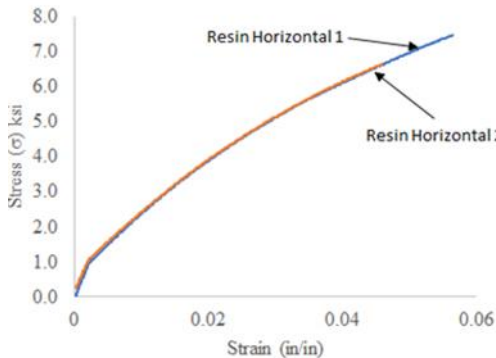


Figure 8. Stress vs. strain line chart of photopolymer resin dogbone tests.

Figure 9 (left) shows the test samples after testing. The PLA samples display a pattern of clean and horizontal fractures in the upper region of the specimen. The resin samples show the fractures near the bottom, and the fractures are more random and even missing pieces of the sample that were lost because of a violent fracture, as shown in Figure 9 (right).



Figure 9. (Left) Image of the test samples after testing. (Right) Image of resin sample fracture.

Dogbone Discussion

The results were somewhat unexpected, in the sense that before any actual or theoretical testing, it was expected that the PLA dogbones would behave as though they were much more ductile. However, quite the opposite occurred; the PLA dogbone samples suffered a brittle fracture, although much more ductile than that of the resin. Fractures occurred in the middle sections of the samples consistently throughout all of the tests. This was expected, as with testing to ASTM standards specimens will typically fail along the middle portion of the dogbone [7]. The fact that the samples failed in the appropriate place that it was supposed to demonstrates that our samples were very consistent, because of the way the test was designed.

The PLA samples were made using a fused deposition molding (FDM) method that melts the plastic together similar to welding in a thermoplastic process. This is a reversible process, meaning that the physical properties are minimally affected and there is no chemical bonding that would prevent the reusability of the material. Thermoplastic polymers are made up of tangled polymer chains with no cross-link between the chains resulting in a weak force of attraction. [8]

With the resin tests, the brittle fractures were much more predictable, having a higher tensile strength and lower modulus of

elasticity. The successful tests from the resin dogbones showed the results lining almost perfectly on top of each other in Figure 8 but with slight difference in UTSs. The fact that they broke and stretched in the same way/pattern is a very good sign as to the consistency and predictability of the resin's material properties, as well as the quality and consistency of the Formlabs 2 resin printer.

The photopolymer resin samples were made using stereolithography (SLA) method [9] that utilizes an ultraviolet laser to cure the resin layer by layer in a thermosetting process. This causes an irreversible permanent chemical bond that is highly resistant to melting and causes a complete change in physical properties (liquid becomes solid). Thermoset plastics are cured to have polymer chains held together by strong covalent cross-link bonds that do not break down as easily, making it stronger.

In Table 1, theoretical values and average results from the experiment are displayed. The values have some discrepancies because an older and slightly altered version of the ASTM standards was used during the testing; however, the values show an acceptable pattern among the two materials. The UTS of the resin as predicted was much higher and allowed it to withstand a larger maximum force than that of the PLA samples. This behavior confirms the predicted trend of the UTS and maximum force. It was anticipated from the theoretical values that the experimental resin samples would have a much lower modulus of elasticity and that held true as shown in Table 1. Note that theoretical and experimental values have slight deviations because different ASTM standards were used.

Table 1. Experimental vs. theoretical comparison of ultimate tensile strength, maximum force, and modulus of elasticity [7]			
Test	UTS (ksi)	Max. force (lbf)	E (ksi)
Resin			
Experiment	6.88	406.5	443.7
Theoretical	9.38	562.8	402
PLA			
Experimental	6.29	371.26	467.44
Theoretical	4.79	287.4	507

The plots from the experiments of both materials from Figures 7 and 8 are shown together on a single diagram displayed in Figure 10.

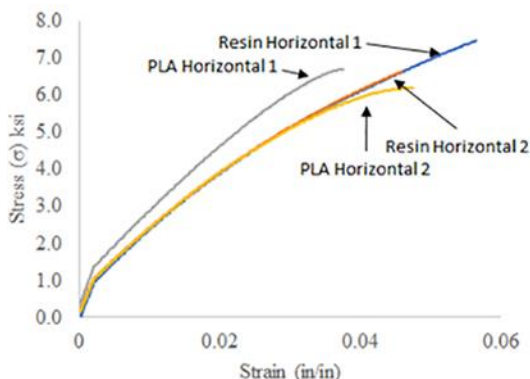


Figure 10. Stress vs. strain line chart of all dogbone tests.

The PLA samples were predicted to be more ductile than the resin samples because of the larger modulus of elasticity value. How the samples behaved during testing, as shown in Figure 9, also confirmed the theoretical assumption that the PLA is a more ductile material than the resin. Figure 10 shows that near the peak of the PLA plot lines, the slope of the lines slowly decreases in an almost identical manner. This decrease in the slopes shows that after the maximum force was applied the material began to elongate and the force slowly decreased until failure. For the resin samples, the plot lines are identical in slope and break at their maximum force; there is no decrease in slope prior to the fracture. Figure 10 is a valid representation that validates the assumption that the higher modulus of elasticity, the more ductile the PLA sample will behave and the more brittle the resin sample will behave.

Wire Tests

Using the wire strands, tape measure, safety glasses, pliers, and the TTA, the secondary procedures were used to complete testing for the wire strand samples. This section of testing involved simple tensile testing of roughly 18" wire lengths of various 1.75-mm plastics, as well as some braided steel cable and tie wire (3 each). The reasoning for comparing these wire samples is because the steel cable and tie wire are very common general-purpose materials that are used for a variety of applications from construction, to agriculture, to even automotive. After completing the analysis for the wire tests, we determined the low carbon wire could withstand up to four times the force as the PLA, as shown in Table 2.

Table 2. Wire strand average maximum applied pulling force (load) and average ultimate tensile strength test results for three strands of each material

Material	Ave. max. load (lbf)	Ave. UTS (ksi)
PLA	24.78	6.64
ABS	19	5.09
PETG	27.15	7.28
Carbon-fiber PLA	27.15	7.28
Braided steel cable	559.36	179.48
LCS tie wire	115.38	48.36
Dogbone resin	406.5	6.88
Dogbone PLA	371	6.29

Wire Results and Discussion

After all the testing was completed, the results for each material were organized into separate Excel spreadsheets for data analysis. Because the testing could not be entirely duplicated, there was a higher source of error, and the testing could not incorporate a strain gauge, so an accurate modulus of elasticity could not be calculated. This is why the focus of this experiment was more on the maximum force that could be applied in tension before these wire strands failed. As predicted the strands containing steel had a substantially higher average maximum load and UTS (Table 2). The common tie wire and braided steel have similar diameters to those of the 3D printing materials, aiding in a better understanding of the mechanical properties they possess. The ABS samples had the lowest values in each section among the test samples. The preprinted PLA strands that were tested had mid-range values among the samples. PETG and carbon-fiber PLA had identical results that were the strongest in both maximum load and UTS among the 3D printing materials.

The preprinted PLA samples had an average UTS of 6.64 ksi. The post printed dogbone PLA samples tested on the Instron had a calculated average UTS of 6.29 ksi. The difference in UTS between the preprinted and postprinted PLA samples was less than 0.4 ksi. The assumption can be made that during printing the material lost some of its strength and integrity from the heating process and that may be the cause of the postprinted samples having a lower average UTS. In comparison to the other FDM thermoplastic 3D printing filaments (ABS, PETG, and carbon-fiber PLA), the PLA filament is a mid-range filament when it comes to strength. It can be predicted that if the dogbone shaped tests were also performed using ABS filament, the maximum force required to fracture the sample and the UTS would be substantially lower than for

the PLA. If the same tests were run using either PETG or carbon-fiber PLA filament, the maximum force and UTS would most likely be greater than for the standard PLA and resin material.

Sources of Error

In the beginning of preparing samples, there were several samples that either printed poorly, slipped out of the original grips, or simply broke while setting up the tests. Because the data was collected for most of these failed tests, there is a considerable amount of data collected that is no longer valid and has led to some confusion and would be one of the first possible causes of error. In Figure 11, the diagram shows another major error that occurred during one of our experiments. As the Instron applied tensile load, the resin sample slipped in the mechanical grips, resulting in discrepancies in the strain values and a rapid decrease in force, which invalidates the data because it causes some fatigue in the material and decreases the overall strength when the load was reapplied.

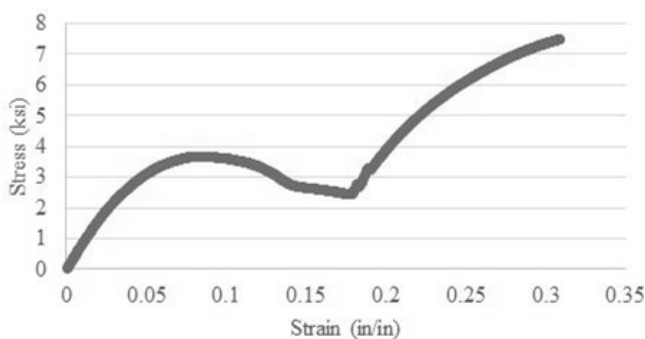


Figure 11. Stress–strain of a photopolymer resin test with data discrepancies.

Conclusion

The samples used in the testing were of identical shape and were subjected to identical strain rates. The specimens at first glance appear to be similar materials, but on an atomic level the bonding is different and causes them to behave differently and have different physical and mechanical properties. From all of the tensile testing done with dogbones, the conclusion that can be made that photopolymer resin suffers a more brittle fracture with higher tensile strength and PLA undergoes a less brittle fracture with a lower tensile strength than resin.

The tangled polymer chains with no cross-link between chains in thermoplastic material such as PLA result in a weaker specimen. The thermoplastic materials have the capability to be recycled, melted, and reused. Thermoset resin materials have an irreversible chemical bond that does not allow the material to be reused, but the material has strong covalent cross-linking bonds that increase the strength of the material. The results of this study can be applied to real-life utilization of 3D printers. If a higher ductility material is needed at the expense of a lower strength, a thermoplastic material such as PLA is an inexpensive and workable solution. If a stronger material with a more brittle behavior is necessary, then a thermoset material like the standard resin used in this experiment is a positive alternative. The resin material does come at an expense as the SLA printing equipment and resin material is a much more expensive method. Theoretically, from the results of the tensile tests using preprinted 3D thermoplastic filaments, carbon-fiber PLA and PETG will have the greatest strength among the 3D printing materials tested in this experiment.

Recommendations

Testing with future experiments regarding this research could be improved by:

1. Experimenting with different infill pattern types when producing the PLA samples.
2. Experimenting with printing both PLA and resin in different orientations.
3. Using more up-to-date standards for testing plastics.
4. Using heat to compare the properties of the thermoplastic PLA and the thermoset photopolymer resin.

Acknowledgments

Without the support of the Department of Engineering and Technology at SUU, these experiments would not have been possible to complete. All of the tensile testing apparatuses were provided by the department.

We would also like to thank Mr. Fausett for allowing us to use his Formlabs Form 2 Resin 3D printer as we would not have had the ability to create the photopolymer resin samples without his equipment and time.

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Tensile Properties and Thermal Conductivity of Fused Polylactic Acid Polymers

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Abstract

The study performed in this paper is part of the undergraduate research performed at Southern Utah University. The research includes evaluating the basic mechanical and thermal properties of the common printing material PLA (polylactic acid). The tests include tensile strength in the three orthogonal orientations and experimentally evaluate the coefficient of thermal conductivity for the material. The results indicate that the samples were strongest when printed with layers parallel to the direction of the applied load. The thermal conductivity for the material is evaluated to be $0.134 \frac{W}{m \cdot K}$ where, according to the SD3D Technical Data Sheet, the published thermal conductivity is $0.13 \frac{W}{m \cdot K}$.

Nomenclature	
Symbol	Meaning
A	Cross-sectional area (m ²)
F	Force (N)
FFF	Fused filament fabrication
K	Thermal conductivity ($\frac{W}{m.K}$)
L _o	Initial length (m)
ΔL	Change in length (m)
PLA	Polylactic acid
Q̇	Rate of heat dissipated
T	Temperature (K)
Δx	Thickness (m)
ε	Strain ($\frac{m}{m}$)
Σ	Stress (MPa)

Introduction

Three-dimensional (3D) printed materials are a useful tool in the prototyping stages of design. Polylactic acid (PLA) is an easily manipulated and renewable material commonly used in 3D printing. PLA is made from fermented biomass, mostly consisting of corn, and is biodegradable. This report covers some of the mechanical properties and the thermal conductivity of 3D PLA filament prints in multiple orientations.

In the early stage of this project, because of the lack of published data on the mechanical and thermal properties of PLA, the objective was to characterize the yield and ultimate stresses for a sample in tension as well as the thermal properties of PLA 3D-printed filament for use with engineering applications.

Two months into the project, a source containing the tensile and thermal properties was published [3], and the focus of our project switched from characterizing independent values to comparing our values with the recently published ones.

Theory

To determine the yield and ultimate strength of the material the normal stress was calculated as

$$\sigma = \frac{F}{A} \quad (1)$$

where σ is normal stress (kPa), F is tensile force (N), and A is the cross-sectional area (m^2). Next, strain was evaluated as

$$\varepsilon = \frac{\Delta L}{L_0} \quad (2)$$

where ε is strain m/m, ΔL is the change of length of the sample (m), and L_0 is the original length of the sample (m).

Elongation at the yield point was determined by referencing a data sheet published by SD3D, a manufacturer of 3D filaments [3]. The orientation of prints will be important in the yield and ultimate stresses because particular orientations will have more material aligned in the direction of the tension load. In this case, those properties are expected to be higher than other orientations.

The thermal conductivity of a plate can be found by applying a heat source to one side and measuring the temperature of both sides until a steady state is reached. With a known constant power diffused by an electric heater applied to the bottom of a well-insulated disk of material over a long period of time, it is possible to determine the coefficient of thermal conductivity as

$$\dot{Q} = -kA_s \frac{\Delta T}{\Delta x} \quad (3)$$

where $\dot{Q}$ is the power input to the system through the electric heater (W), k is the thermal conductivity, Δx is the thickness of the disk (m), A_s is the surface area of a face of the disk (m^2), and ΔT is the difference in temperature (K) of the two faces of the disk.

Rearranging Eq. (3) to evaluate the thermal conductivity ($\frac{\text{W}}{\text{m}\cdot\text{K}}$) results in

$$k = -\frac{\dot{Q} \cdot \Delta x}{A_s \cdot \Delta T} \quad (4)$$

Materials

PLA (polylactic acid) is a thermoplastic that is commonly used in FFF (fused filament fabrication), sometimes referred to as FDM (fused deposition manufacturing). PLA is the most common bioplastic used, even outside of 3D-printing applications. It is used for applications in disposable tableware, medical implants, and diapers, among other things. It is sourced from starch, more specifically the lactic acid in the starch, and is composed of chains of $\text{C}_3\text{H}_4\text{O}_2$. This structure is made by opening up the lactic acid structure and chaining them together through multiple methods.

PLA has been used as a 3D-printing material for a long time. The material is easy to print compared with most other 3D-printing materials because it does not require a heated bed or an enclosure. It is also generally the most effective option by weight. These advantages are undercut by the mechanical properties of PLA. It is more brittle than most engineering materials and has high tensile strength, compared with acrylonitrile butadiene styrene, polyethylene terephthalate glycol, and resins. PLA possesses poor impact resistance and very low thermal properties because of its low glass transition temperature and the melting point when compared with other FFF materials, to the point that it is unsuitable for most applications that are above room temperatures. For our testing, we used eSUN PLA+. Figure 1 shows a basic overview of FDM printing. A certain amount of plastic is pushed through a hot end to melt the plastic and simultaneously push the melted plastic through a nozzle. As the melted plastic is extruded the bed that it is being extruded onto moves to create the shapes needed.

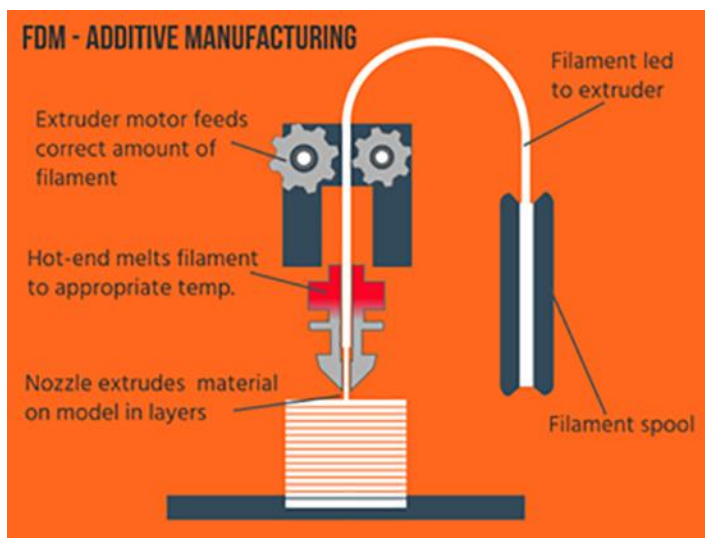


Figure 1. Inner working of a 3D-printing nozzle [1].

Because of the nature of FFF, the orientation of the part during printing changes the mechanical properties of the specimen. To analyze the possible minimum and maximum strength properties for the tensile testing, the three basic orientations for 3D printing were fixed universally. These three orientations are shown in Figure 2. The layer

orientation can either increase or decrease the strength of a part when a force is applied in a specific direction relative to the layer lines. When

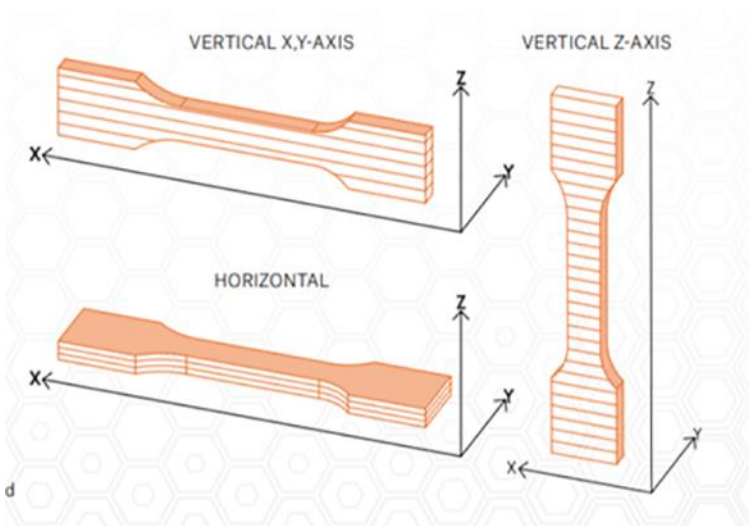


Figure 2. Printing orientations for the sample testing [2].

engineering a part that will be manufactured through FFF, all directions do not have the same mechanical properties because of the interface of the printed layers being in a particular direction. So, it is important to know the strength of the material based on the orientation that it was printed. Figure 3 shows one of the ASTM Type V tensile bar printed in the vertical orientation.



Figure 3. ASTM Type V tensile bars.

Equipment

Two printers were used to print the sample used in the testing. The first printer was a Flashforge Creator Pro. This printer printed the majority of the samples. The second printer is an Ender 3; this printer was used to print the vertical samples and the disc. This approach was selected because the Flashforge Creator Pro's build volume was not tall enough to fit the samples inside.

The tensile samples were tested on a universal testing machine. The universal testing machine uses wedge grips to achieve a sufficient grip for a tension test. The test load is applied to the through lead screws moving a cross bar up. The universal testing machine, seen in Figure 4, is used in joint with CoolTerm, a serial monitor with logging capabilities.

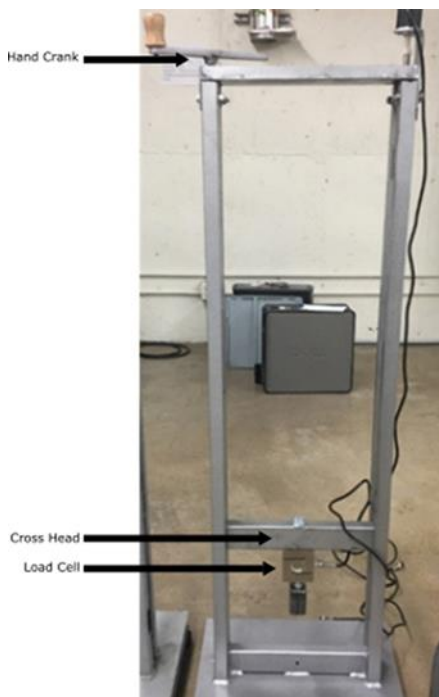


Figure 4. The universal testing machine used for the tensile tests.

For testing the thermal conductivity of the PLA, a custom testing jig was designed and constructed inhouse. These tests determine the thermal conductivity of the material by measuring the temperature difference on both sides of a sample with known thickness. To create an

environment where those values can be accurately measured, two PVC pipes are used to construct a cylinder for the sample to be placed as seen in Figure 5. Thermocouples are placed centrally on both sides of the sample and the system is insulated. A resistive heater provided the thermal energy (heat) as seen in Figure 5, and thermocouples are used to measure the temperature of the sample on both sides.

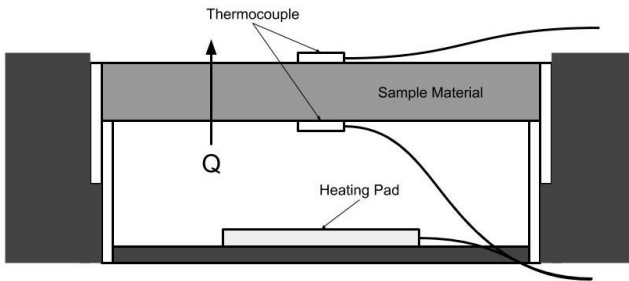


Figure 5. Diagram of the thermal conductivity testing setup.

Procedures

3D-printing tensile test bars

1. Get ASTM D368 .stl file from online source seen in Figure 6.
2. Verify the dimensions in mm of the 3D model file.
3. Load .stl into Cura.
4. Rotate the model to the correct orientation.
5. Set the slicer to create a solid part with 4 perimeters, 0.2-mm layer height, and at 215°C.
6. Export the resulting .gcode file.
7. Upload the .gcode file to the printer.
8. Print the file.
9. Repeat steps 3 through 8 with the other orientations.

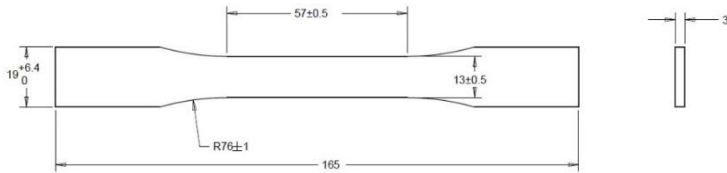


Figure 6. Dimensions of the tension bar (units in mm).

3D-printing thermal conductivity disk

1. Model a disk in Solidworks and export to an .stl file.
2. Load .stl into Cura.
3. Set the slicer to create a solid part with 4 perimeters, 0.2-mm layer height, and at 215°C.
4. Export the resulting .gcode file.
5. Upload the .gcode file to the printer.
6. Print the file.

Tensile

1. Connect a computer to the universal testing machine via CoolTerm Serial Monitor.
2. Fix tensile sample in wedge grips as seen in Figure 7.
3. Begin recording to textfile.
4. Apply tension to bar by slowly and consistently turning the handle until fracture.
5. End recording to textfile.
6. Remove sample from grips.



Figure 7. Tension bar loaded into the universal testing machine.

Thermal conductivity

- 1 Place disk of material on the thermal conductivity testing setup seen in Figure 8.
- 2 Tape thermocouples to the center of the disk with Kapton tape.
- 3 Seal bottom with foam plug with electrical heating element inside.
- 4 Attach thermocouples to thermocouple reader and begin logging.
- 5 Connect heating element to a 0.75W power source.
- 6 Wait for system to reach steady-state condition.
- 7 End the data logging.
- 8 Disconnect power and thermocouples.
- 9 Remove SD card from thermocouple reader, and download file to a computer.

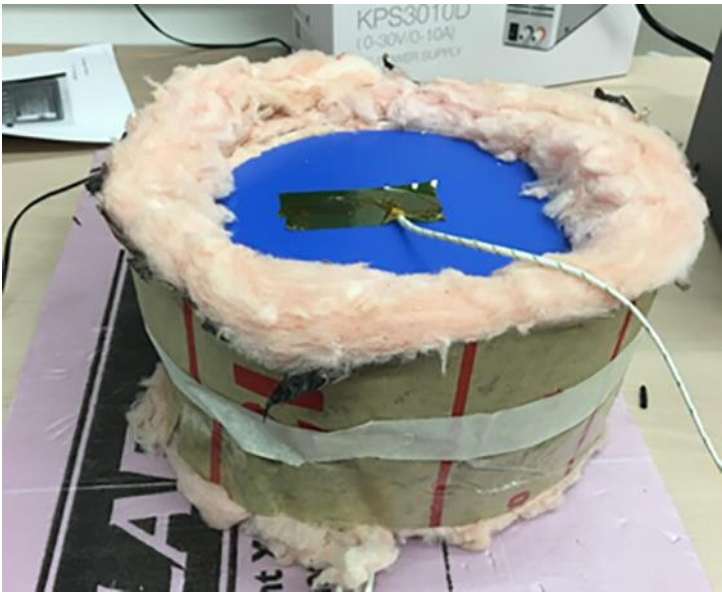


Figure 8. Thermal conductivity test disk in the insulated environment.

Results

The average results of the tensile tests are recorded in Table 1, and the stress-strain plots of samples of each orientation are shown in Fig. 9.

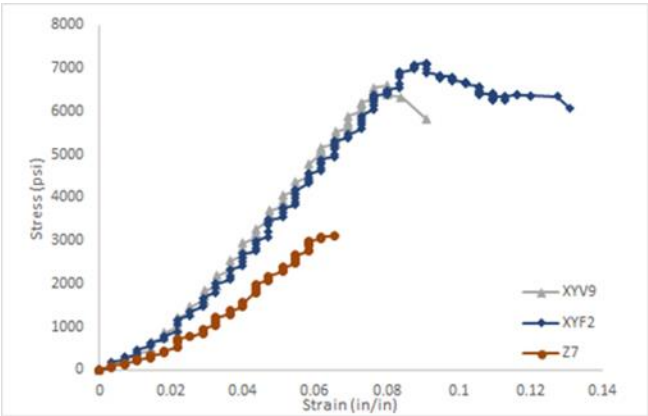


Figure 9. Examples of stress-strain plots of horizontal, vertical, and Z-oriented samples.

Table 1. Average of ultimate tensile stress and tensile yield stress for the various orientations		
Orientation	Ultimate stress (PSI)	Yield stress (PSI)
Horizontal	6685	1260
Vertical X	6383	1362
Vertical Z	3184	612

For the thermal conductivity test, the temperatures found for the top and bottom of the disk are presented in Figure 10. The test ended when the temperature reached the steady state.

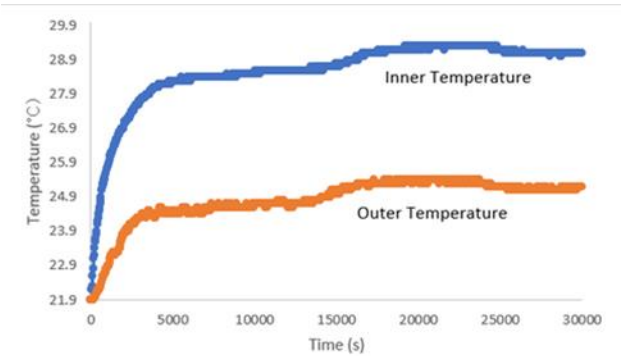


Figure 10. TC's temperature profile.

Discussion

The strongest direction in tension was the horizontally oriented samples, followed closely by the vertical samples, with the Z-oriented samples being the weakest by a wide margin as shown in Table. 2. The percent errors were calculated from the theoretical values found in the publication by SD3D shown in Table 3.

Table 2. The ultimate and yield stresses of the orientations compared with the theoretical values from SD3D [3]				
Orientation	Ultimate stress (PSI)	Yield stress (PSI)	Ultimate stress % error	Yield stress % error
Horizontal X	6685	1260	5.6%	85.7%
Vertical X	6383	1362	9.8%	84.6%
Vertical Z	3184	612	55.0%	93.1%
Theoretical	7080	8840		

Table 3. An excerpt from the data sheet published by SD3D listing several material properties [3]

Tensile Properties ASTM D638 - Type V		
Property	Imperial	Metric
Toughness*	7.7 ft-lb/in ²	16.2 KJ/m ²
Tensile Modulus	293000 psi	2.3 GPa
Ultimate Tensile Strength	7080 psi	26.4 MPa
Tensile Strength at Yield	8840 psi	35.9 MPa
Elongation at Yield	2%	2%
Elongation at Break	4%	4%

Running the thermal conductivity test for about 20,000 seconds (5.5 hr) resulted in a steady-state temperature difference between the two sides. Once steady state is reached, the temperature difference between the two faces was 3.9°C. Using this temperature difference in Eq. (4), the thermal conductivity was evaluated. For this calculation, power of 0.75 W, diameter of 6 in., and thickness of 0.5 in were used. The evaluation resulted in the thermal conductivity of $0.134 \frac{\text{W}}{\text{m}\cdot\text{K}}$.

The value of thermal conductivity published by SD3D is $0.13 \frac{\text{W}}{\text{m}\cdot\text{K}}$. This value is very close to the value obtained, but there are not enough significant figures to determine an accurate percent error. Determining the percent error at two significant figures, we get a 0% error (Table 4). Table 5 presents an excerpt from the data sheet published by SD3D listing several thermal properties.

Table 4. The theoretical and experimental thermal conductivity ($\frac{\text{W}}{\text{m}\cdot\text{K}}$) of the disk of PLA

Experimental thermal conductivity	Theoretical thermal conductivity	Percent error
0.13	0.13	0.0%

Table 5. Data sheet published by SD3D [3]

Property	Imperial	Metric
Glass Transition by DSC, ASTM E1356	134 F	57 C
Glass Transition by DMA, ASTM D792	145 F	63 C
Heat Deflection Temperature, ASTM D648	121 F	49 C
Coefficient of Thermal Expansion, ASTM E832	23 x 10 ⁻⁶ in/inR	41 x 10 ⁻⁶ m/m·K
Heat Capacity, ASTM E1269	0.43 Btu/lb/°F	1,800 J/kg·K
Thermal Conductivity, ASTM C518	0.9 Btu-in/hr/ft ² /°F	0.13 W/m·K

Sources of Error

One of the sources of error was related to testing unprinted strands of filament; they showed a more ductile behavior compared with a printed sample. This could be due to the geometry of the samples as the

infill's orientation may have changed the way the force was distributed on the sample.

Because of this error, the samples that were printed had a determining stress concentration at the necking of the central portion. Most of the samples broke in this area, which may have to do with the high percent error noted in the yield stress.

Because of a lack of information on the orientation and fabrication method, the theoretical values of the PLA used were assumed to be for injection-molded PLA instead of FFF PLA. Presumably, injection-molded materials would be stronger than FFF materials in any orientation. This might be why the values of the ultimate stress were lower than predicted.

Another possible source of error may be traced to the printing process. Little nuances in the environment and the printer may influence the prints to have small defects. Not having a large enough sample size would allow the defects to impact the results.

Variance in the thermocouple introduced a variance into the temperature differential for the thermal conductivity test. The value of 3.9°C used was the average of these temperatures in the steady-state region.

Conclusion

Modern engineering has integrated 3D printing into many steps within the design and manufacturing process. PLA has multiple benefits including its ease of printing, sustainability, and its ability to be recycled easily. During these tests, the tensile strength and thermal conductivity properties were evaluated. After conducting the tests, the results showed that the horizontal orientation has the highest ultimate strength of 6685 PSI. The theoretical ultimate strength is 7080 PSI. This gives a percent error of 5.6%.

The test for the thermal conductivity of a cylindrical 3D-printed disk determined that the thermal conductivity of the PLA disc was $0.13 \frac{\text{W}}{\text{m}\cdot\text{K}}$. The theoretical thermal conductivity was also $k=0.13 \frac{\text{W}}{\text{m}\cdot\text{K}}$ showing a percent error of zero at this level of significance.

The results that were concluded were representative of the results that we supported by the SD3D Technical Data Sheets. The percent error found was not significant, which begins to give the credibility of the results. Moving forward, the data could gain further credibility by repeating the tests to back the data up.

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Thermoelectric Devices: A Study of Material-Based Efficiency and Operation

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Abstract

The purpose of this experiment was to determine the performance of different thermoelectric devices by comparing efficiency based on material selections and device configurations. Dissimilar semiconductors create a relation between heat flux and electricity in the thermoelectric junction based on the Peltier Effect. The most common materials are bismuth alloy (BiSn), bismuth telluride (Bi_2Te_3), antimony telluride (Sb_2Te_3), and bismuth selenide (Bi_2Se_3). An apparatus consisting of two cooling blocks, two thermoelectric devices, and two heaters was used to conduct the experiment. A steady-state temperature differential was maintained by ceramic plate heater on the hot side and an aluminum cooling block on the cold side. Multiple configurations were tested for power generation at a variety of temperatures. The measured maximum efficiency of the thermoelectric generator was approximately 5.6%, and the published maximum efficiency from the manufacturer was listed as 5.03%. Multiple devices were tested in an

attempt to draw connections between material combinations and efficiency for the thermoelectric coolers or generators. Although the test apparatus provided consistent and relatively accurate data, the raw material combinations and manufacturing methods used for thermoelectric devices are proprietary. However, a comparison between different thermoelectric devices showed a correlation between the intended application of the device and the efficiency when used for power generation. When used for power generation, the thermoelectric devices intended for heating and cooling were consistently less efficient than the devices that were purpose-built for power generation.

INTRODUCTION

Thermoelectric devices create an energy relation between heat and electricity. When heat flows through the device, the heat essentially carries electricity with it, generating electric power. By creating a difference in temperature between the two sides of the device, a voltage is generated that could be used for additional processes [1]. These devices also work in the opposite direction, such that providing electrical power to the device will create a temperature difference across the device. Both functions are described by the thermoelectric effect. The thermoelectric effect refers to how the movement of heat between materials relates to electrical charge [2].

Thermoelectric devices use a “P-N junction” between two semiconductor materials (one for the hot side, another for the cold side) to generate electricity [3]. Improving the efficiency of these devices could greatly increase the widespread use of these devices, which in turn could cut energy consumption and improve performance for many other applications.

The scope of this research was to explore a topic that has real-world applications and room for improvement. Many processes in industry generate waste heat, and scavenging some of this waste heat could increase the efficiency of many processes. This study includes determination of the efficiency of thermoelectric devices based on the materials from which they are made in the interest of exploring improvements to the design of thermoelectric devices. If the efficiency of thermoelectric devices could be improved, these devices could be used for refrigeration and cooling, as well as power generation using thermal energy. Geothermal, solar, or any other process which produce heat could then be harnessed to generate electricity.

EQUIPMENT AND MATERIALS

- Power supply (Eventek KPS3010D)
- Test meter (Fluke 115)
- Plate heater (heat scientific, 40x40 mm, 1.5 Ω)
- Cooling blocks (aluminum, 40x40x12 mm)
- 1/4" inner-diameter x 3/8" outer-diameter Poly tubing
- 1/4" to 3/4" reducer
- Thermal paste (silver compound)
- 1/4" barbed T fitting
- Thermoelectric generator (Marlow TG12-6-01L aluminum oxide ceramic and bismuth telluride junction)
- Thermoelectric cooler (Tetech HP-127-1.4-1.15-71, and VT-127-1.4-1.15-71 bismuth, tellurium, antimony, and selenium, plus dopants depending on junction type)
- Clamps
- Insulation
- 20AWG wire (alligator leads work fine, 3 total)
- Cooling water

PROCEDURE

The test setup was based on a previous research project presented in the *Journal of Electronic Materials* with some modifications because of parts availability and project budget [4]. A combination of devices intended for power generation and heating/cooling was used to determine how different materials affect the efficiency of power generation. These devices were constructed from bismuth telluride, bismuth selenide, and antimony telluride, depending on the intended application [5]. The revised test design for this experiment is shown in Fig. 1. This configuration provides symmetry and uses matched surface areas to minimize the parasitic heat loss between the components. W_{in} is the energy put in to the system by the heaters (W), W_{out} is the energy harvested by the TEG devices (W), and Q_{out} is the cold sink to generate the necessary temperature differential across each TEG (W). Using a water-cooling system as the cold sink causes the thermal capacity of the cold sink to greatly exceed the capacity of the heaters, allowing the cold sink to be treated as an infinite cold reservoir. The efficiency of the TEG can then be calculated directly by comparing the power supplied to the heaters (W_{in}) with the power harvested by the TEG (W_{out}).

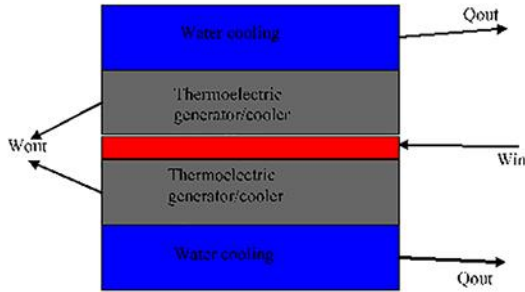


Figure 1. Test setup overview.

Constructing the test apparatus and performing the experiment is as follows:

1. Cut tubing to the following lengths: 2 ft (5 pieces).
2. Affix a piece of tubing to each of the barb fittings on the cooling block(s) (4 connections total).
3. Connect the tube from one side of each cooling block to the T-fitting.
4. Connect a section of hose to the other end of the T-fitting.
5. Connect the other end of the tube section (away from the T-fitting) to the 1/4"-3/4" reducer.
6. The other lines coming from the cooling block (not attached to the T-fitting) are the drain lines. These lines should be placed where the water can flow into an open drain.
7. Connect the water-cooling system to the water source, run and check for leaks (Fig. 2 shows the finished water-cooling setup for reference).



Figure 2. Water cooling system.

8. Apply thermal paste to all contacting surfaces.
9. Assemble the components as shown in Fig. 1. The hot side of each TEG module faces inward towards the heaters and the cold side faces outward towards the cooling blocks. Refer to Fig. 3 for the complete test setup.

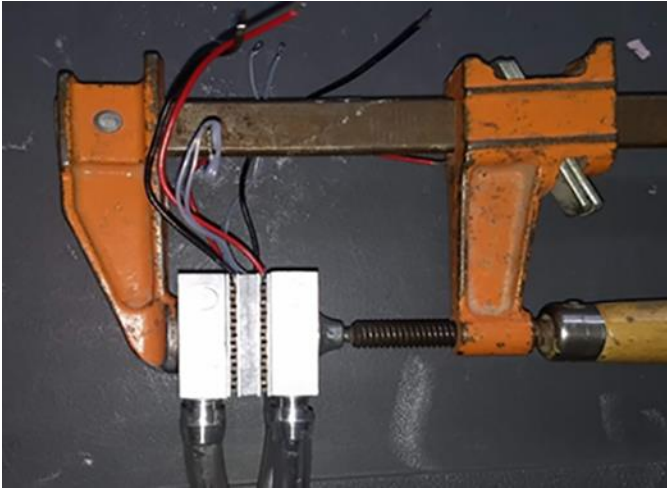


Figure 3. Test setup

10. Clamp the assembly together.
11. Connect the heaters in series (no polarity orientation required).
12. Connect power supply to heater assembly, adjust current limit to 3.25 A.
13. Connect both thermoelectric devices in series (positive of one device to negative of other device, remaining two wires are power out).
14. Connect test meter to thermoelectric devices.
15. Turn on the water supply to get uniform water flow.
16. Turn on power supply with voltage set at zero.
17. Adjust voltage up until maximum current is reached.
18. Wait until output voltage of TEG reaches steady state (no change over ~ 1 min interval).
19. Measure voltage and current output from TEG device.
20. Record voltage and current measured from TEG, as well as voltage and current from power supply.
21. Adjust current on power supply down by 0.25 A.
22. Repeat steps 19–21 for a total of 10 samples to generate an accurate performance curve.

23. Disassemble assembly and exchange thermoelectric device for next type; repeat steps 8–25 with next device.
24. Clean thermal paste from all equipment.
25. Replace all parts in clearly labeled packaging.
26. Plot power in vs power out for all devices tested.

RESULTS AND DISCUSSION

As demonstrated by industry, our test results have shown that the thermoelectric devices are not very efficient. To generate any usable power, a very high temperature difference is needed. In our first attempt to perform the experiment, the original heaters did not produce enough heat to generate any significant power through the thermoelectric devices because the resistance was too high for the intended operating voltage. The original heaters had an average resistance of $500\ \Omega$ and could not produce sufficient heat because the equipment used had a maximum voltage of 30 V. This resulted in a maximum power output from the heaters of around 1.8 W. As such, new heaters that were capable of producing much higher temperatures were obtained. The new heaters had an average resistance of $1.5\ \Omega$, which could provide a maximum of 600 W to the system. Once an accurate experiment setup was constructed, two types of device were tested. One intended for power generation and one for heating/cooling. The devices were chosen because of the different materials used. As such, comparing the devices showed a relation between material combination and thermal efficiency. Fig. 4 shows the first test of a thermoelectric device with accurate results.

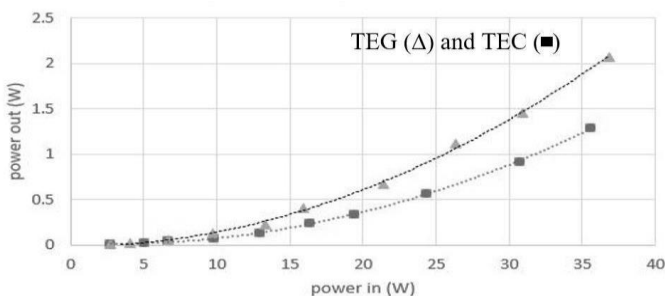


Figure 4. TEG module and TEC module performance.

The first test was conducted on thermoelectric generators from IIV-I Marlow. The company was contacted for material specifications, and it was determined that these devices were made out of bismuth telluride. These devices are made just for producing power; however, as seen in

Fig. 4, the maximum efficiency in the test setup is 5.6% and the maximum efficiency for these modules is specified at 5.03% [5,6], which suggests that the test setup is capable of providing relatively accurate results.

The low efficiency of thermoelectric devices explains why these devices are not practical in everyday applications. The test data also suggests that operating the devices at or near their maximum temperature rating will likely provide the greatest efficiency. Last, by comparing performance between the devices, it is obvious that the combination of materials used in the thermoelectric device has a significant effect on performance. Manufacturer performance data for the first thermoelectric devices tested are shown in Fig. 5. The efficiency vs. temperature of the TEG, as published by the manufacturer is shown in Table 1, and was the

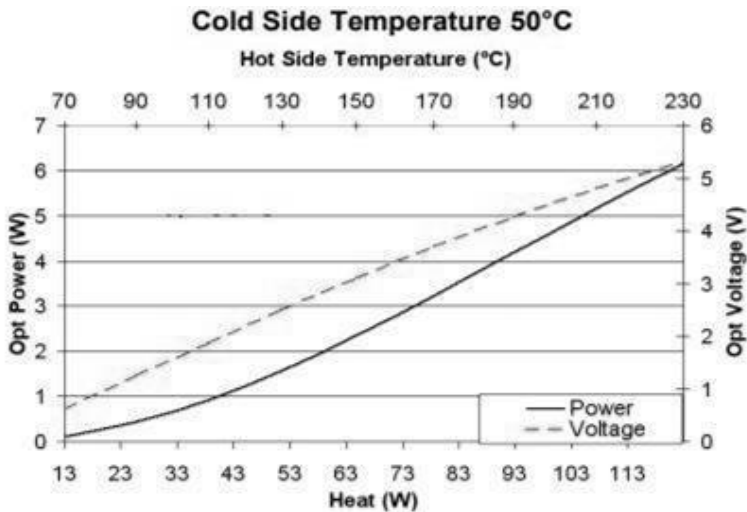


Figure 5. Performance characteristics for thermoelectric device used in the first test [5].

primary method of comparison for the test results. The maximum efficiency of the thermoelectric device as tested by the manufacturer is listed as 5.03% in Table 1, and the performance curves for power in versus power out are shown in Fig. 5. The performance curves generated from our test (shown in Fig. 4) are intended to verify manufacturer performance data up to approximately 40 W of heat being supplied to the TEG. The voltage output and temperature are plotted by the

manufacturer; however, these data points are outside the scope of our experiment and were not used in this study.

Table 1. Manufacturer test data for TEG [5]		
Temperature (°C)		Optimum efficiency (%)
Hot side	Cold side	
230	50	5.03
170	50	4.14
110	50	2.42

After the test setup was validated using devices with known power generation characteristics (Table 1 and Fig. 5), the next set of devices were tested. These devices are made of bismuth, tellurium, antimony, and selenium, manufactured by Tetch, and intended for cooling/heating operation.

From Fig. 4, it can be seen that the efficiency of these thermoelectric devices, which are not intended for power generation, is much lower than those that are intended for power generation. Throughout the test of the TEC devices, the performance curve remains below that of the TEG devices. In the results shown above, the maximum efficiency of the bismuth telluride thermometric device was measured to be 5.6%, whereas the maximum efficiency of the bismuth, tellurium, antimony, and selenium thermoelectric device was measured at 3.62% (see Appendix 1 for raw test data). This discrepancy is entirely due to the construction of each device. Devices used for power generation are constructed from a different combination of materials than devices used for power generation. The material combinations are proprietary information and are optimized for the intended application; however, from previous research, the thermoelectric coolers used in this test are likely made of bismuth telluride, bismuth selenide, and antimony telluride [2]. This combination of materials maximizes the temperature differential when used as a heat pump, at the cost of efficiency when used for power generation.

Because the material combination is proprietary information, the exact material combination of each device is unknown. This prevented any further exploration of the devices in terms of material combination other than the comparison of devices shown above. Further research is required to more precisely define the material combination for each device. If the materials were better defined, the experiment could provide clear connections between material selection and efficiency. However, with the available information, further conclusions cannot be made about how each material affects the performance of the thermoelectric device.

SOURCES OF ERROR

Although the test results are very close to the manufacturer's listed values for the first test, there were still some errors in the test setup. First, the test setup was not insulated because doing so restricted access to the device to take measurements, which could cause heat to escape the sides of the test setup (parasitic heat loss), thus skewing the results. The heaters themselves also have what is called a positive temperature coefficient. The positive temperature coefficient means that as the temperature increases, the power running through the element decreases. This makes the heaters good for reaching steady-state operation, but it makes measuring power output somewhat difficult, as the whole test apparatus tended to drift in output as power is drawn from the thermoelectric device. The equipment itself was also not tested for accuracy, so the test apparatus itself may have had some error in readings during normal operation. Lastly, the test results were recorded manually (power data written in a lab notebook), which introduces the possibility of misreading measurements and/or taking measurements incorrectly.

Other testing methods proved to be unfruitful, as these methods did not account for some unknown variables, such as parasitic power loss in additional wiring. The procedure listed above essentially measures peak power from the device at a constant temperature. This was accomplished by taking power measurements before the power drain caused the thermoelectric generator to change temperature. An attempt was made to measure power at steady-state, but the results were extremely inaccurate when compared with known data from the manufacturer. The inaccurate test procedure and results are shown in Appendix 2 for reference.

By measuring steady-state operation with both voltage and current simultaneously, an unknown error was introduced into the test setup. The possible sources of error included losses in the test setup itself and losses in the electrical connections. Although all the devices are size-matched, the heat transfer between the devices may not have been ideal, which could have contributed to losses and skewed the readings. In addition, the additional wiring required by the test setup may have contributed to other losses that reduced efficiency. Regardless of the exact cause of the error, steady-state measurements using procedure B were highly inaccurate and were not used in the experiment shown above.

CONCLUSION AND RECOMMENDATIONS

The goal of this experiment was to determine the efficiency of thermoelectric devices based on the materials from which they are made. Using the temperature difference provided by the heat source and heat sink, multiple devices were characterized. When efficiency was

compared with manufacturer data, it was close to the listed specifications. However, because the manufacturers did not provide exact details on material combinations, only very simple conclusions could be drawn. No definitive conclusions between material selection and device performance could be drawn based on the available information. It was determined that purpose-built devices for generating were more efficient than devices that were intended for heating/cooling and used as power generators. This suggests that the devices use a different combination of materials to achieve greater efficiency.

To improve this experiment, the materials in thermoelectric devices should be known to accurately compare performance between material combinations and configurations. If the devices were constructed from a precisely determined set of materials, tests would provide a more useful data set when determining the relation between materials and efficiency for the given application. In addition, measuring the temperature on both sides of the thermoelectric device would aid in validating test results. Finally, changing the heaters so that the test configuration can more easily maintain steady state operation would make measurements both easier and more accurate.

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APPENDIX 1

Raw test data

Table A1. Performance data for IIV-I Marlow TEG		
% eff	power in (w)	power out (w)
5.6345109	36.8	2.0735
4.711165	30.9	1.45575
4.2509506	26.3	1.118
3.1149533	21.4	0.6666
2.5959119	15.9	0.41275
1.6959196	13.332	0.2261
1.3419178	9.688	0.130005
0.8147707	6.716	0.05472
0.5447368	4.104	0.022356
0.1988261	2.726	0.00542

Table A2. Performance data for Tetch TEC		
% eff	power in (w)	power out (w)
3.62359551	35.6	1.29
2.97557003	30.7	0.9135
2.33704918	24.4	0.57024
1.75515464	19.4	0.3405
1.47512195	16.4	0.24192
0.99046154	13	0.12876
0.77257143	9.8	0.075712
0.65917213	6.716	0.04427
0.47677165	5.08	0.02422
0.2845735	2.755	0.00784

APPENDIX 2

Other procedures in the experiment

1. Cut tubing to the following lengths: 2 ft (5 pieces).
2. Affix a piece of tubing to each of the barb fittings on the cooling block(s) (4 connections total).
3. Connect the tube from one side of each cooling block to the T-fitting.
4. Connect a section of hose to the other end of the T-fitting.
5. Connect the other end of the tube section (away from the t-fitting) to the $\frac{1}{4}$ "- $\frac{3}{4}$ " reducer.
6. The other lines coming from the cooling block (not attached to the T-fitting) are the drain lines. These lines should be placed where the water can flow into an open drain.
7. Connect the water cooling system to the water source, run and check for leaks (Fig. 2 shows the finished water cooling setup for reference).
8. Apply thermal paste to all contacting surfaces.
9. Assemble the components as described in Fig. 1. The hot side of each TEG module faces inward towards the heaters, and the cold side faces outward towards the cooling blocks. Refer to Fig. 3 for the complete test setup.
10. Clamp the assembly together.
11. Connect power supply to heater, adjust current limit to 3.25A.
12. Connect both thermoelectric devices in series (positive of one device to negative of other device, remaining two wires are power out).
13. Connect voltage meter to thermoelectric devices.
14. Connect current meter and load in series with thermoelectric devices.
15. Wrap assembly in insulation (optional).
16. Turn on the water supply to get stable water flow.
17. Turn on power supply with voltage set at zero.
18. Adjust voltage up until maximum current is reached.
19. Wait until output voltage of TEG reaches steady state (no change over ~ 1 min interval).
20. Measure voltage and current output from TEG device.
21. Record voltage and current measured from TEG, as well as voltage and current from power supply.
22. Adjust current on power supply down by 0.25A.
23. Repeat steps 19–21 for a total of 10 samples.
24. Disassemble and exchange thermoelectric device for next type; repeat steps 8–25 with next device.

25. Clean thermal paste from all equipment.
26. Replace all parts in clearly labeled packaging.
27. Plot power in vs power out for all devices tested.

The test data obtained from the procedure shown above are shown in Fig. A1.

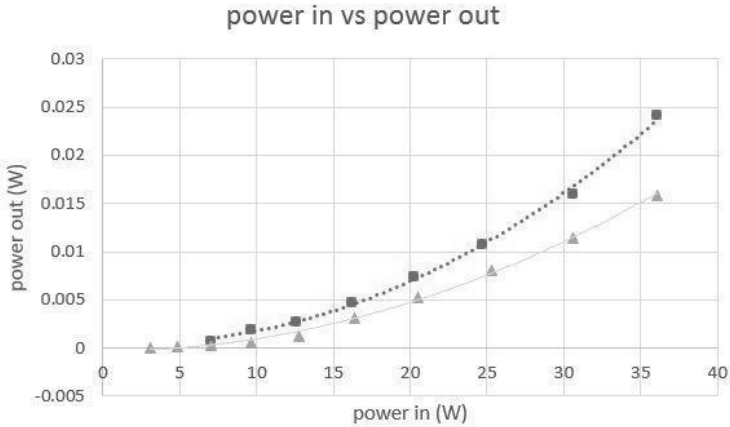


Figure A1. Test data obtained using incorrect procedure. Output power levels are off by an order of magnitude compared with the manufacturer's test data.

Lead Levels in the Wing Bones of Utah Eagles, Measured by X-ray Fluorescence

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Abstract

Lead is a known toxicant for which adverse effects have been detected in both humans and animals, even at very low exposure levels. Eagles and other raptors are primarily exposed to lead through the presence of lead shot within game they ingest. There are only minimal data for lead levels of eagles in the United States, and few studies that have evaluated the resulting effects of exposure. Because of the long biological half-life of lead within bone, a measurement of bone lead levels can be used to assess lifetime exposure to the element. The noninvasive technique of x-ray fluorescence was used to assess the bone lead levels for 10 eagles found dead in Utah (4 bald eagles and 6 golden eagles). Eight of the 10 eagles measured had elevated bone lead levels, greater than 20 $\mu\text{g/g}$ of bone mineral. Four of the six golden eagles had levels in excess of 30 $\mu\text{g/g}$, with the greatest measured bone lead concentration being 78.2 $\mu\text{g/g}$.

Introduction

Lead is a known toxicant for both humans and animals. It enters the body through either ingestion or inhalation and primarily affects the nervous and cardiovascular systems (World Health Organization 2019). Assessment of lead in the environment reflects both the quantity of lead in our ecosystems and the potential for human exposure.

Lead exposure of wild raptors, such as eagles, comes predominantly from spent ammunition (shot, bullets, or fragments of both) consumed while feeding on game species (Pain and Amiard-Triquet 1993, Elliott *et al.* 1992, Wayland and Bollinger 1999). Studies have shown that lead shot and bullets fragment substantially while passing through tissue, which means that scavenger birds can be at risk to lead poisoning even if the whole shot or bullet is not itself ingested (Scheuhammer *et al.* 1998, Hunt *et al.* 2006, Knopper *et al.* 2006). Lead-poisoned birds have similar organ systems affected as do humans—nervous system, kidneys, and circulatory system. Some of the visible signs of lead poisoning in birds include green watery feces, weight loss, anemia and drooping posture (Redig *et al.* 1980, Reiser and Temple 1981, Custer *et al.* 1984, Sanderson and Bellrose 1986). A variety of sublethal physiological and behavioral changes may result even with very low levels of exposure (Scheuhammer 1987).

Because of fragmentation of lead shot and bullets, another marker for lead exposure is needed other than imaging or dissection to detect the presence of lead shot. For both humans and birds, one of the simplest tests for lead exposure is measuring the lead concentration in blood. Blood circulates lead throughout the body where it is deposited in other tissues or removed by the liver and kidneys. However, the biological half-life of lead in blood is on the order of weeks in both humans and birds, which implies blood lead concentrations only reflect very recent exposure to lead. As described by Pain *et al.* (2009), liver and kidney tissue lead concentrations remain elevated for weeks to months following exposure, making them ideally suited for determining whether a bird died because of acute lead exposure. However, lead that binds within bone tissue is far less mobile, and bone lead levels remain elevated for months to years following a bird being exposed to lead. Measuring bird bone lead levels is thus a measurement of lifetime exposure to lead (Pain 1996), and these levels will remain elevated long after the lead exposure has passed.

Despite the usefulness of bone lead levels providing the best picture of lifetime exposure to lead, there have only been a handful of studies that have investigated the impact of bone lead on eagles and other scavenger birds. A fairly large study was conducted by Clark and

Scheuhammer (2003), in which they measured 184 raptors of 16 species found dead across Canada. Of these, only 9 were bald eagles, and slightly more were golden eagles. Bone lead levels greater than 10 $\mu\text{g/g}$ were taken to be elevated. "Evidence from [this] study, along with other published research, indicates that upland-foraging birds of prey and scavengers that typically include game birds and mammals in their diets, are at risk for lead poisoning from the ingestion of lead projectiles from ammunition used in upland hunting. The use of non-lead ammunition for hunting upland game would effectively remove the only serious source of high lead exposure and lead poisoning for upland-foraging raptors." (Clark and Scheuhammer, 2003). From 2004 to 2014, Saving Our Avian Resources (SOAR) collected lead data for 322 bald eagles admitted to wildlife rehabilitators in Iowa, for which only 5 bone lead measurements were conducted. Four of the five bone lead measurements were classified as "clinical" (>20 ppm) and one was "subclinical" (10–19.9 ppm) (Yaw *et al.* 2017). Further research on bone lead levels for raptors is critical for understanding the overall risk that lead shot in the environment poses to them.

Materials and Methods

The noninvasive technique of x-ray fluorescence (XRF) was used to measure the lead level in wing bones of eagle carcasses found in Utah. XRF is a well-established technique for nondestructively determining elemental composition. Although other techniques are available to perform this measurement, such as atomic absorption spectroscopy, XRF has the advantage of being noninvasive and thus leaving the carcasses unaltered. This was desirable because eagles are a protected species under the Bald and Golden Eagle Protection Act (BGEPA). Both live and dead eagles are covered by the act, as well as eagle parts, nests, and eggs.

A total of 10 carcasses were obtained from the Utah Division of Wildlife. The carcasses were found in locations surrounding the Great Salt Lake during the years of 2005 and 2006. Four were bald eagles, *Haliaeetus leucocephalus* (two from 2005, two from 2006) and six were golden eagles, *Aquila chrysaetos* (two from 2005, four from 2006). All carcasses had been frozen by the Division of Wildlife to minimize decay but were thawed for the XRF measurements. The target bone for the XRF measurement was the center of the ulna (wing bone). The ulna, being a hard bone, has a slower turnover rate than soft bones.

Bone lead XRF measurements consist of a radioactive source used to eject the K-shell electrons from lead atoms in the sample, followed by the subsequent measurement of characteristic x-rays emitted as the lead

atoms de-excite. Cadmium-109 is ideally suited for lead XRF as its gamma rays (88.04 keV) are just above the K-shell ionization energy for lead, resulting in the largest cross-section for electron ejection (Streli *et al.*, 1999). The Cd-109 source used (AEA Technologies) had an activity of 10–20 mCi at the time of the measurements. A high-purity germanium (HPGe) semiconductor detector collected the incoming low-energy photons. The detector (Canberra GL2020R) was a cylindrical germanium crystal with 20 mm radius and 20 mm thickness, with a 0.6-millimeter-thick carbon composite window on the front of the detector. A 180° geometry (illustrated in Figure 1) minimized the Compton background beneath the lead x-ray peaks. The center of the ulna (wing bone) was placed approximately 1 cm in front of the Cd-109 source. Each eagle was measured for two hours in real time. Unlike other chemical analysis techniques, which would require a biopsy, the XRF measurement caused no long-term change in the birds. Carcasses were refrozen immediately after measurement and returned to the Division of Wildlife in the same condition they had been received.

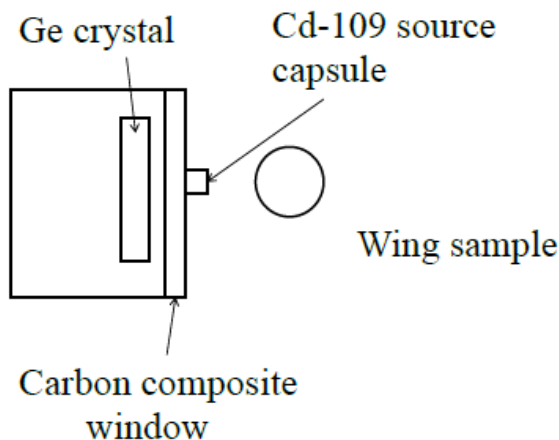


Figure 1: Schematic diagram of K-shell lead XRF system at Weber State University. 1-cm source-sample distance.

Signal processing was done using Canberra DSA 1000 digital electronics and coupled Genie 2000 software. A sample lead XRF spectrum is shown in Figure 2. The spectrum consists of lead x-rays at 72.8 and 75.0 keV (L-K transitions or $K\alpha$) and 84.5 and 85.0 keV (M-K transitions or $K\beta$), as well as a coherent scatter peak at 88 keV and a rather large, incoherent (Compton) scatter peak centered at

approximately 66 keV. Note that the $K\alpha_1$ emission is higher in energy (75.0 keV) than the $K\alpha_2$ peak (72.8 keV). A larger number of electrons follow the $K\alpha_1$ transition (L_3 -K) relative to the $K\alpha_2$ (L_2 -K) transition, which causes the $K\alpha_1$ emission to be more intense than $K\alpha_2$.

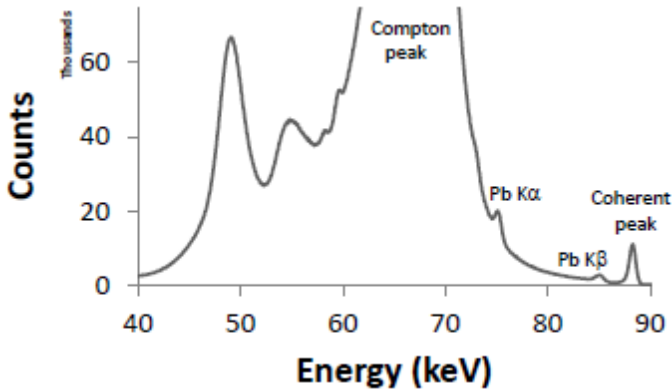


Figure 2: Sample XRF spectrum for a 200-ppm bone lead phantom, showing coherent peak, Compton peak, and lead $K\alpha$ and $K\beta$ peaks. Note that this spectrum is shown for one of the lead phantoms used for calibrating the bone lead measurements because the height of the lead peaks for the actual bone measurements are typically very small and need to be determined using fitting routines.

The coherent peak is predominantly from Cd-109 88 keV photons elastically scattering off high Z materials in the sample, giving a measure of “amount of bone present.” A slight correction was made to account for the difference in scattering properties between the bone phantoms (Plaster of Paris) and actual bone. For each eagle measured, the ratio of the lead $K\alpha_1$ peak height to coherent peak height was calculated, giving a measure of lead concentration (ppm or $\mu\text{g/g}$ of bone). A second independent bone lead measurement was determined using the lead $K\beta$ peak to coherent peak height. The alpha and beta measurements for each of the 10 eagle carcasses were within one standard deviation of each other. These two values were then averaged to give the final reported lead concentration (in ppm). The average was an inverse variance weighted mean, in which the value with the smaller uncertainty was given a heavier weighting. Computing the ratio of lead x-ray peaks to coherent peak makes bone lead XRF a very robust measurement (Somervaille *et al.*, 1985) because both sets of peaks are affected to the same extent by overlying tissue thickness, source-sample distance, and

other geometrical variables. System calibration was performed using 10 lead doped plaster of Paris phantoms to simulate bone, with lead levels ranging from 0 to 200 ppm.

Results and Discussion

The results for the 10 eagles measured are given in Table 1.

Table 1. Bone lead concentrations measured for bald eagles and golden eagles		
Bald Eagles		
Year	Bone Lead (ppm)	Uncertainty (ppm)
2005	19.6	3.8
2005	23.8	4.4
2006	23.9	4.7
2006	27.5	5.1
Average (St. Dev.)	23.7 (3.2)	
Golden Eagles		
2005	7.3	4.0
2005	36.4	3.1
2006	27.8	5.7
2006	30.0	5.4
2006	40.3	3.4
2006	78.2	4.7
Average (St. Dev.)	36.7 (23.3)	

All but two birds had bone lead levels greater than 20 ppm, and four of the six golden eagles had levels greater than 30 ppm with the greatest level being 78.2 ppm.

There are few data relating lead tissue concentration to health effect in birds in general or eagles specifically; however, previous studies involving eagles have considered bone lead levels between 10 and 20 ppm to be “exposed” and greater than 20 ppm to be “poisoned” (Neumann 2009). Levels as high as 78.2 ppm are extraordinarily high. It is likely that all but two of these birds would have shown clinical signs of lead poisoning (Yaw *et al.* 2017). Note that in addition to there not being significant data relating bone lead levels to effect, there is also no way of knowing what the “background” or “normal” level of lead in birds should be, in particular because this has been complicated with lead added to the environment by human endeavors such as hunting.

Although bone lead levels were only measured for 10 birds in this study, this is substantial because of the extreme lack of literature in this field. In particular, there is no literature for eagles in the state of Utah. It

is readily accepted that lead exposure is harmful, and many regulations have been instituted to minimize lead in our environment; however, regulations for the use of lead shot in hunting are still controversial in the United States even though it has been prohibited in other nations. For example, Denmark and the Netherlands have a complete ban on lead gunshot use in all types of habitats. It is hoped that this study will stimulate further investigations of lead levels for eagles and other raptors high on the food chain, and the resulting impact of this exposure.

Acknowledgments

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Continuous Trajectories for the Quantum Harmonic Oscillator

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Abstract

Bohmian mechanics is a formulation of quantum theory that describes particles having continuously defined trajectories. These trajectories give an intuitive picture of the dynamics of a quantum system. However, they are highly nonclassical. Numerically calculated trajectories for several states of the simple harmonic oscillator are shown, and nonclassical effects are explained in terms of an additional potential, called the quantum potential. The method for obtaining these trajectories is also explained.

Setting the Stage: On the Importance of Bohmian Mechanics

Quantum mechanics is arguably among the most successful scientific theories ever devised. It has opened our understanding to the microscopic world in unprecedented ways [1] and continues to lead to the creation of powerful technologies [2].

Unlike classical Newtonian mechanics, quantum mechanics describes a world that is fundamentally inaccessible to our senses. To an intuition based on notions of determinism and continuity of matter, it is not immediately clear whether the quantum formalism completely describes the physical reality [3]. As a consequence, quantum mechanics has been fertile in producing a host of different interpretations. Of the many interpretations that have been proposed, there is one that provides us with continuous trajectories, and thereby a first step towards a more familiar vision of microscopic physics.

After writing one of the classic texts on quantum theory [4], David Bohm, dissatisfied with certain aspects of the standard interpretation, developed his own interpretation of the theory in 1952 [5, 6]. His interpretation, now referred to as Bohmian mechanics, was similar to previous considerations by other physicists but that had never been fully developed [7, 8]. In essence, Bohm assumed that particles exist continuously with well-defined position and momentum and that their trajectories, if not observable, can at least be described. Based on this assumption he recast the Schrödinger equation to extract the desired trajectories.

Bohmian mechanics gives predictions identical to those of the standard interpretation whenever the latter gives predictions [9]. The unique predictions made by Bohmian mechanics are of such a nature that they have not yet been experimentally verified [10, 11, 12].¹ Thus, it is as of yet impossible to experimentally distinguish Bohmian mechanics from the standard interpretation or from any other viable interpretation. For this reason, some physicists characterize the debate regarding the relative merit of quantum interpretations as fruitless.

Yet Bohmian mechanics presents several advantages. Chief among these is that it grounds quantum theory in the language of physical reality, allowing discourse regarding what *really is*, as opposed to simply outlining the limits of our knowledge. In other words, Bohmian mechanics takes quantum theory from its epistemological stance and grounds it in ontology. Discussion on this idea and its importance can be found in Jaynes [13].

Another advantage is that the trajectories produced by Bohm's methods can be used as tools for further discovery. The trajectories are derived from the same Schrödinger equation that governs the quantum mechanical wave function, which is the main object of interest in the standard interpretation. Yet these trajectories contain information that is not accessed in the standard interpretation. Even in the event that the

¹ For Bohm and Hiley [12], see especially pages 35–38.

trajectories are not physically real in the sense we imagine them to be, they encode information about the system that is otherwise neglected. For scientists to disregard certain ideas without justification limits *a priori* the avenues of thought that may be pursued and thereby forfeits an opportunity for discovery. If instead we analyze this additional information, we may make discoveries that otherwise would have been missed. Indeed, this has already been found to be the case [14, 15, 16, 17].

Lastly, though not least importantly, Bohmian mechanics gives us a clear, intuitive picture of what is happening at a microscopic level. It produces trajectories that are governed by a *quantum potential* similarly to how classical trajectories are governed by classical gravitational or electromagnetic potentials. As we explain in the next section, applying classical intuition via Newton's second law (9) to a system, while considering the quantum potential, results in precisely the trajectories that are predicted by the Schrödinger equation as seen in de Broglie (7). Quantum mechanical average quantities can be recovered by averaging over statistical distributions of these trajectories. Arguably, thinking about quantum mechanics in these terms would make the transition from classical to quantum mechanics easier for the student of physics and would make quantum mechanical principles readily accessible, allowing one to rely on the already formed classical intuition.

The purpose of the current paper is to present numerically calculated Bohmian mechanical trajectories for the quantum mechanical simple harmonic oscillator (SHO) as well as use this example to demonstrate the virtues of Bohmian mechanics. The SHO is solved in every introductory course on quantum mechanics but is not addressed by Bohm² in his book with Hiley [12]. The SHO is an excellent approximation to many systems occurring in nature. For these reasons, it is an excellent starting point for the ontological study of quantum theory from both a practical and a pedagogical point of view. In the next section, we present the tools of Bohmian mechanics, after which we analyze the SHO using those tools.

The Bohmian Mechanical Tool Box

The purpose of this section is to impart an understanding of Bohmian mechanics sufficient to understand the topics discussed throughout the remainder of the document. Only single-particle systems will be treated. Readers interested in further details regarding the

² Although not addressed by Bohm, the SHO is examined by Holland [18] and Bowman [19], which the reader can reference for additional perspectives.

Bohmian mechanical machinery can refer to Bohm's 1952 papers [5, 6] and Bohm and Hiley's 1993 book [12], upon which works this exposition is based.

Let $\Psi : \mathbb{R}^4 \rightarrow \mathbb{C}$ represent an arbitrary single-particle wave function in space $\mathbf{x} \in \mathbb{R}^3$ and time $t \in \mathbb{R}$. The behavior of the wave function Ψ for a particle of mass m in the presence of an external potential $V(\mathbf{x}, t)$ is governed by the Schrödinger equation

$$i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m} \nabla^2 \Psi + V(\mathbf{x}, t) \Psi \quad (1)$$

where $\hbar$ is Planck's constant. In polar form, factorizing the amplitude $R(\mathbf{x}, t)$ and the phase $S(\mathbf{x}, t)$, Ψ can be written as

$$\Psi(\mathbf{x}, t) = R(\mathbf{x}, t) e^{i \frac{S(\mathbf{x}, t)}{\hbar}} \quad (2)$$

where $R : \mathbb{R}^4 \rightarrow \mathbb{R}$ and $S : \mathbb{R}^4 \rightarrow \mathbb{R}$ are real-valued functions of position and time. Plugging (2) into (1) and separating the real and imaginary parts, we obtain two coupled equations:

$$\frac{\partial R^2}{\partial t} + \nabla \cdot \left(R^2 \frac{\nabla S}{m} \right) = 0 \quad (3)$$

and

$$\frac{\partial S}{\partial t} + \frac{(\nabla S)^2}{2m} + V(\mathbf{x}, t) - \frac{\hbar^2}{2m} \frac{\nabla^2 R}{R} = 0. \quad (4)$$

Equation (3) is a conservation equation of probability, with $|\Psi|^2 = R^2$ the probability density. Equation (4) is of more immediate interest to us, having a form similar to the classical Hamilton-Jacobi equation:

$$\frac{\partial S_{cl}}{\partial t} + \frac{(\nabla S_{cl})^2}{2m} + V(\mathbf{x}, t) = 0, \quad (5)$$

where S_{cl} is the classical negative time integral of energy.

Indeed, (4) differs from (5) only in the addition of the term

$$Q(\mathbf{x}, t) = -\frac{\hbar^2}{2m} \frac{\nabla^2 R}{R} \quad (6)$$

which must have units of energy. Bohm refers to (6) as the *quantum potential*, while referring to V as the *classical potential*. Defining the *total potential* as $U(\mathbf{x}, t) = V(\mathbf{x}, t) + Q(\mathbf{x}, t)$ and substituting this expression in (4), we see that its form exactly matches that of (5).

Hamilton-Jacobi theory, from which (5) is derived, is a formulation of classical mechanics equivalent to Newtonian mechanics [20]. Thus, by associating (4) and (5), we justify the use of tools provided by Hamilton-Jacobi theory, taking into account the additional information

contained in (6), to obtain quantities of interest. In particular, we identify S with S_{cl} in order to obtain particle velocity $\mathbf{v}$ from momentum $\mathbf{p}$:

$$\begin{aligned}\mathbf{p}(\mathbf{x}, t) &= m\mathbf{v}(\mathbf{x}, t) = \nabla S(\mathbf{x}, t) \\ \Rightarrow \mathbf{v}(\mathbf{x}, t) &= \frac{\nabla S(\mathbf{x}, t)}{m},\end{aligned}\quad (7)$$

where S is determined by (4). In the one-dimensional case, the vector $\mathbf{v}$ becomes the scalar v , the vector $\mathbf{x}$ becomes the scalar x , and the gradient operator ∇ becomes the partial derivative $\frac{\partial}{\partial x}$ with respect to x .

The vector $\mathbf{v}$, having spatial dependence, describes a time-dependent velocity field. It does not describe any single trajectory, but all possible trajectories simultaneously. The trajectory taken by a given particle is determined by its initial position.

In practice, solving (3, 4) as a system of equations is difficult. However, as this system is mathematically equivalent to the Schrödinger equation, we can solve (1) for Ψ and extract R and S from the polar form (2).

For the basis states of a system, finding the polar form is generally straightforward. For a superposition of basis states, one can show [21] that, if $\Psi = \sum_{n=1}^N c_n \Psi_n = R e^{iS/\hbar}$, where $\Psi_n = R_n e^{iS_n/\hbar}$, then

$$S = \hbar \arctan \left(\frac{\sum_{n=1}^N c_n R_n \sin(S_n/\hbar)}{\sum_{n=1}^N c_n R_n \cos(S_n/\hbar)} \right). \quad (8)$$

Throughout this discussion, we will rely additionally on the classical law governing acceleration a ,

$$a = -\frac{1}{m} \frac{d}{dx} U(x, t) \quad (9)$$

to analyze the relationship between the total potential $U(x, t)$ and the trajectories produced by (7).

Bohmian Trajectories for the Simple Harmonic Oscillator

We now apply this method to a particle in the time-independent potential of the SHO in one dimension. Here, $V(x) = \frac{1}{2} m \omega^2 x^2$, where ω is the classical frequency of oscillation. The time-independent part of the n th basis state of the quantum SHO is given by

$$\psi_n(x) = \frac{1}{\sqrt{n!}} A^n \psi_0(x) \quad (10)$$

where

$$\psi_0(x) = \left(\frac{m\omega}{\pi\hbar}\right)^{\frac{1}{4}} e^{-\frac{m\omega}{2\hbar}x^2} \quad (11)$$

The zeroth state (11) is referred to as the *ground state*. Here, the operator $\mathbb{A}$ allows us to find the excited states from the ground state (11). The time-dependent wave function $\Psi_n(x,t)$ is formed by multiplying ψ_n by a standard time-dependent factor:

$$\Psi_n(x, t) = \psi_n(x)e^{-iE_nt/\hbar}, \quad (12)$$

where $E_n = (n + \frac{1}{2})\hbar\omega$ is the energy associated with the n th state.

Noting that (12) is already in polar form, we can extract S_n directly. Evidently, $S_n(t) = -E_nt$. This is consistent with S_n as the action (the negative time integral of energy), as E_n is constant in time. $S_n(t)$ is constant in space. Thus, for every basis state, including the ground state, we obtain $v(x, t) = \frac{1}{m} \frac{\partial}{\partial x} S_n(t)$. The corresponding trajectories, showing the evolution of one-dimensional position in time, are obtained by numerical application of (7) and (8), and are plotted in Figure 1.

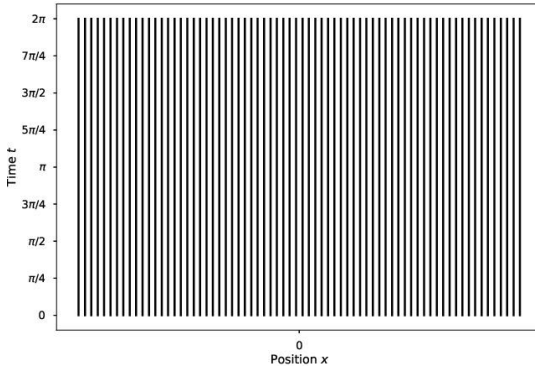


Figure 1: Bohmian trajectories for basis states $\Psi_n(x,t)$ of the SHO. Position is plotted horizontally, and time vertically. Each line represents a distinct trajectory based on a different initial position. As is shown, the SHO basis states exhibit no particle motion.

The trajectories corresponding to basis states exhibit no particle motion—a particle in any eigenstate is stationary.³ We expect a particle in a harmonic potential to be stationary only if its initial position is the

³ It is appropriate that the basis states are often referred to as *stationary states*, though for a different reason.

center of the potential and the initial velocity is zero; otherwise, we expect any displacement from the center or any nonzero initial velocity to produce sinusoidal oscillations with an amplitude determined by the initial displacement or velocity. This serves to highlight the fact that Bohmian mechanics is an interpretation of quantum theory still very different from classical mechanics. The correspondence with the classical oscillator is found in considering the *coherent state* (an oscillatory wave packet consisting of an infinite superposition of eigenstates, considered in detail in Holland [18] and Lawyer [21]) and *not* in the behavior of the eigenstates.

The explanation of this behavior is found by considering the quantum potential. A particle that feels a potential will accelerate according to (9). In this case, the particle acceleration is dependent not only on the classical potential $V(x) = \frac{1}{2}m\omega^2x^2$, which we specify when we write down the Schrödinger equation, but also on the quantum potential (6), which is determined by (3, 4) after we specify the classical potential. The quantum potential corresponding to any stationary state has the form of a negative parabola:⁴ $Q(x) = C - \frac{1}{2}m\omega^2x^2, C \in \mathbb{R}$. Thus, the total potential is $U(x) = V(x) + Q(x) = C$. For the ground state, this is illustrated in Figure 2.

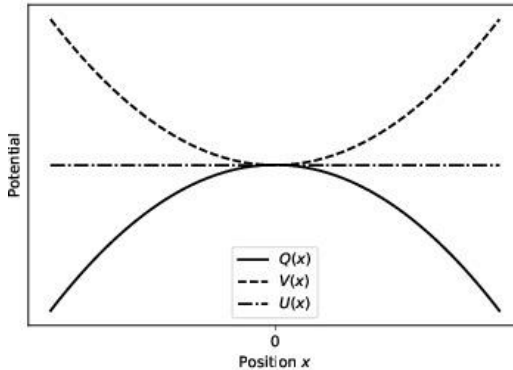


Figure 2: For the ground state, the x -dependent term in $Q(x)$ completely cancels the x -dependent term in the $V(x)$, resulting in a constant potential.

⁴ This can be seen by considering equation (4). The first term is constant, and the second term is zero. Thus, the sum of the last two terms must equal a constant (the negative of the first term).

One may ask how making an energy measurement on an eigenstate of the SHO can result in observation of a nonzero energy if the particles involved are stationary. In quantum mechanics, the term associated with kinetic energy is the first term on the right-hand side of the Schrödinger equation (1), an equation describing the wave function, not the associated Bohmian particle. In equation (4), this energy is shared between the second term (describing the kinetic energy of the Bohmian particle) and the fourth term (the quantum potential). In this case, the second term is zero, but the energy is still present in the quantum potential.

Superposing states leads to interesting new behavior. In Figure 3, the trajectories corresponding to the state $\Psi(x,t) = \frac{1}{\sqrt{2}} (\Psi_0(x, t) + \Psi_1(x, t))$ are shown. This state corresponds to the ground state superposed with the first excited state.

At time $t = 0$ the trajectories slightly left of center are evenly spaced but rapidly move to the left, gradually accumulating in a band arcing gently to the left until time $t = \pi$ (in appropriately scaled units of time), at which time the band arcs back to the right and the trajectories spread back to their initial positions by time $t = 2\pi$. The trajectories are cyclic with period 2π , so this abrupt spreading and re-accumulation of trajectories at times, which are integer multiples of 2π has the visual appearance of a cusp in the plot. In Figure 3, slightly more than one cycle is shown to make this cusp more visible.

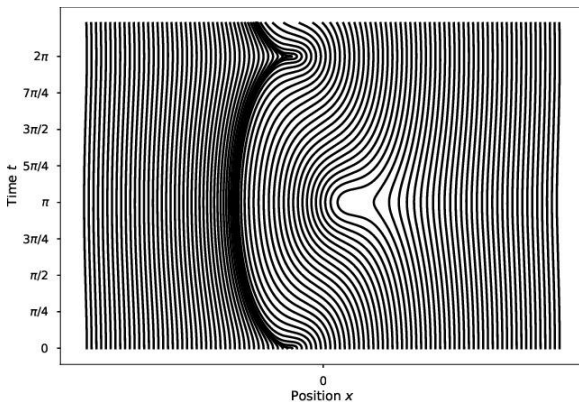


Figure 3: Bohmian trajectories for the state $\Psi(x,t) = \frac{1}{\sqrt{2}} (\Psi_0(x, t) + \Psi_1(x, t))$. Compare with Figure 1.

It is interesting to note that none of the trajectories shown here cross. Indeed, this is a general feature of Bohmian mechanics, and not only of this state: trajectories cannot cross. Proof of this fact can be found in Appendix B of Lawler [21]. In this case, it is logical to expect that where trajectories display different velocities they compress into bands. This feature of Bohmian mechanics will not be discussed further, but the reader is encouraged to keep it in mind as further states are examined.

Just before time $t = \pi$, the trajectories slightly right of center move to the left and spread out, then undo this motion just after time $t = \pi$, forming an apparently empty pocket, which when reflected over the time axis has the shape of the cusp formed by the trajectories on the left.

It is important to note that these trajectories are mutually exclusive—if a particle takes one trajectory, it will not take any other. There are infinitely many hypothetical trajectories that can be taken. The one actually taken depends on the initial particle position. We plot only a finite number of hypothetical trajectories to give an approximate map of the velocity field available to the particle. Hence, the density of trajectories at any point depends on the initial sampling. For these trajectories, initial positions were sampled uniformly in x at time $t = 0$. Had initial positions been sampled uniformly in x at time $t = \pi$, we would have a distribution that is evenly spaced at times that are odd-integer multiples of π . The empty pocket on the right would then contain an even sampling of trajectories, which at following times would be compressed into bands, similarly to the way it occurs for trajectories on the left. Similarly, choosing to sample at time $t = \pi/2$ would produce a distribution of trajectories which would favor neither the right nor the left. Thus, the band structure on the left is present on the right, although not apparent in this plot. This structure is symmetric in space about the center of the potential, though shifted in time across this center point by $\Delta t = \pi$.

Here we remind the reader to keep in mind the fact that Bohmian trajectories cannot cross, in order to better conceptualize the behavior which we analyze. Trajectories near the center of the potential and located between the two band-forming regions are somewhat sinusoidal in form, which we can appreciate in a harmonic potential, and are bounded by the bands, reminiscent of the classical concept of a strict turning point related to energy level. However, these trajectories are not at all what is predicted by the Newtonian theory. Although the collection of trajectories is symmetric about the center of the potential, individual trajectories are not. Some trajectories even fail to cross the center of the potential altogether. This is especially true of trajectories considerably further from the center of the potential than the bands of accumulation, where trajectories remain nearly stationary. Quantum mechanics tells us

that there is a nonzero probability of finding the particle beyond the classical turning points corresponding to its energy. Bohmian mechanics then tells us that if found there, the particle will never approach the bottom of the classical parabolic potential.

Let us now consider in greater detail the total potential $U(x,t) = V(x,t) + Q(x,t)$ corresponding to this superposition state. The total potential is time dependent. Five constant time plots spaced evenly over one half of one cycle are shown in Figure 4.

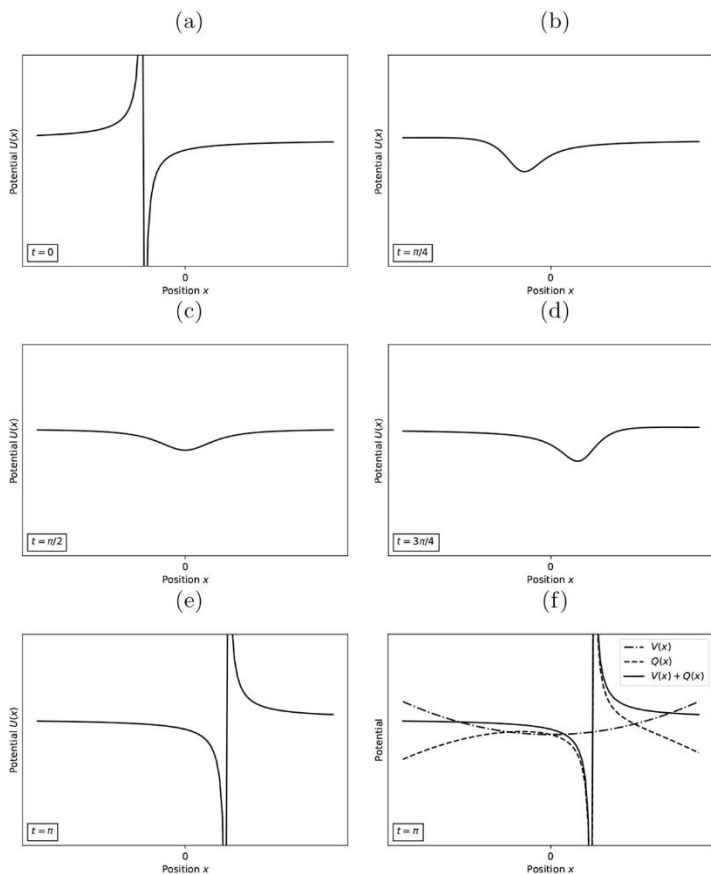


Figure 4: In frames 4a through 4e, the total potential $U(x,t)$ corresponding to the state $\Psi(x,t) = \frac{1}{\sqrt{2}}(\Psi_0(x,t) + \Psi_1(x,t))$ is plotted in time increments of $\pi/4$ for $0 \leq t \leq \pi$. In frame 4f, the total potential is plotted alongside the quantum and classical potentials at time $t = \pi$ for completeness, showing that $U(x,t) = V(x,t) + Q(x,t)$.

In Figure 4a, there is a singularity slightly left of center. The derivative is positive on both sides of the singularity, so a particle on either side will be accelerated to the left. The slope is steepest near the singularity and drops off quickly on either side, so that the acceleration is greatest near the singularity. Thus, the hypothetical trajectories near the singular point will be bent left violently, with the effect dropping off quickly with distance, so that trajectories far off are only slightly drawn to the left. The difference in accelerations here results in a nonzero relative velocity between trajectories, so that the distance between them is reduced and they accumulate in a bundle to the left of the singularity. This singularity exists for a very short span of time, and quickly evolves into a nearly flat potential with a small dip where the singularity once was, as seen in Figure 4b, so that acceleration to the left decreases. The derivative is now positive to the right and negative to the left of the dip. Trajectories to the right will continue to accelerate gradually to the left until they pass the dip, and trajectories to the left (including those who crossed over from the right) will continue to travel to the left, while accelerating to the right. In the subsequent frames, the dip becomes shallower and migrates to the right side of the center point, where it again deepens (Figures 4c-4e). Here, in Figure 4e, it forms a new singularity, with derivatives opposite those occurring in the singularity on the left in Figure 4a. Trajectories are now accelerated violently to the right near the singular point, and more gently further away. The cycle is completed with the repetition of these steps in reverse order, until the conditions again match those in Figure 4a.

Logically, the behavior of the trajectories that we expect from our analysis of the total potential must match the actual behavior plotted in Figure 3. As shown by Bohm and Hiley [12], the quantum mechanical phenomena that we observe in the laboratory can be explained in terms of trajectories by statistically averaging the behavior of the trajectories. But our analysis of the behavior of the trajectories from the quantum potential relied only on (9). Thus, we have shown that, when viewed through the lens of Bohmian mechanics, Newtonian intuition can be used to easily understand the behavior of quantum systems.

Many more interesting states can be analyzed in a similar manner. To conclude, we briefly consider a state superposing three basis states instead of two. We will take the ground state superposed with the first two excited states. Trajectories for this state are shown in Figure 5. Again, we see accumulation of trajectories into a belt with periodic behavior and symmetric structure across the center of the potential.

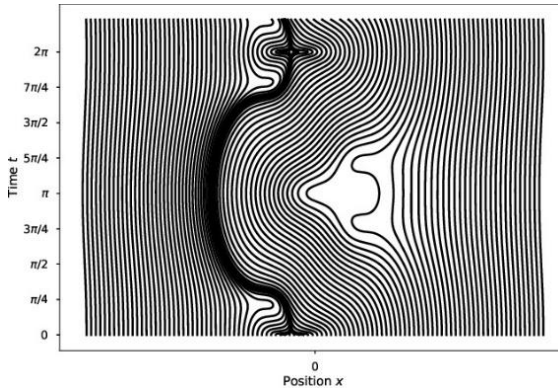


Figure 5: Bohmian trajectories for the state $\Psi(x,t) = \frac{1}{\sqrt{3}}(\Psi_0(x,t) + \Psi_1(x,t) + \Psi_2(x,t))$. Compare with Figures 1 and 3.

One important qualitative difference between this state and the state in Figure 3 is that, where at times that are integer multiples of 2π , the trajectories in Figure 3 are all swept in the same direction (to the left) as they accumulate into bands, here they are drawn from opposite directions to a central point of accumulation. This feature can again be explained in terms of the quantum potential. The total potential $U(x,t)$ at time $t = 0$ is shown in Figure 6. Similar to Figure 4, at time $t = 0$ we have a singularity slightly left of center; however, in this case the derivative has opposite sign on either side of the singular point, so that trajectories everywhere are accelerated to varying degrees towards this point. This effect is more severe for trajectories closer to the singular point.

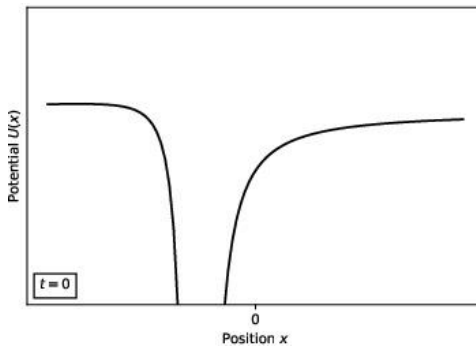


Figure 6: The total potential $U(x,t)$ corresponding to the state $\Psi(x,t) = \frac{1}{\sqrt{3}}(\Psi_0(x,t) + \Psi_1(x,t) + \Psi_2(x,t))$ plotted at time $t = 0$.

This behavior and other interesting features of this and other states are analyzed more completely elsewhere [21].

Conclusion

We have now shown in some detail how Bohmian mechanics provides us with an intuitively accessible set of tools through which to view the quantum theory, namely the dynamical relationship between the quantum potential and the trajectories. It is easy to see how this approach to quantum mechanics would be more easily understood by students of physics having taken a course in Newtonian mechanics. As discussed in the Bohmian Mechanical Tool Box section, Bohmian mechanics in practice solves the Schrödinger equation as is done in standard quantum mechanics and the trajectory information is extracted from the wave function. Thus, a student trained in Bohmian mechanics will be well versed in using the tools and techniques of standard quantum mechanics.

We have also seen that the Bohmian view in no way eliminates the nonclassical aspects of quantum theory. In fact, nonlocality plays a central role [12]. The difference between Bohm's formulation and the standard formulation is that Bohm provides an intuitive and self-consistent picture of microscopic phenomena, with all nonclassical effects essentially due to the quantum potential (6). To take (7) seriously is simply to favor an interpretation which is intuitive, which goes beyond an epistemology of microscopic phenomena, and which opens a door to future discovery.

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Developing Selective Absorbers for Solar Water Heating: Undergraduate Materials Research at Weber State University

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Abstract

The materials group at Weber State University (WSU) has been working with undergraduate students primarily from the physics and chemistry departments on research projects that combine recipe design for materials growth, multiple characterization methods, and device testing. We present an example of ceramic-metal composites (cermet) selective solar absorbers (SSAs) of SiO_2 with Mo incorporated through sputtering growth. The SSA layers and prototype water heating device were tested and the growth method refined in a scaled-down version of the iterative cycle of materials development. We describe the project here with two purposes in mind. Primarily, this contribution is a description of the type of opportunities available to WSU students in the materials program. The research component of the work is primarily an independent confirmation of the work of others described in the references.

Introduction

Materials development is an interdisciplinary field with a wide range of applications. Materials deposition, characterization, and device prototyping comprise the development process for a new material. Exposing an undergraduate student to each of these areas is important to conveying the big picture of what it takes to develop a device based on a new material either in graduate school or in industry. Studies show that undergraduate research experiences encourage students to identify with being a scientist [1]. Adopting a holistic approach to undergraduate materials research projects by fully developing a new material from the initial film to the end prototype: (1) readies them for graduate school and industry; (2) can increase their ownership of the project as they see a working final result; and (3) offers the opportunity to collaborate with other students, faculty, and even other departments.

We are using single-layer, thin-film selective solar absorbers (SSAs) made from varying ratios of molybdenum and silicon dioxide as a platform for materials development with our undergraduates. SSAs from Mo and SiO_2 are actively being pursued in more complex multilayer stacks for solar thermal to electricity conversion. Our research offers a confirmation of previously reported results [2, 3], while verifying an optimization procedure in an undergraduate setting with less expensive characterization tools. Thus, this contribution can be taken as a proof-of-principle of basic materials research at WSU or a comparable institution. Although our films are not as complex as others being made for actual commercialization, we can draw from the literature during their development. These films can be made through codeposition in a sputtering system providing the opportunity to learn about new recipe development and the design of experiments. By varying the ratio of Mo to SiO_2 , the recipe can be optimized to achieve the desired film properties of light absorption and heat retention by coupling deposition with various materials characterization techniques. The SSAs are tested in a solar water heater prototype using a similar design to that of Ni et al. [4]. The solar water heater prototype is ideal for an undergraduate research experience because the parts are inexpensive and easy to obtain and it provides the opportunity for prototype improvement.

Selective Solar Absorbers

SSAs of the type we are studying trap incoming light through multiple reflections at dielectric/metal interfaces in composite materials. Multiple designs of SSAs exist to incorporate dielectrics and metals into a thin film. A balance between the absorption of light and the retention of heat within the material is struck by achieving an optimal mass

fraction and geometry of dielectric and metal [5]. For this project, we focused on a cermet-based SSA structure as shown in Figure 1. Metal nanoparticles of Mo are embedded in a dielectric matrix of SiO_2 . Our devices are codeposited SiO_2 and Mo through RF sputtering. These films were deposited on stainless steel foil (for device and emissivity testing) and glass microscope slides (for other characterization techniques) using Ar gas at a pressure of 3 mTorr. The SiO_2 was deposited (cosputtered) at 200 W, and the ratio of SiO_2/Mo was varied by changing the power of the Mo in each sample. All other deposition parameters were held constant. After deposition, the thickness of each film was measured using a surface profiler.

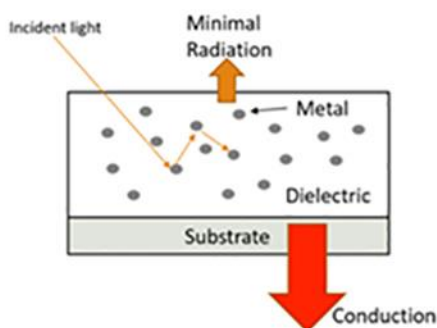


Figure 1. Schematic of selective solar absorber using cermet structure.

Many variables are involved in effectively making a material and give students the opportunity to understand how the design of experiments can help navigate a complex experimental process. Additionally, many depositions are necessary in helping students to learn effective strategies for organizing information.

Materials Characterization

As SSAs depend on the optimal ratio of dielectric to metal and the geometry of their incorporation to achieve the right level of light absorption and heat retention, we used multiple characterization techniques to probe the samples. The various combinations of characterization methods were used to study and optimize material properties. SSAs provide a good platform for this type of analysis.

For each sample developed, scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) were used to understand the composition and microstructure of the material [6].

Figure 2 (top) shows an example of an SEM image of one of our samples. EDS measurements, like the one in Figure 2 (bottom), were used to understand the relative changes in the ratio of SiO_2/Mo on average in each sample. EDS was also used to identify larger regions of Mo in each sample like the one shown in the box in Figure 2 (top). In initial EDS measurements, a field scan and spot scan were used to understand how the relative intensities of the SiO_2 and Mo depend on the region scanned and the uniformity of the material.

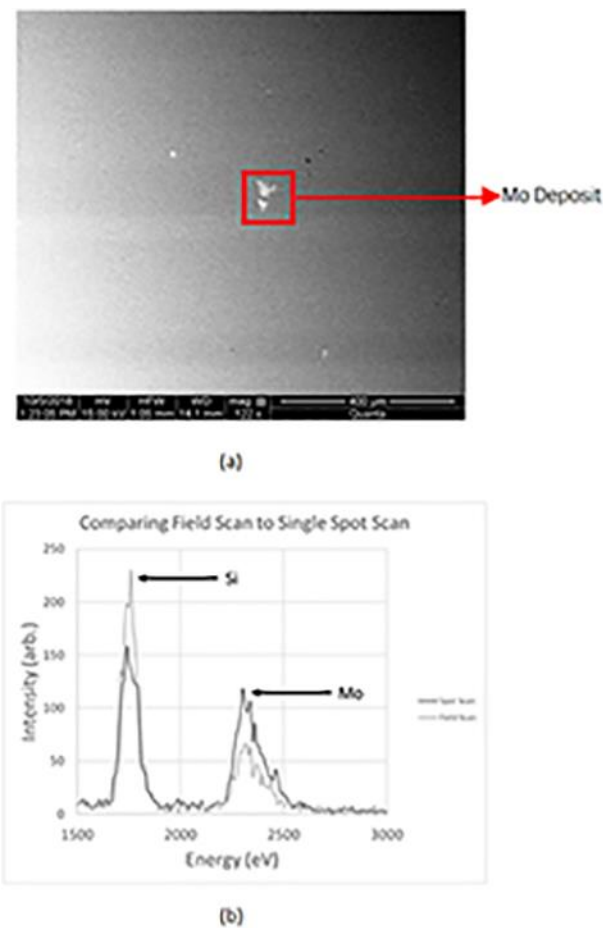


Figure 2. Example of SEM (top) and EDS (bottom) measurements for SSA sample.

Codeposition results in heterogeneous materials at the microlevel as seen by the SEM, making it important to determine how uniform their bulk properties are over the full surface. The uniformity of the samples' light absorption was tested using light transmission measurements via ultraviolet–visible (UV-VIS) spectroscopy [7]. Each sample was cut into four sections, as shown in the inset of Figure 3. The light transmission for each of the sections of the samples were collected and measured with light ranging from 200 nm to 1100 nm in wavelength. Examples of transmittance (fraction of incident light transmitted through the material) vs. wavelength are shown in Figure 3 for three different samples and their respective four sections (pieces). Each sample shows little change in transmittance across the surface, lending evidence of good uniformity given the heterogeneous nature of these films.

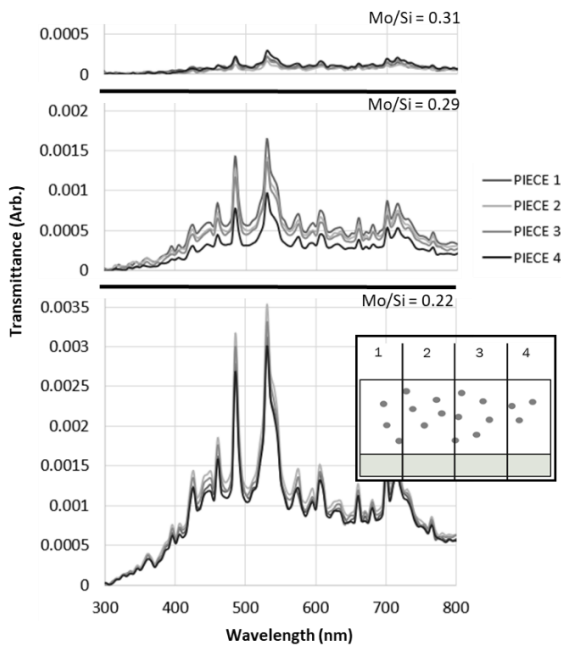


Figure 3. Uniformity testing of samples using UV-VIS. Inset shows how samples were prepped.

UV-VIS spectroscopy was also used probe how transmittance changed with increasing Mo content across the samples. Figure 4 shows transmittance decreasing as the Mo content increased with these samples, which is to be expected. However, high Mo content will have

the undesirable effect of increasing emissivity, which is the ratio of the intensity of the emitted thermal radiation of the sample to that of a perfect blackbody. Emissivity testing was used in conjunction with UV-VIS to determine the optimal ratio of SiO_2 to Mo.

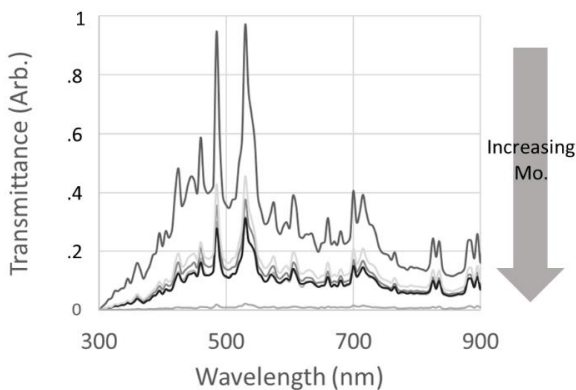


Figure 4. Decreasing transmittance with increasing Mo content for several SSA samples deposited.

We used a Fluke TiS10 thermal camera, with a spectral band range of $7.5\ \mu\text{m}$ to $14\ \mu\text{m}$ and an adjustable emissivity parameter to determine relative emissivity values for our series of samples [8, 9, 10]. The samples deposited on stainless steel foil were taped to a hot plate, and three thermocouples were adhered to the surface of the sample across the surface. The thermocouples were connected to monitor temperature, and the thermal camera was used to take an image at each of these positions. The emissivity parameter was adjusted until the temperature readout of the thermal camera matched the readout of the thermocouple. Although there are several sources for systematic errors in this setup, we were able to see trends in the relative emissivity as a function of temperature as shown in Figure 5. For each sample, the emissivity decreased as the temperature of the hot plate was increased. More importantly, between the samples, the emissivity decreased as the amount of Mo decreased, which was expected.

Because these emissivity measurements are made through a home-built set-up unlike SEM, EDS, and UV-VIS measurements, they provide the opportunity to improve the experimental design. Through the process of improving the design and retaking data, the importance of understanding experimental uncertainty and systematic errors can be explored.

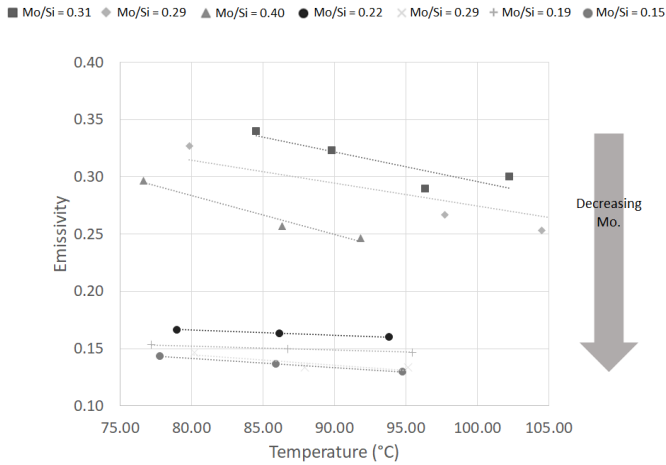


Figure 5. Emissivity of SSA samples with decreasing Mo content.

The emissivity and transmittance trends were plotted with the ratio of Mo to SiO_2 in Figure 6. The ratios of Mo/SiO₂ in the figure are ratios of atomic percent as calculated by the EDS software. The grey (triangles) data shows emissivity and corresponding trend line and the black (circles) data shows transmittance and corresponding trend line. Ideally, zero emissivity and total absorption would produce the optimal performance of the SSA. However, both ideal levels of the properties cannot be attained simultaneously. Using these data, we hypothesized that the best, attainable ratio of Mo/Si would be somewhere within the region outlined by the black box in Figure 6 where the trendlines intersect. The value of Mo/Si at the trendline intersection is 0.19.

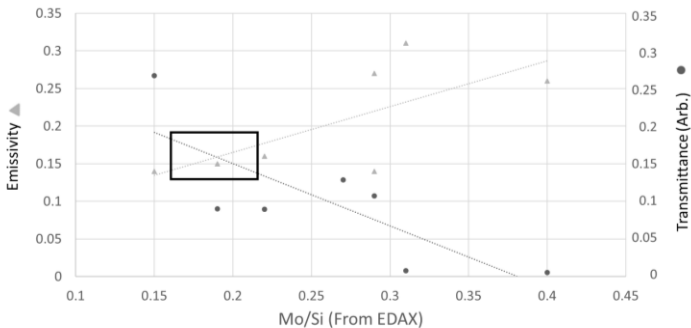


Figure 6. Correlating emissivity and transmittance trends with Mo to SiO_2 ratio.

Prototype Device

We created a prototype solar water heater using a design similar to that in Ni et al. [4]. Figure 7 (top) shows a schematic of the water heater design. Styrofoam was used as an insulator from a water reservoir. A wicking fabric (cotton) pulled water from the reservoir to the SSA. Bubble wrap was placed on top of the SSA to restrict convective cooling from occurring at the SSA interface. We used a home-built solar simulator lamp to test the samples under incident light as shown in Figure 7 (bottom). The water reservoir remained at roughly room temperature as measured by a thermocouple. Another thermocouple was placed between the wicking fabric layer and the top of the Styrofoam insulating layer. The temperature of the water on the cloth touching the thermocouple was monitored for 30 minutes until a saturation temperature was achieved. This saturation temperature was used as the highest temperature achieved by the prototype with the corresponding SSA. While steam has not yet been generated, water actively condensed on the underside of the bubble wrap from several of our SSA samples.

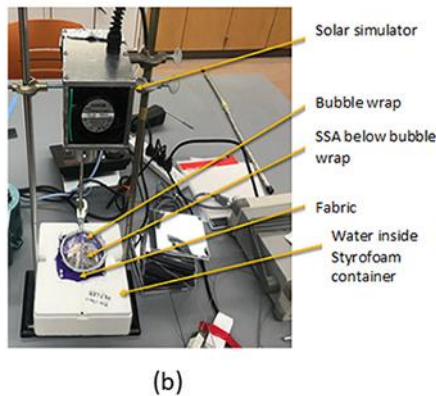
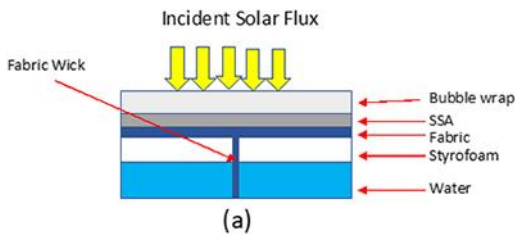


Figure 7. Testing of SSAs in solar water heating applications. (Top) Schematic of setup (based on design of Ni et al. [4]). (Bottom) Picture of actual prototype.

The films that achieved the highest temperature under the lamp were not far from the hypothesized ratio of 0.19 Mo/SiO₂, a rough but reasonable estimate based on the intersection point of trend lines shown in Figure 6. The films with ratios of 0.22 to 0.27 Mo/SiO₂ achieved that highest thermocouple temperatures and most condensed water visually. Table 1 shows the maximum recorded temperatures under the solar simulator lamp for several samples organized by each sample's Mo/Si ratio.

Table 1: Maximum temperatures achieved by SSA samples	
Sample represented by Mo/Si ratio	Maximum temperature achieved under solar simulator lamp (°C)
Mo/Si = 0.15	77.5
Mo/Si = 0.19	83.9
Mo/Si = 0.22	88.5
Mo/Si = 0.27	88.1
Mo/Si = 0.29	87.8
Mo/Si = 0.29	72.28
Mo/Si = 0.31	68.3
Mo/Si = 0.40	84.0

The solar water heater apparatus is very appropriate for undergraduate experiments. The whole apparatus can be built from inexpensive parts, and the visual confirmation of condensed water is a very gratifying result to students. Many electronic devices made from thin-film materials are much harder to successfully create in an undergraduate laboratory and achieve successful results. Additionally, there are many ways to modify and improve this setup leading to discussions of error analysis and error mitigation in prototype testing.

Conclusions

Through the SSA development process, students can learn not only about the exact material itself but also the general process used in all materials development. Students are able to understand the cyclic process of optimizing a film for a specific application where many iterations of deposition and testing are necessary. Through this iterative process, a student learns about the handling and management of many data sets and how to correlate trends between a variety of characterization techniques and testing.

The next step in the materials development process will be to vary the SiO₂ content while keeping the Mo deposition parameters the same

to optimize SSA performance. There are also other deposition parameters that can be changed besides the power. A more complex stack using a Mo infrared reflector back layer and SiO_2 antireflection coating will also increase the performance of the film [2]. For each of these changes, more characterization is necessary. In the prototype, wool or silk fabric can be explored to understand how wicking affects the steam generation process. Additionally, this prototype should be tested outside under natural conditions.

Several pieces of this development process open up opportunity for collaboration with other Utah institutions that have materials development capabilities. Other materials for the cermet structure can be tested and even the cermet structure can be changed. Additional solar water heater prototypes can be explored as well.

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Robustness of a Quantum Algorithm in the Presence of Noise

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Abstract

Quantum algorithms offer efficient solutions to computational problems that are expensive to solve classically. However, their implementation on quantum computers requires dealing with inevitable sources of error such as noise and decoherence. We present a quantum implementation of Simon's algorithm for a simple toy problem whose quantum algorithmic solution enjoys an exponential speed-up over any classical solution. We then develop a model for noise simulation on IBM's Qiskit framework to analyze the effect of noise on the algorithm's effectiveness. We also compare results of noise simulations with implementations on an actual quantum computer at IBM. We find that when the noise is sufficiently weak, the algorithm performs its task satisfactorily in simulations. Tests on actual computers reveal that two-qubit gates are more susceptible than single-qubit gates to introducing errors into the algorithm. Our results point us to the importance of adapting quantum circuits to the physical implementations of the computers they run on to avoid noise introduced as a result of automatic transpilation.

Introduction

Simon's Algorithm is a method of solving the toy computational problem known as Simon's Problem, which was introduced in 1994 by Daniel Simon [1]. This problem bears many similarities to the problem of factorizing large semiprimes (composite numbers with exactly two factors) because its algorithmic solution resembles Shor's algorithm for factoring composite numbers with the quantum Fourier transform [2]; in fact, Simon's Algorithm utilizes a first-order approximation of the quantum Fourier transform [3].

In spite of the significant technical progress of quantum computers in recent years, they are still subject to noise from classical sources, such as stray fields, and quantum fluctuations as well as from decoherence through inevitable interactions with their environment. IBM, a major player in quantum computer development, claims that errors due to such noise are fundamental [4]. We consider noise to be any undesired source that changes the quantum system. Because of the prevalence of noise, any quantum algorithm that is to be implemented and put to use in real-life scenarios must be able to perform its task with a high probability of success despite the presence of such noise. Analytical methods indicate that an approximation of the quantum Fourier transform can provide better performance than its full version in the presence of decoherence [3]. Including randomized gate defects in numerical calculations has revealed that the quantum Fourier transform can still perform its task to an acceptable degree of success in spite of such defects [5].

We expand on this latter approach and explore the robustness of Simon's Algorithm by introducing gate defects that can be attributed to either noise or decoherence. We first perform simulations with three types of artificially defective gates on IBM's Qiskit platform [6] and then compare the results of these simulations to the results of experiments on actual quantum computers at IBM. This allows us to determine whether our simulated gate defects accurately reflect noise in real-world quantum systems. Although our tests are performed by running Simon's Algorithm, we arrived at general conclusions about simulation of noise on quantum computers.

In the first sections, we delve into the theory and implementation of a problem that is solved more efficiently by a quantum algorithm than by a classical algorithm. Readers who are primarily interested in our simulation of noise and comparison with results from tests on an actual quantum computer may prefer to proceed immediately to the section entitled "Simulating Noise: Perturbing Hadamard Gates" and the sections after that. For a comprehensive introduction to the field of quantum computation, see Mermin [2] and Chuang and Nielsen [7].

Simon's Problem

Simon's Problem is to find a special number a that acts like a period in a function. We are given a function f that maps n -bit integers to $(n-1)$ -bit integers. This function has the property that there is some nonzero n -bit number a for which, if x and y are any two n -bit numbers, then $f(x) = f(y)$ if and only if $y = x \oplus a$, where $\oplus$ indicates bitwise modulo-2 addition (also known as the xor operation). In this case, we see that $f(x) = f(x \oplus a)$, so the function is periodic under the $\oplus$ operation. The task of Simon's problem is to find the period a .

Classically, if we seek to find a , we must test many different values of x and make a note of x and the output $f(x)$, continuing until we find a different input y where $f(x) = f(y)$. Once this happens, we know a by calculating $x \oplus y$. As x is an n -bit number, there are 2^n possible values to use as input, and each x has exactly one y for which $f(x) = f(y)$, so there are $\frac{2^n}{2} = 2^{n-1}$ pairs of x and y values. This means that we must compute $f(x)$ for up to 2^{n-1} distinct values of x in order to find a , so the algorithm scales exponentially in n , the number of bits in a .

The quantum solution to this problem requires an amount of circuit runs linear in n to find a . This is accomplished by putting the n input qubits into a balanced superposition before calculating f , which is a standard quantum computational procedure that allows for speed-up in many problems where quantum speed-up is possible. The result of the quantum circuit requires classical postprocessing to find a . The algorithmic solution, Simon's Algorithm, is detailed in the next section.

Simon's Quantum Algorithm

We use a quantum circuit of $2n - 1$ qubits with readout onto an n -bit classical register. A schematic for the operations to be performed is presented in Figure 1. We represent our basis states with the convention that $|x\rangle_n$ refers to n qubits whose state is the n -bit binary expansion of x . For example, $|4\rangle_3 = |1\rangle |0\rangle |0\rangle$ since 4 is represented as 100 in binary. The first n qubits, initialized to the state $|0\rangle_n$, are used as input qubits to f , and the next $n - 1$ are used as the output and initialized to the state $|0\rangle_{n-1}$. We assume that f has been provided in a perfect black box that computes the output $f(x)$ via a $(2n - 1)$ -qubit unitary transformation U_f .

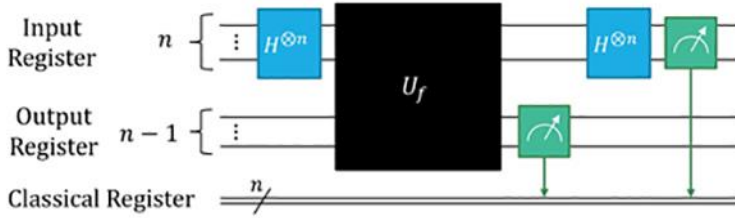


Figure 1: Schematic for the quantum algorithm solving Simon's problem. The n -qubit register is referred to as the input register and the $(n-1)$ -qubit register as the output register. The lines at the bottom are an n -bit classical register.

We begin by applying a Hadamard gate, represented by H , to each qubit in the input register. A Hadamard gate works on a single qubit and will change it from the $|0\rangle$ state to a balanced superposition of the $|0\rangle$ and $|1\rangle$ states. Applying one to each qubit in the input register puts it in a balanced superposition of every state from $|0\rangle_n$ to $|2^n - 1\rangle_n$.

Next, U_f is applied to the input and output registers, which puts the state of the quantum registers in an entangled superposition of each input with its corresponding output. For example, if we were to measure the input register at this point in the algorithm and find a resulting state of $|\hat{x}\rangle_n$, where $\hat{x}$ is any possible n -bit input number, we know the output register must be in the state $|f(\hat{x})\rangle_{n-1}$.

We instead perform a quantum measurement of the output register and record the resulting $(n-1)$ -bit integer onto $n-1$ bits of the classical register. The readout from this measurement is irrelevant for our solution, as the values of $f(x)$ are completely independent of a . The measurement itself is important because it collapses the superposition in the output register, but the resulting value $\hat{f}$ is unimportant. Because there are exactly two inputs, $\hat{x}$ and $\hat{y} = \hat{x} \oplus a$, that correspond to any particular output $\hat{f} = f(\hat{x}) = f(\hat{y})$, this measurement leaves the output register in the state $|f(\hat{x})\rangle_{n-1}$ and the input register in a superposition of the $|\hat{x}\rangle_n$ and $|\hat{y}\rangle_n$ states.

We finally apply Hadamard gates to each qubit in the input register. This results in an input register state that consists of a superposition of only values z for which $z \cdot a = 0$, where $x \cdot y$ refers to the bitwise dot product between two numbers x and y , taken modulo 2:

$$x \cdot y = x_0y_0 + x_1y_1 + \cdots + x_ny_n = \sum_{i=0}^n x_iy_i \pmod{2}$$

Note that x_i refers to the i th element in the n -bit binary expansion of x .

If we finally measure the input register and store the results on the n bits of the classical register, we are guaranteed to read out one of these numbers z that satisfies $z \cdot a = 0$. If the circuit is run m times ($m \geq n$) and n unique results are recorded, we can build a system of n modulo-2 equations which we can solve to find a .

Each unique z value has a probability of $\frac{1}{2^{n-1}}$ of being measured. After m runs of the circuit, the probability of being able to determine a is no smaller than

$$P_{min} = 1 - \frac{1}{2^{m-n+1}} \quad (1)$$

[2]. We can thus determine a to a high probability with a linear number of shots (circuit runs) in n ; this probability increases as the quantity $m - n$ increases. If $m = n + 4$, then we can achieve over a 96% chance of determining a after m shots. On the other hand, with the classical algorithm, we require up to 2^{n-1} queries of the function f to be able to find a with 100% probability; with fewer queries than this, a is not guaranteed to be found. The number of classical queries grows much faster than the number of quantum queries n does, revealing the exponential speed-up of the quantum algorithm over the classical one.

Quantum Algorithm Implementation: Constructing the Circuit

We described the transformations needed to implement Simon's algorithm in the preceding section. In this section, we detail the construction of the quantum circuit that performs these operations.

As mentioned previously, we have an n -bit input register and an $(n - 1)$ -bit output register. On the input register, we apply a Hadamard gate on each qubit.

To include U_f in the circuit, we need to open the black box to see its operation and then construct it out of simpler gates. Since f takes n -bit numbers to $(n - 1)$ -bit numbers, we can encode the action of f as a $(n - 1) \times n$ matrix $\mathbb{U}$ whose elements are 0 or 1, a result from Roetteler [8]. These entries are 0 or 1 because we are working with the vectorized binary expansions of the inputs to f . If the matrix has rank $n - 1$, then there exists a unique n -vector $\mathbf{a}$ that spans the kernel of $\mathbb{U}$. If we choose this $\mathbf{a}$ to have components that are the binary expansion of the a in Simon's problem, then the matrix $\mathbb{U}$ is a valid representation of the action of f . We can use this representation to construct U_f from controlled-NOT gates, represented by cX . If the matrix element in the i^{th} row and j^{th} column in $\mathbb{U}$ is a 1, then we introduce a cX gate from the j^{th} qubit in the input register to the i^{th} qubit in the output register of the circuit. Where there are zeros,

nothing is added between the corresponding qubits. The collection of all cX gates corresponding to each nonzero entry in U forms the U_f transformation we desire.

At this point in our implementation of the algorithm, the circuit includes n more Hadamard gates, one applied on each qubit in the input register. This is followed by a measurement of the output qubits in sequence. Finally, the qubits of the input register are measured in sequence.

The implementation of this circuit in Qiskit for $n = 3$ is depicted in Figure 2. This represents the circuit as it runs in simulations, which may not necessarily be identical to how it is implemented on an actual quantum computer. We chose $n = 3$ because of the limited availability of quantum computers with more than 5 qubits; this is the largest n value for which Simon's algorithm can fit on a 5-qubit quantum computer because the circuit requires $2n - 1 = 2(3) - 1 = 5$ qubits.

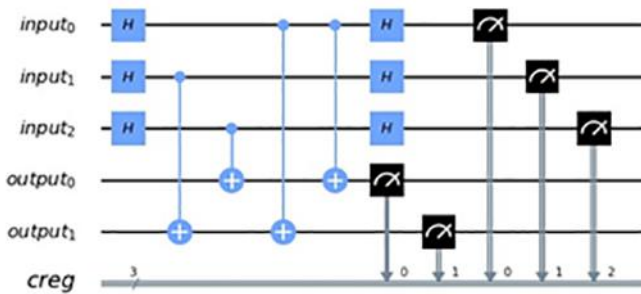


Figure 2: Quantum circuit implementation of Simon's Algorithm in Qiskit for $n = 3$, using a binary a value of 111.

Noiseless Simulations

Using Qiskit's QASM simulator [9], a simulator on which quantum circuits can be tested, we ran the circuit in Figure 2 to confirm that the algorithm works in simulations and to verify the bound on the probability of success given in Eq. (1). We performed m shots, where m ranged from 3 to 10. The lower bound 3 was chosen because it represents the minimum number of shots after which unique determination of a is possible for $n = 3$. The upper bound of 10 was chosen somewhat arbitrarily and simply represents a point at which further incrementing the number of shots ceases to be useful.

As a measure of success, we introduce the ratio P of trials in which we were able to uniquely determine a in postprocessing to the total number of trials for that m value.

For each value of m , we performed 1000 trials with $a = 111$. The result and comparison with the theoretical bound from Eq. (1) are plotted in Figure 3. It is clear that with a noiseless circuit, the probability of finding a approaches 1 after a sufficient number of shots. In addition, the simulation probabilities are always greater than or equal to the theoretical lower bounds, which verifies the correct performance of our implementation in ideal conditions.

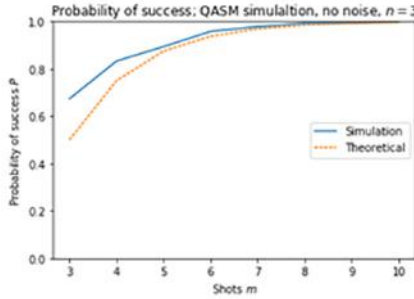


Figure 3: Probability of being able to determine a uniquely after m shots. Each data point is the averaged result of 1000 trials.

Simulating Noise: Perturbing Hadamard Gates

Because of the vast amount of possibilities for sources of noise and the random nature of its effects on quantum systems, identifying a specific noise source and replicating it in simulations is difficult. Our approach is to add random defects to gates in the circuit for the algorithm and perform simulations using these noisy gates and then proceed to compare the results of these simulations with results obtained from implementing the ideal algorithm on an actual quantum computer.

A more versatile gate known as the U_3 gate can be used to replicate the effect of a Hadamard (H) gate [10]. U_3 gates are parameterized by three angles θ , ϕ , and λ ; in particular,

$$U_3(\theta = \frac{\pi}{2}, \phi = 0, \lambda = \pi) = H.$$

Thus, we can simulate a Hadamard gate with random noise by perturbing the angles θ , ϕ , and λ with small random numbers. We classify three types of noise, each of which can have static or nonstatic implementations.

1. The first is *superposition* noise, wherein we perturb only the angle θ . This noisy Hadamard gate creates a superposition that is weighted more towards one state than another instead of a balanced superposition.
2. The second is *phase* noise, which results from keeping $\theta = \frac{\pi}{2}$ and instead perturbing φ and λ by the same amount simultaneously. This noise source puts phase factors into the qubits' states that can alter interference effects; this can particularly change the result of the second array of Hadamard gates in the algorithm. The first array of Hadamard gates will be less significantly affected because the qubits that this first array acts on are initialized to the $|0\rangle_n$ state.
3. The third type of noise is a *combination* of both phase and superposition noise. All three angles are perturbed, but the superposition perturbation of θ is independent of the phase perturbation of φ and λ .

In all noisy Hadamard gates, the perturbation amounts were randomly generated from the interval $[-d, d)$ for some small d . Effectively, d acts as a bound on the amount of error. Because d bounds how much the angles θ , φ , and λ can change, the maximum deviation from intended gate operation happens at $d = \pi$. Such perturbations can affect measurement probabilities by as much as d per gate.

Another consideration in our noise simulations was static versus nonstatic noise implementations. In noisy simulations with *static* noise, the perturbation was the same for each Hadamard gate in an algorithmic step. This could represent noise from an external source that affects the whole circuit uniformly, such as if the qubits are in the presence of an electric field. In *nonstatic* noise simulations, these perturbation amounts were regenerated for each gate in the circuit, which is more representative of individual gates being only probabilistically accurate.

Noisy Simulations

We constructed a noisy circuit with $n = 3$ by replacing Hadamard gates from the circuit in Figure 2 with perturbed gates as described in the previous section. We performed each set of trials using noise values bounded by $d = 0.01, 0.05, 0.1, 0.25$, and 0.5 . We performed 100 trials of running the circuit m times for m ranging from 3 to 10 and measured the percentage of trials in which a was able to be uniquely determined from the readout. The results of these experiments are presented in Figure 4.

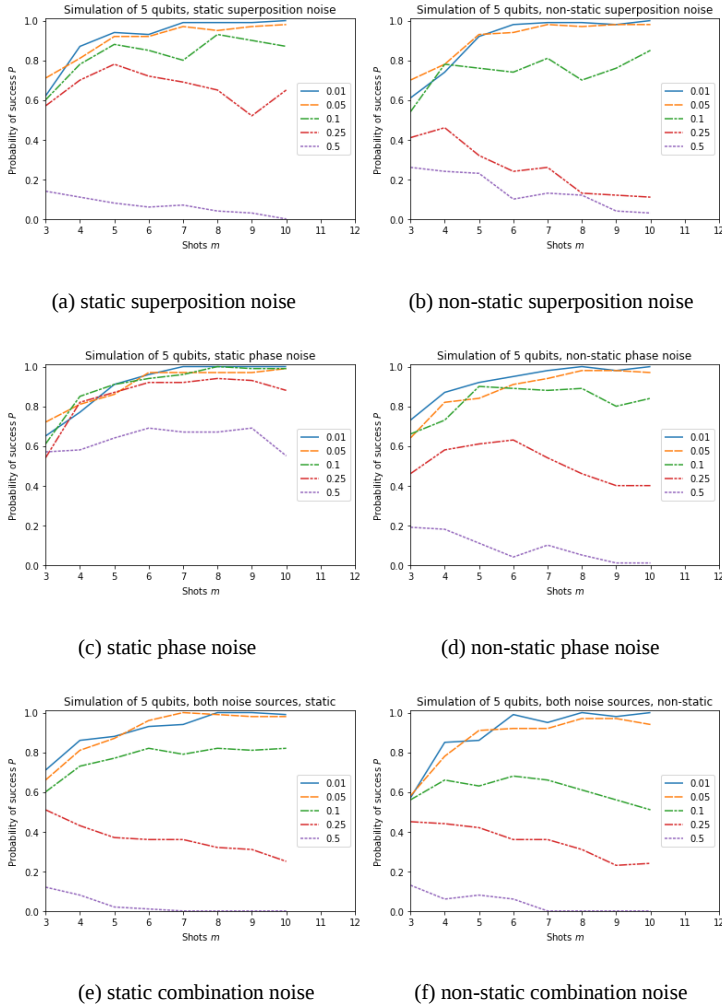


Figure 4: Results from simulations of Simon's Algorithm on an $n = 3$ circuit with noisy Hadamard gates for several d values, using the same measurement of success as in Fig. 3.

As expected, the algorithm performs very well for small noise values. As the magnitude of the noise increases, however, performance deteriorates, a trend that was seen for all six types of perturbed gates. Superposition noise and phase noise seem to have similar effects, although in some cases, seen in Figures 4c and 4d compared with 4a and 4b, superposition noise is noticeably more detrimental to the success of

the algorithm for higher noise values. Unsurprisingly, combination noise leads to even worse performance than either of the individual sources.

We also see that nonstatic noise is generally worse for the success of the algorithm than static noise. This implies that systematic noise has a smaller impact on the algorithm than entirely random noise.

For large magnitudes of noise, the probability of success is seen to fall off as the number of shots increases, unlike the ideal algorithm. This is partially due to our measurement of success: if, for some $k < m$ the first k shots would allow for a unique determination of a , but the $(k + 1)^{\text{th}}$ shot gave a result z that did not satisfy $z \cdot a = 0$, then the classical postprocessing would determine that a was unable to be determined, even though it could have determined a from the first k shots.

Tests on a Quantum Computer

We now compare the results of these simulations with those obtained from running the algorithm on an actual quantum computer. Through Qiskit, IBM provides access to quantum computers with up to 15 qubits on which we were able to run our circuit. We wrote Python code to build and send the circuit pictured in Figure 2 to the 5-qubit computer `ibmq_ourense` [11]. This is a publicly available machine that is shared with other users, so in our trials we experienced queue times that ranged from a few seconds to an hour. We performed only a few trials for each m value because of this limitation. To deal with these large delays, 20 trials of m shots for each m value were performed to determine the success rate of the algorithm. The results are plotted in Figure 5.

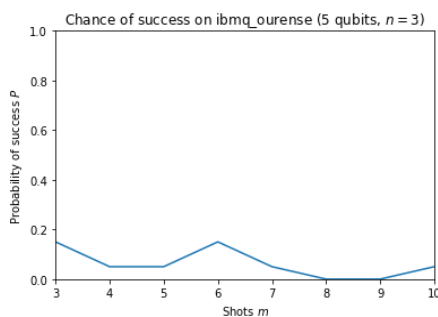


Figure 5: Probability of success in trials using IBM quantum computers, with our $n = 3$ circuit on `ibmq_ourense`. Each data point represents the probability of success in 20 trials.

We note the low probability of success of the algorithm for all values of m ; the success rate never rises above 15%, and it even reaches zero for some values of m . By comparing Figure 5 with Figures 4e and 4f, we see that the magnitude of error is similar to both types of simulated combination noise, but the simulation data indicates a nearly monotonically decreasing trend in success probability whereas the quantum computer test data lacks such a trend. Clearly, the algorithm performs much worse on quantum computers than in most of our noisy simulations. In the next section, we will address the cause of the low probabilities observed.

Transpiled Circuit

It is important to note that the circuit as presented in Figure 2 is not exactly the same as the circuit that gets run on IBM's quantum computers. Because of physical restrictions, IBM quantum computers have limited connectivity between qubits. Most qubits in the computers are only directly connected to two or three other qubits; by contrast, we assumed full connectivity between qubits in our simulations. In Figure 6, the connectivity for `ibmq_ourense`, the computer on which the circuit was run, is displayed.

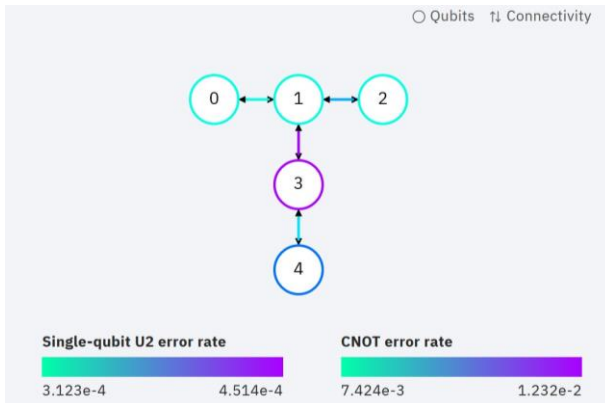


Figure 6: Qubit connectivity and gate error rate for `ibmq_ourense`, as published by IBM and calibrated at 1:42 AM on April 28, 2020. Quantum circuits are decomposed into a series of single-qubit U_2 gates and double-qubit cX gates. The colored circles on the figure indicate the error rate of U_2 gates applied on the circled qubit. The shaded arrows between pairs of qubits indicate the error rate of cX gates applied between the pair. Note the limited connectivity between qubits. Image obtained from IBM Quantum Experience [11].

Limited connectivity is not an issue that prohibits algorithmic design [12]. Using ancilla qubits, qubits in the computer that are not dedicated to a task in the algorithm, we can chain cX gates between intermediate qubits that *are* connected in a way that the cX gate is applied between two unconnected qubits and the intermediate qubits are returned to their original state. Qiskit performs these and other conversions between circuit designs and implementations automatically using a “transpiler.” The transpiled version of our circuit for an a value of 111 is presented in Figure 7. We particularly note the significant increase in cX gates.

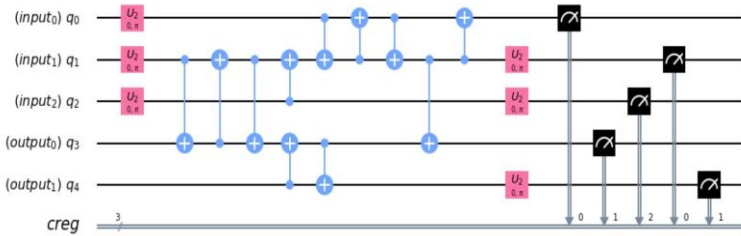


Figure 7: Circuit diagram of the circuit in Figure 2 after running through Qiskit’s transpiler for `ibmq_ourense`. Note that $U_2(\varphi, \lambda) = U_3(\pi/2, \varphi, \lambda)$, so the arrays of U_2 gates at the beginning and end of the circuit are equivalent to Hadamard gates.

Error Analysis

Ideally, such cX chains should not impact our algorithm at all, as they leave the intermediate qubits unchanged. However, because of the nonzero error rate of cX gates on IBM quantum computers, adding cX gates to the circuit can cause it to perform significantly worse than expected. In our case, the transpiler added seven cX gates to our circuit that originally only had four, resulting in a circuit with a total of 11 cX gates. Even if we were to make the most optimistic assumption and take the minimum error rate of 7.424×10^{-3} as shown in Figure 6 for *all* cX connections, the probability $P_{no\ error, cX}$ that *no* cX gates error out in one shot of the transpiled circuit would be

$$P_{no\ errors, cX, transpiled} = (1 - 0.007424)^{11} = 92.1\%$$

compared with

$$P_{no\ error,cX,original} = (1 - 0.007424)^4 = 97.1\%$$

for the original, nontranspiled circuit. Because the actual error rate for each cX gate in our circuit is actually larger than this rate, it is practically inevitable that some cX gate will not perform its task correctly in at least one of the m shots of the circuit. In terms of our algorithm, this means that the U_f gate, which applies the function f to the qubits, could be affected as much as to represent an entirely different function.

We have not taken into account the single-qubit U_2 error rate depicted in Figure 6. The U_2 gate is defined by $U_2(\varphi, \lambda) = U_3(\pi/2, \varphi, \lambda)$; notice that the Hadamard gates in our circuit have been converted into $U_2(0, \pi)$ gates (cf. Figure 7), which are equivalent to Hadamard gates. Thus, this U_2 error rate is the error rate of the Hadamard gates in our circuit. Our circuit only requiring $2n$ Hadamard gates and their single-qubit nature rendering them unaffected by limited connectivity means that this is a smaller contribution to error in the circuit. In addition, the greatest U_2 error rate of any qubit on `ibmq_ourense` was 4.514×10^{-4} at calibration time, which is an order of magnitude lower than the cX error rates. For our circuit, then, the *worst case* estimate of the probability $P_{no\ error,H}$ that no Hadamard gate in the circuit errors out is

$$P_{no\ error,H} = (1 - 0.0004514)^6 = 99.7\%,$$

which is the same pre- and post-transpilation.

The difference between single-qubit gate error rate and cX gate error rates is likely the reason for the significant difference in success rate between running our algorithm in our noise simulations and on a quantum computer. Our simulations focused on the external circuitry around U_f and how errors in its function might affect our algorithm. By contrast, this part of the algorithm was likely the *least* noisy part when run on an actual quantum computer. We will address this issue in the final section.

Discussion

Our noise simulations indicate that a sufficiently low magnitude of noise in the Hadamard gates only somewhat reduces the success rate of Simon's Algorithm; under our assumptions, if the magnitude of noise remains below $d = 0.1$, the algorithm has an 80% success rate for all sources of noise except for nonstatic combination noise, for which it still boasts a success rate over 50%. This is good news for quantum computation, as it demonstrates an allowable amount of error that largely

preserves the function of the algorithm. If the noise gets too far beyond this threshold, however, then this success rate falls more significantly. In addition, the benefit of performing many shots diminishes, which means that the algorithm loses its exponential speed-up over the classical algorithm; ordinarily, the speed-up would originate in the fact that we could guarantee success up to a probability arbitrarily close to 1 with a number of shots linear in n .

Our tests of the algorithm on actual quantum computers also indicate that the success rate of the algorithm significantly diminishes because of errors caused by the noise of the computers' environments. However, both the data and our error analysis suggest that this reduction in success rate comes from a different source than what was considered in our noise simulations. Although we chose to run our simulations on the assumption that U_f was computed by a perfect black box, our tests on actual quantum computers seem to be most dramatically affected by the implementation of this transformation. In fact, errors in the single-qubit Hadamard gates of our circuit are likely not a significant contribution to the reduced performance of our algorithm. We can therefore conclude that our method of simulating noise is not the appropriate one for Simon's Algorithm. It may, however, be more useful on algorithms with fewer two-qubit gates.

Much of the discrepancy between our simulations and trials on actual quantum computers originates in Qiskit's transpiler, which changes our circuit in a way that allows for the physical limitations of the quantum computer to be overcome while theoretically leaving the algorithm unaffected. This change can introduce an unholy amount of cX gates into our circuit, which are subject to higher error rates than single-qubit gates. Because the number of cX gates in U_f scales at least linearly with n (being the length of the target number a), the algorithm therefore suffers worse performance as n increases.

We performed similar tests to those mentioned in this paper using circuits that correspond to an n value of 6 and found that the transpiler introduces significantly more gates than it did in the $n = 3$ case treated here, adding 52 cX gates to a circuit that originally had 11. This led to our algorithm being entirely unable to complete its task for any value of m , indicating that this algorithm's performance on an actual quantum computer worsens as n increases because of the transpiler.

Although our conclusions are the result of exploring Simon's Algorithm, we believe that they apply generally to other quantum algorithms. If noisy gates are to be simulated, it is preferable to insert simulated noise in double-qubit gates before single-qubit gates to ensure the simulation is closer to reality. If noise is to be simulated in single-

qubit gates, they should experience an order of magnitude less than the double-qubit gates.

Future Prospects

We note that our implementation of simulated noise involves introducing random but guaranteed errors into the function of the gates, whereas errors in IBM quantum computers are unpredictable. In the future, it would be informative to test the algorithm with noisy gates that are probabilistic in their error generation to more accurately model the error present in the actual quantum computers.

The discrepancy between our simulated noise and the noise experienced by actual quantum computers running Simon's Algorithm seems to be caused by our choice to modify Hadamard gates and assume cX gates were ideal. We suspect that simulating noisy cX gates by replacing them with controlled gates perturbed by small random angles would give results that align more closely to those obtained from actual quantum computers.

We expect that an implementation of Simon's Algorithm to detect an a value with a matrix U that corresponds to a unitary transformation U_f that minimizes the number of cX gates that must be added by the transpiler would find much higher success rate than observed in our tests. In addition to our tests on circuits with $n = 6$ mentioned above, we also performed similar tests on a circuit with $n = 8$ that was specifically designed to require no cX gates to be added by the transpiler; performing tests on an actual quantum computer with this circuit revealed results similar to Figure 5. This indicates that careful consideration of the qubit topology of the physical quantum computer is paramount to maximizing success rate in quantum algorithms.

The approach presented in this paper could also be applied to other quantum algorithms to determine their performance in the presence of noise. Using a protocol like Qiskit Ignis [13] to simulate algorithms in a way that simulated noise is similar to real-world noise experienced by quantum computers could also prove very useful for quantum algorithm development. In addition to this, progress is being made in the fields of quantum error mitigation and correction [14]. The latter suffers from a need to greatly increase the number of qubits and gates and is not yet appropriate for addressing the noise found in the quantum computer we used, but both are promising future prospects for helping quantum algorithms perform their tasks more reliably.

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A Proposal for a Universal Three-Qubit Logic Gate for Quantum Computation: A Deutsch Gate from Two Quantum Dots and a Flying Photon

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Abstract

Quantum computation is an active area of research that has the potential to perform computations that classical computers are incapable of. Finding useful universal gates and constructing their hardware has been a challenge. In this proposal, we focus on the Deutsch gate. The Deutsch gate is a three-qubit universal quantum logic gate, meaning that any quantum computing task can be completed using a combination of Deutsch gates. To our knowledge, no Deutsch gate has been experimentally realized so far. We store two qubits in the spins of two electrons confined to GaAs/InAs quantum dots and the third qubit in the polarization of a photon. This photonic qubit interacts with the quantum dots by traveling through the designed circuitry thereby achieving the Deutsch gate.

Introduction: On the Importance of Universal Gates

Quantum information has made the news for ushering in new quantum technologies [1]. Three main categories of quantum technologies of interest are quantum communication, quantum sensing, and quantum computing. Quantum communication uses quantum phenomena—like entanglement—to share information between two parties and is useful for things like unbreakable quantum cryptography [2]. Quantum sensing uses the laws of quantum physics to measure some physical quantity [3]. A common and simple example is an atomic clock. Lastly, quantum computing involves using quantum phenomena, especially entanglement and superposition, to perform computations more efficiently. Quantum computing has interesting applications for computer science [4], including a speed-up for integer factorization via Shor's algorithm, which could overcome classical encryption methods. The topic of this contribution aligns most closely with the area of quantum computing. Any computer requires hardware and software. The software of computers involves the actual operations that transform the inputs into outputs. The hardware is the physical device that carries out the operations. This contribution concerns itself with a proposal for creating a hardware component that could be used to build a fully functional quantum computer. Quantum computers are made up of quantum logic gates, smaller hardware components that each perform an operation. Building a fully functional quantum computer requires a universal set of quantum logic gates. We propose to build the Deutsch gate [5], which is a universal logic gate. (We describe its operation later in this section; see the text around Eq. (1) below). Because the Deutsch gate is a universal quantum logic gate, one could build a quantum computer just out of Deutsch gates rather than using many different gates. Aside from universality, the Deutsch gate has other advantages, which we cover in the discussion. For some quantum computing tasks, the Deutsch gate proves more useful than the universal sets typically used in quantum computing today. As an example, the Deutsch gate implements higher-qubit gates more efficiently than typical universal sets.

But first, what is a logic gate? A logic gate is a physical realization of a logical operator. In classical computing, logic gates act on bits, which can hold the value of either 0 or 1. A common classical logic gate is the AND gate represented in Fig. 1. The AND gate takes in two bits and returns a single bit in the state 1 if both input bits are in a state 1 and a 0 otherwise.

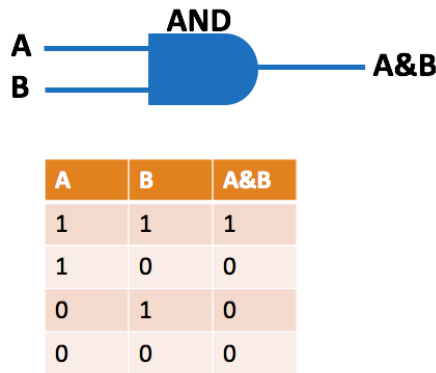


Figure 1. AND gate schematic and truth table. The AND gate returns a 1 if both inputs are 1 and a 0 otherwise.

For quantum logic gates, information is stored in qubits rather than bits. Qubits are in a superposition of the basis states $|0\rangle$ and $|1\rangle$. So, instead of being in a state 0 or 1 as in classical computing, qubits are in a state $\alpha|0\rangle + \beta|1\rangle$, where α and β are normalized constants that indicate how likely a measurement will result in the associated basis state. Additionally, for quantum logic gates, no information can be destroyed: every operation is reversible. In the classical AND gate, given the output 0, the inputs could have been 0 and 1, 1 and 0, or 0 and 0. The input state of the AND gate gets erased following the operation. In contrast, quantum logic gates retain information. Given an output state of an operation, the input state cannot only be determined but recovered with the inverse of that operation. What this contribution truly concerns itself with, however, is a universal quantum logic gate.

A universal set of gates is a set of gates that can create any other gate through some combination of the set. As an example, Figure 2a shows a universal set and how it might be used to create some desired target gate. Because any gate can be created with a universal set, any quantum computing task can be completed with a universal set. We examine a universal three-qubit gate called the Deutsch gate [5]. We denote the Deutsch gate $D(\theta)$. The angle θ reflects that the Deutsch gate performs a different operation with each angle between 0 and 2π . A universal gate is simply a universal set of size one. So, a combination of Deutsch gates ($D(\theta_1), D(\theta_2), D(\theta_3), \dots$) can create any quantum logic gate. It then follows that a combination of Deutsch gates can complete any quantum computational task. How the Deutsch gate might be used to create some desired target gate is shown in Figure 2b.

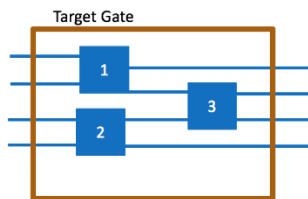
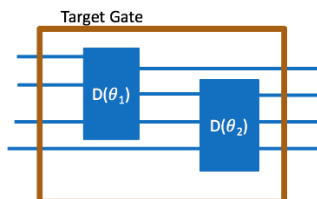
Universal Set: {1,2,3}**Universal Gate: $D(\theta)$** 

Figure 2. An example of how some target gate could be created with (a) a universal set of gates and (b) the universal Deutsch gate.

Typically, quantum computing is done with a universal set of logic gates. Despite the broad use of universal sets, the use of a single universal gate rather than a set has several advantages. Using a single universal gate bypasses the challenge of achieving a high fidelity on each type of gate in a set. The fidelity of a gate is a measure of how accurate the gate is and is defined to be between 0, low fidelity, and 1, perfect fidelity. Specifically, the fidelity of a gate is how often, on average, the output of the gate is the desired output. Uncontrollable noise like decoherence is inherent to all systems and limits how high a fidelity gates can attain. So, using the Deutsch gate would only require making sure that the Deutsch gate has a high fidelity. On the other hand, a universal set requires you to assess how high a fidelity several different gates have. Additionally, known universal gates—like the Deutsch gate—have an angular dependence that allows for simple changes in the operation performed by the gate [5]. This flexibility can help in designing quantum computers. One last advantage is that most universal sets used today are comprised of at most two-qubit gates [6]. A two-qubit gate is a gate that has two input and two output qubits. It turns out that two-qubit gates sometimes run into challenges when used to create higher-qubit gates. As an example, Yu *et al.* [7] found that a useful three-qubit gate for quantum error correction [8], the Toffoli gate, takes a minimum of five two-qubit gates to implement. A single Deutsch gate, meanwhile, can implement the Toffoli gate. The Deutsch gate may not always be more efficient than other universal sets for a particular quantum computational task. However, the Deutsch gate can complete some quantum computational tasks more efficiently than universal sets.

The Deutsch gate is a three-qubit universal quantum logic gate first proposed by David Deutsch in 1989 [5]. The Deutsch gate performs the following operation on an input state $|\Psi_{in}\rangle = |a\rangle|b\rangle|c\rangle$:

$$|\Psi_{in}\rangle \mapsto \begin{cases} i\cos(\theta)|a\rangle|b\rangle|c\rangle + \sin(\theta)|a\rangle|b\rangle|1-c\rangle & a = b = 1 \\ |a\rangle|b\rangle|c\rangle & \text{otherwise,} \end{cases} \quad (1)$$

where $|a\rangle$, $|b\rangle$, and $|c\rangle$ each are in a superposition of basis states $|0\rangle$ and $|1\rangle$. The ket $|1-c\rangle$ represents the state following a NOT operation on $|c\rangle$, which switches $|0\rangle$ to $|1\rangle$ and $|1\rangle$ to $|0\rangle$. So, if $|c\rangle = \alpha|0\rangle + \beta|1\rangle$ then $|1-c\rangle = \alpha|1\rangle + \beta|0\rangle$. The kets $|a\rangle$ and $|b\rangle$ are control qubits, meaning that the gate's operation depends on their states. The ket $|c\rangle$ functions as the target qubit that undergoes a transition if the control qubits are in the right state. Here, the target qubit $|c\rangle$ undergoes a transition only if $|a\rangle = |b\rangle = |1\rangle$. The angle θ allows the Deutsch gate to complete many different operations. So, in a sense, the Deutsch gate is an uncountable set of gates—a different gate at each angle. For example, choosing $\theta = \pi/2$ results in the Toffoli gate above. The angular dependence of the Deutsch gate creates difficulty for coming up with Deutsch gate protocols. Possibly because of this, a physical realization of the Deutsch gate has yet to be achieved, and there exists only one other protocol for the Deutsch gate, proposed by Shi [9], which uses Rydberg blockade of neutral atoms. Shi's protocol tunes θ to any value between 0 and π by adjusting the strengths of external control fields.

In our proposal for the Deutsch gate, we use two GaAs/InAs quantum dots alongside linear optical elements to build a circuit. We then send a flying photonic qubit through the circuit to realize the Deutsch gate. A flying qubit is a qubit that connects different gates. The spins of each electron in the quantum dots and the polarization of the photon function as the physical degrees of freedom to encode the qubits. Our proposal sets the angle θ using half-wave plates resulting in fast and simple changes to the Deutsch gate's operation. In our scheme, the two electron spins take on the role of control qubits while the photonic qubit functions as the target qubit. Only when both electrons are spin-up does the photonic qubit undergo a transition. The flying photonic qubit also allows for quantum communication because it can go on to interact with other gates. Table 1 compares Deutsch gate protocols by the type of qubits used. Although there is not much published work on creating a Deutsch gate, the GaAs/InAs quantum dots used in our protocol have been used for many quantum information applications [10-14] following the work of Hu *et al.* [15,16], who showed that GaAs/InAs quantum dots could be used as entanglement beam splitters.

Table 1. Deutsch gate protocols comparison by qubits used			
Deutsch gate protocol	Target qubit	Control qubit 1	Control qubit 2
Shi [9]	Rydberg	Rydberg	Rydberg
Bailey [this paper]	Flying photon	Quantum dot	Quantum dot

Our Proposal: Incorporating Two Quantum Dots to Form Deutsch Gate Circuitry

Our Deutsch gate protocol makes use of GaAs/InAs quantum dots and various linear optical elements. The GaAs/InAs quantum dot essentially consists of an electron in a cavity. Circularly polarized photons undergo transitions after interacting with the electron in a singly charged GaAs/InAs quantum dot as described by Bonato *et al.* [10]. We will only present these transitions in the amount of detail needed for our purpose, which is to describe the state of a photon before and after interacting with a GaAs/InAs quantum dot. More detailed descriptions of these transitions are available elsewhere [10,15-17].

We assume an arbitrary state for the electron in the GaAs/InAs quantum dot,

$$|e\rangle = k_1|+\rangle + k_2|-\rangle,$$

where $|+\rangle$ represents the electron spin-up state with respect to the axis of the incoming photon, $|-\rangle$ represents the spin-down state with respect to that same axis as seen in Fig. 3, and k_1 and k_2 are normalized coefficients. The incoming photon is in some superposition of right circularly polarized light $|R\rangle$ and left circularly polarized light $|L\rangle$. The incoming photon will either couple the electron to the cavity and reflect off the quantum dot and invert its polarization, namely go from $|R\rangle$ to $|L\rangle$ or vice versa, or will not couple the electron to the cavity but transmit through the quantum dot, picking up a phase shift of π while keeping its polarization state. In either case, the state of the electron remains unchanged. These transition rules are found in Figure 3.

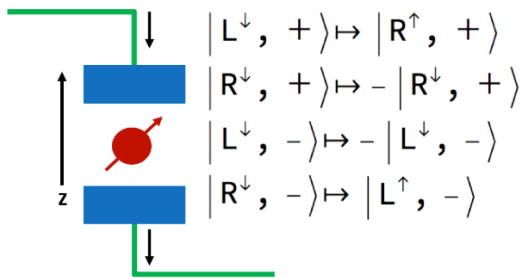


Figure 3. Photon transition rules after interacting with the GaAs/InAs quantum dot. The arrow superscripts indicate the direction of travel for the photon.

As was shown by Hu *et al.* [15,16] these interactions result in an entanglement between the photon polarization and electron spin. If we

start with a right circularly polarized state $|R\rangle$ and send it through the quantum dot from above we can see from the transition rules that this results in a state

$$|\Psi\rangle = -k_1 |+\rangle|R\rangle + k_2 |-\rangle|L\rangle \quad (2)$$

From Eq. (2), we see that if we were to measure the electron state, a measurement of spin down would result in right circularly polarized light and a measurement of spin up would result in left circularly polarized light. Likewise, measuring the state of the photon would give the state of the electron. Thus, the photon and electron are entangled following the interaction of the light with the quantum dot. Their states are perfectly correlated.

Alongside GaAs/InAs quantum dots, our Deutsch gate protocol uses half-wave plates, quarter-wave plates, mirrors, π phase shifters, linear polarizing beam splitters, and circularly polarizing beam splitters. The wave plates affect the polarization of the light as described by Peatross and Ware [18]. The π phase shifters just induce a minus sign on the state of the photon. Mirrors invert the polarization of the light switching $|R\rangle$ to $|L\rangle$ and vice versa. The linear polarizing beam splitters send the horizontal component of light in one direction and vertical light in the other. Similarly, circular polarizing beam splitters send right circularly polarized light one way and left circularly polarized light another. In the diagram of the Deutsch gate seen in Figure 4, horizontally polarized light passes through linear polarizing beam splitters, while vertically polarized light is reflected. For circularly polarizing beam splitters, the right circularly polarized light transmits, while the left circularly polarized light reflects.

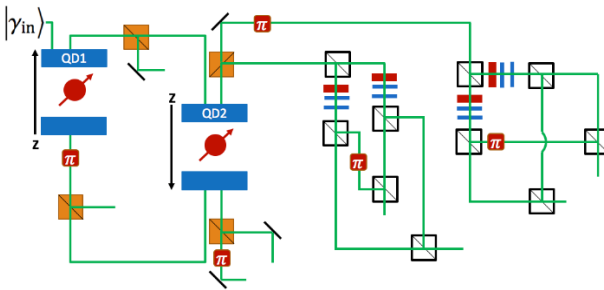


Figure 4. Schematic of the proposed circuitry for a universal Deutsch gate. The meaning of symbols and icons is detailed in the text.

The full Deutsch gate protocol is displayed in Fig. 4. The two GaAs/InAs quantum dots are labeled QD1 and QD2. The green lines

represent the paths the incident photon may take. Mirrors are represented by diagonal black lines. The red squares indicate paths phase shifted by π . Thick red lines represent half-wave plates, while thin blue lines represent quarter-wave plates. The orange beam splitters are circularly polarizing, while the white beam splitters are linearly polarizing. Notice that each quantum dot has a different reference axis indicated by an arrow labeled z , which affects the transitions that happen between it and an incoming photon.

The protocol starts with an incident photon in the polarization state $|\gamma_{in}\rangle = \alpha|R\rangle + \beta|L\rangle$, where $|R\rangle$ represents a right circularly polarized state, $|L\rangle$ represents a left circularly polarized state, and α and β are normalized constants. The electrons in the quantum dots start out in the spinor states $|e_1\rangle = c_1|+\rangle + c_2|-\rangle$ and $|e_2\rangle = d_1|+\rangle + d_2|-\rangle$, where $|+\rangle$ and $|-\rangle$ represent the electron in each quantum dot being in the spin-up or spin-down state, respectively, with respect to the z axes labeled in Fig. 4, and c_1 , c_2 , d_1 , and d_2 are all normalized constants. Note again that each electron state is defined according to different axes as indicated in Fig. 4. Our circuit transform our three-qubit input state $|\Psi_{in}\rangle = |\gamma_{in}\rangle|e_1\rangle|e_2\rangle$, according to Eq. (1) with $|a\rangle = |e_1\rangle$, $|b\rangle = |e_2\rangle$, and $|c\rangle = |\gamma_{in}\rangle$, into a new three-qubit state

$$|\Psi_{out}\rangle = c_1|+\rangle d_1|+\rangle [i\cos\theta(\alpha|R\rangle + \beta|L\rangle) + \sin\theta(\alpha|L\rangle + \beta|R\rangle)] \quad (3) \\ + c_1|+\rangle d_2|-\rangle (\alpha|R\rangle + \beta|L\rangle) \\ + c_2|-\rangle (d_1|+\rangle + d_2|-\rangle) (\alpha|R\rangle + \beta|L\rangle),$$

or equivalently

$$|\Psi_{out}\rangle = c_1|+\rangle d_1|+\rangle [i\cos\theta |\gamma_{in}\rangle + \sin\theta |\gamma_{in} - 1\rangle] \quad (4) \\ + c_1|+\rangle d_2|-\rangle |\gamma_{in}\rangle + c_2|-\rangle |e_2\rangle |\gamma_{in}\rangle,$$

where each of the eight circularly polarized terms in Eq. (3) correspond to a separate output beam in Fig. 4. We see that $|\gamma_{in}\rangle$ is unchanged except for when each quantum dot's electron is in the $|+\rangle$ state, in which case it undergoes a transition described by Eq. (1). Here, $|\gamma_{in}-1\rangle$ represents the ket of $|\gamma_{in}\rangle$ having undergone a NOT operation where the polarization is inverted. Thus, $|\gamma_{in}-1\rangle = \alpha|L\rangle + \beta|R\rangle$. Note, also, that each electron stays in its initial spinor state as can be seen from the GaAs/InAs quantum dot transition rules in Fig. 3. Thus, our circuitry achieves the Deutsch gate with the flying photonic qubit acting as the target qubit and the two electron spins acting as control qubits.

Results: A Universal Set of Elements

We showed that a Deutsch gate could be created with GaAs/InAs quantum dots and linear optical elements. The Deutsch gate is a universal

quantum logic gate, and a series of Deutsch gates can achieve any quantum computational task. This means a fully functional quantum computer could be created with Deutsch gates. The Deutsch gate has several advantages over universal sets currently used in quantum computing. First, the universal sets typically used consists of at most two-qubit gates. This creates difficulty when implementing operations that use more than two qubits. As mentioned in the introduction, a minimum of five two-qubit gates is required to implement the Toffoli gate. On the other hand, a single Deutsch gate with $\theta = \pi/2$ results in the Toffoli gate. So, the Deutsch gate is better suited for some purposes than current universal sets. Second, the Deutsch gate also simplifies quantum computing because, in contrast with a universal set, it requires only achieving a high fidelity for one type of gate rather than for several.

A proposal by Shi [9] to create a Deutsch gate using Rydberg blockade of neutral atoms is the only other Deutsch gate proposal currently available. Shi's protocol tunes the angular dependence θ of the Deutsch gate by adjusting the laser field strengths. In contrast, our protocol just requires changing the angles of two half-wave plates to affect θ . Shi's protocol does not use flying qubits like ours does. This means that connecting gates may be more difficult using Shi's protocol. On the other hand, Shi's protocol may be better suited for storage than our own. Both proposals have the potential for high fidelities. Under realistic conditions, Shi predicted fidelities as high as .992 for the Deutsch gate using Rydberg Blockade of neutral atoms. The detailed analysis of the fidelity of the presently proposed Deutsch gate is beyond the scope of this contribution, and we intend to publish it elsewhere. We found that under realistic conditions, a fidelity as high as .975 could be reached for this Deutsch gate and changes negligibly with θ . That is to say that 97.5% of the time our Deutsch gate protocol would result in the intended output state.

Possibly because of the fact that the Deutsch gate has not been considered in the past, there is a lack of algorithms that utilize the Deutsch gate. Deutsch gates can complete any quantum computational task, but how? In a sense, the Deutsch gate is a solution waiting for a problem. Some computations are likely simpler to implement using the Deutsch gate, but few have been identified. Significant progress could result from additional algorithms that utilize the Deutsch gate. Finding smaller quantum computational tasks fitting for the Deutsch gate would take advantage of its universality. This could take the form of finding new gates that the Deutsch gate implements quickly similar to the Toffoli gate. More applications of our design can be found elsewhere [17].

A universal Deutsch gate can be created with quantum dots and optical elements. This gate could lead to more efficient and more

accessible quantum computing. The Deutsch gate could at least prove more useful than current universal sets for certain quantum computational tasks; implementing the Toffoli gate serves as an example of this. In addition, the lack of multiple gates simplifies the need for each type of gate to reach a high fidelity.

This contribution also further verifies the usefulness of GaAs/InAs quantum dots for quantum computing. Bonato *et al.* [10] and Kim *et al.* [12] found efficient applications in quantum computing with these GaAs/InAs quantum dots. However, the fact that a Deutsch gate can be created with these quantum dots means that any quantum computational task can be completed with them. Since the Deutsch gate is universal, the elements that make up a Deutsch gate can be considered—in some sense—a "universal set of elements."

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“Ripple in Still Water”: Psychedelic Rock Resistance

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Abstract

Psychedelic rock music sprang from a fascinating amalgam of influences, but perhaps none more so than the Beat Generation. Several Beat authors and poets had settled in San Francisco in the 1950s, sowing the seeds of countercultural dissent and advocating the use of mind-expanding drugs as a pathway to freedom from the quintessential American status quo. At the same time, a Cold War ethos that encompassed a brutal and costly war in Vietnam provided an unsettling and disillusioning sociohistorical backdrop to the era. These elements would have a profound influence on the counterculture in the San Francisco Bay Area, including the psychedelic rock bands from this milieu who would sing their own particular brand of resistance music in their time. This paper is an exploration of psychedelic rock music through a theoretical framework that builds on dramaturgical approach as well as oppositional culture and resistance theories—a framework that can be equally termed performance as resistance as well as oppositional performance. Through a content and thematic analysis of the lyrics of selected psychedelic rock bands, the paper will reveal frank oppositional performance in the psychedelic music era.

Introduction

Along came LSD and that was the end of that whole world. The whole world just went kablooeey.... It changed everything, you know. It was just—ah, first of all, for me personally, it freed me, you know, the effect was that it freed me because I suddenly realized that my little attempt at having a straight life and doing that was really a fiction and just wasn't going to work out.

(Jerry Garcia quoted in Wenner and Reich 1972)

This quote from Jerry Garcia, legendary member of the Grateful Dead, encapsulates significant themes in the psychedelic rock era. The quote is all about a fascination with and sense of enlightenment from the use of mind-expanding drugs—in this case, LSD. In addition, the quote describes an entire sea change in Jerry Garcia's worldview, removing a profound obstacle to realizing his full self and potential. That obstacle is “having a straight life” or a conventional, status quo, American life—which is so intolerable and constraining that he needs to be “freed” from it. Here we have just a few elements of a more far-reaching resistance counterculture in this era.

This paper is an exploration of psychedelic rock music as a form of resistance to the mainstream sociohistorical context. Psychedelic rock reflects the alienation, disenchantment, and consciousness-raising of mainly young, middle-class whites in the San Francisco Bay Area. The paper examines some of the influential psychedelic artists of this era by drawing on oppositional and resistance theories as well as the dramaturgical approach to create a conceptual lens we can call *performance as resistance*, or similarly, *oppositional performance*.

Oppositional Performance: Resistance in the Psychedelic Rock Era

Psychedelic rock music made its appearance in the San Francisco Bay Area in the Sixties. The genre would become a signifier of a new worldview that openly defied the social mores of the American mainstream. Psychedelic artists would question and subvert long-standing American values, institutions, and leadership. Drawing together an array of influences, the music would have its day in the public eye and would be part of a growing number of musical genres that questioned the status quo. We will start with a few major influences on this new musical genre.

Turn on and tune in

In the early 1950s, some Beat poets and writers drifted west from their original homes in New York City to San Francisco, where poet James Ferlinghetti would establish City Lights Bookstore and Allen Ginsberg would organize “Six Poets at the Six Gallery,” both in 1953 (Szatmary 2007: 146, see also Farber 1994). Framing their philosophy as a quest for “Beatitude” within Zen Buddhism, the Beats considered the bums of the Bowery, from their old haunts in New York, to be the beatified souls of their anti-establishment ethos, and the beats of jazz and folk rock artists as the ethos’s soundtrack (Farber 1994, Szatmary 2007). The Beats “found little nourishment in the early marriage/new car/TV/suburbs” that were so much a part of quintessential, materialistic American life and sought freedom through the use of mind-expanding drugs—drug trips were a requisite for “psychic exploration” and “a higher wisdom of the body and soul” (Farber 1994: 172).

Although the Beats would leave San Francisco—under attack on several establishment fronts, but notably from then-FBI Director J. Edgar Hoover—several would return in the Sixties to have a lasting and profound influence on what would come to be known as the “counterculture” in the Bay Area. The vanguard of the counterculture were the long-haired youth—the “freaks” and “hippies”—who were mainly young, middle-class whites who took their cue from the Beats, denouncing the middle-class norms and values of their Depression-era parents (Farber 1994, Szatmary 2007). Hair was grown long, nudity was encouraged, sexuality was freely and fluidly expressed, and mind-expanding drugs were commonly used and encouraged (Farber 1994, Szatmary 2007). Moreover, as noted by historian Arnold Toynbee, these youth repudiated

the affluent way of life in which making money is the object of life and work . . . They reject their parents’ way of life as uncompromisingly as Saint Francis . . . rejected the rich cloth merchants’ way of life of his father in Assisi . . .

(Toynbee 1967: 1)

Interestingly, Farber suggests that it was “the counterculture, more than the antiwar or Black Power groups, that seemed to many older Americans to be most threatening to their families and loved ones” (1994: 168).

A cold war

The old-world order of their parents had much to answer for in the minds of the counterculture. The youth “who flocked to the Haight” viewed their parent’s world as rife with hypocrisy, doomed by “spiritual and emotional impoverishment,” and blind to a plethora of societal ills (Echols 1999: xii, see also Farber 1994, Szatmary 2007). The parents of the counterculture bought wholesale into a Cold warrior nationalistic bubble, bunkered down within affluent, suburban, white middle-class nuclear families (May 1988:8). May suggests that “the powerful political consensus that supported cold war policies abroad and anti-communism at home fueled conformity to the suburban family ideal” (May 1988: 198). The challenge, of course, would come from their children, the baby boom, who would create the counterculture.

A catastrophic offspring of the Cold warrior ethos was the war in Vietnam, which “seemed to most Americans and most policymakers so seamlessly a part of the grand Cold War adventure of the United States that they required only perfunctory explanation and legitimization” (Farber 1994: 117). Farber describes the escalation in graphic, human terms.

In 1961 there had been 3,200 American advisers; in 1963 there were 16,300; in 1964, 23,300. By the end of 1965 there were 184,300 American troops in Vietnam. In three years, 550,000 U.S. military personnel would be serving there. And by the end of 1968, 30,610 American servicemen had been killed in action. (Farber 1994: 145).

Moreover, this was a war fought mainly by disenfranchised young men, while young men from “America’s well-to-do suburbs and fashionable city neighborhoods chose not to enlist” or were able to obtain deferment (Farber 1994: 146). Interestingly, as Farber 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”—coincidental with the formation of Bay Area psychedelic rock bands (Farber 1994: 155).

The counterculture in the San Francisco Bay Area would call the Cold War American ethos into question in myriad ways. Wars, hypocrisy, and other societal ills would be measured and found wanting by psychedelic bands that emerged from this singular ethos, reflecting a countercultural consciousness.

Oppositional performance

Psychedelic artists were a remarkable reflection of disenchanted middle-class white youth who were sickened by the Cold War ethos and the war in Vietnam as they sought enlightenment from mind-expanding drugs and spiritual journeys. Psychedelic rock, then, was part of a profound cultural and social transformation—a reflection of the discontent of American youth who flocked to the Bay Area not only to wear flowers in their hair but also to question the order of things.

Mitchell and Feagin (1995: 68) introduced the theory of *oppositional cultures* or *cultures of resistance* to suggest that oppressed peoples historically resist oppression by drawing on their own rich cultural knowledge. They emphasized that oppositional cultures can serve “to provide an alternative construction of identity (one not based entirely on deprivation), and to give members of the dominant group an insightful critique of their own culture” (Mitchell and Feagin 1995: 69). Oppositional cultures, according to Mitchell and Feagin (1995: 73), can be many things, but particularly can find expression in artistic and cultural mediums. Mitchell and Feagin introduced oppositional cultures or cultures of resistance as emergent among people of color, and the theory also has broader applications for understanding and analysis of other oppressed and repressed groups.

The oppositional cultures that Mitchell and Feagin introduce also resonate with the work of Erving Goffman, specifically his dramaturgical approach (1959). Goffman describes the dramaturgical approach as a method of understanding the social world by literally looking at behavior as a scripted performance with human beings as actors on the public stage—actors who frame their actions with a consciousness of audience responses. In this regard, we offer front-stage and back-stage performances. In the front stage, we cater to the audiences we seek to influence or please. Back stage, we are our true selves—we take off or shed all fronts and “let down our hair.” Goffman’s framework is useful in discussing oppositional performance artists who are living in an atmosphere of repression.

It is the central argument of this paper that psychedelic music artists engaged in oppositional performances, providing “an alternative construction of identity” to the mainstream and giving “members of the dominant group an insightful critique of their own culture” (Mitchell and Feagin 1995:69). Psychedelic rock artists, as privileged, mainly white performers, offered a bold back-stage countercultural ethos in an era marked by societal repression and empty materialism, as well as a brutal war overseas (Goffman 1959, Mitchell and Feagin 1995). For psychedelic artists living this particular Sixties historical moment,

critical music was a bold act of *oppositional performance* or *performance as resistance*.

The Haight-Ashbury Phenomenon

Social scientists have a long-standing interest in popular culture (Benjamin 1969, Becker 1976; Frith, 1981, Hebdige 1988). Recent studies that look specifically at popular music cut a broad swath of interests (Booth 2011, Marshall 2011, Baker and Huber 2013, Barron 2013, Ertrachter et al. 2013, Morris 2013, Nauright 2013, Askin and Mausek 2017, Donze 2017, Van der Hoeven 2018). The current study is focused on psychedelic music as a deliberate oppositional performance art that spoke truth to power during a time of profound societal upheaval. Research in this area speaks directly to the countercultural era.

Explorer scientists of alternate experience

First, an interesting slew of scholarly work looks at the Sixties countercultural era as an early hub of specific and unique societal transformations. Kirk (2007) explores the creation of the *Whole Earth Catalog* by Stewart Brand in 1968, suggesting that the catalog started out as sort of countercultural DIY and became a forum for pragmatic environmentalism. Turner (2008) also focuses on the *Whole Earth Catalog*, navigating the linkage between the Sixties counterculture and the World Wide Web. Turner asserts that

Together, the creators and readers of the *Whole Earth Catalog* helped to synthesize a vision of technology as a countercultural force that would shape public understandings of computing and other machines long after the social movements of the 1960s had faded from view.

(Turner 2008: 6)

Kaiser (2011) delves into an intriguing connection between the counterculture and, believe it or not, physics. A rogue group of Berkeley physics graduate students formed the “Fundamental Fysics Group,” who dabbled in everything from LSD to psychic mind-reading, planting seeds that “contributed to a sea change in how we think about information, communication, computation, and the subtle workings of the microworld” (Kaiser 2011: xvii, xix). Ott and Joseph (2017) take a fine-tuned look at the “Summer of Love” and find a unique blending of technology and mysticism. Achenbaum (2017) decries the fallout of the Summer of Love with sex, drugs, and rock and roll as central themes.

Slonecker (2017) notes that many countercultural communities dismissed feminist discourse and actualization, while becoming a marketed aesthetic by corporate and entrepreneurial interests. At the same time, Slonecker argues that the counterculture led to the creation of counter-institutions like underground newspapers and communes, redefined the family, and laid down the ground floor for today's ecological consciousness and the legalization of marijuana.

People in motion

In addition, a collection of captivating histories focuses on the era or particular artists, some through vivid personal accounts. Perry (2005) proffers a spectator's history of "the Haight-Ashbury phenomenon" that is itself a wry, thoughtful storytelling of the psychedelic era. McNally (2003) treads a path of consciousness with the Grateful Dead, faithfully chronicling their history as individuals and as a band. Gleason (1969) chronicles the story of the San Francisco sound and includes absorbing interviews with members of Jefferson Airplane and Jerry Garcia. Kramer (2013: 9) suggests that psychedelic rock music inspired into existence an actual "republic of rock," that influenced not only the counterculture of the Bay Area but soldiers fighting in Vietnam. Finally, a fascinating variety of works look broadly at particular years within the psychedelic rock era to offer anecdotes within collages of color, space, and depth as descriptors of what was going on in the Bay Area (Jackson 2015, Henke et al. 1997, Kubernik 2017).

In all, the Sixties countercultural era and psychedelic rock specifically look to be a time and a musical form that reimagined who we are as individuals and how we should respond to our society—a unique and transformational American moment. The present study will analyze the lyrics of artists from the psychedelic rock era, grounding analysis through a theoretical lens of *performance as resistance* or *oppositional performance*.

A Few Words on the Method

Music from the psychedelic rock era is the focus of this analysis, specifically a content analysis of resistance themes in the songs of two bands who played a significant role in the history of the psychedelic rock era from its inception—Jefferson Airplane and the Grateful Dead (Gleason 1969, Farber 1994, Perry 2005, Kramer 2013). This study uses an analytical rubric in which "analysis is conceived as an emergent product of a process of gradual induction...very much a creative act" (Lofland and Lofland 1995: 181-182). As Reinharz 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” (1992: 159). Guided by our theoretical lens, we will find that these psychedelic music artists shaped their *oppositional performance* or *performance as resistance* as a countercultural questioning of the Cold War standpoint of their parents’ generation.

Psychedelic Sound

Jefferson Airplane and the Grateful Dead both formed in the year 1965. Drawing on Mitchell and Feagin (1995) as well as Goffman (1959), we will find that both bands spoke deliberately to the hypocrisy of their time, embracing back-stage performances—letting their hair down literally and figuratively. Our psychedelic rock artists threw off pretenses and personas as they unleashed profound critiques of their parent’s generation—acts of *oppositional performance* for their time (Goffman 1959, Mitchell and Feagin 1995).

Everybody must get stoned

Psychedelic rock bands would lean in to the countercultural use of mind-expanding drugs like marijuana and LSD (Perry 2005, Friedlander 2006, Szatmary 2007, Kaiser 2011, Jackson 2015, Achenbaum 2017). They would also take their cue from music artists like Bob Dylan, who “had recorded a witty song about getting stoned,” and the Beatles, who were dropping “seductive” hints in their music and album covers that suggested they “were against the Vietnam War and conceivably trying drugs” (Perry 2005: 51, 50). Oppositional performance among psychedelic rock artists in the Bay Area was all about a countercultural life—unapologetically open to using LSD, pot, and other mind-expanding drugs in bracing back stage performance (Goffman 1959). Thereby, these artists provided “an alternative construction of identity” and “an insightful critique” of their parents’ Cold warrior generation (Mitchell and Feagin 1995: 69).

The song “White Rabbit” by Jefferson Airplane (1967) speaks directly to experiences with substances that alter consciousness, but also a journey or trip where one encounters an array of unique and sometimes threatening sights and sounds. The lyrics refer to Alice, who can provide guidance on the truth and nature of things—“go ask Alice, I think she’ll know.” Alice is a reference to the little girl in the Lewis Carroll novel who inadvertently travels to Wonderland (Carroll 1920), but her presence also suggests youth, innocence, and a journey “down the rabbit hole.” Of course, there is also the “white rabbit” itself—the herald and

sign that one has entered the altered state and the harbinger Alice chases on her journey.

The lyrics in the song suggest that substances or “pills” can alter perceptions of one’s self and the world—making one “larger” and “ten feet tall,” but also “small.” Moreover, users of substances—“a hookah smoking caterpillar”—can “call” one to a process of experimentation, growth, and transformation, as caterpillars turn into butterflies. But, interestingly, the “pills” provided by the older generation don’t provide anything of meaning—“the ones that mother gives you don’t do anything at all.” Perhaps, this is a reference to alcohol and tobacco as substances of choice for the parents of the counterculture, substances that don’t tend to provide enlightenment, growth, or transformation. Farber writes,

In the early 1960s, a majority of adult Americans used a nicotine “high” to get through their day (while prime-time TV and AM radio were ruled by alluring cigarette commercials). A vast majority of adult Americans regularly drank alcoholic beverages and many young people had seen their elders blasted more than a few times. But tobacco and alcohol were old highs.

(Farber 1994: 173)

In addition, there are elements in the song that indicate entities that try to harm or control Alice and perhaps the listener, but also intimate that there are ways to resist them. A first indication of this is the mention of “men on the chessboard” who “tell you where to go” but more importantly, the first line of the final verse, “When logic and proportion have fallen sloppy dead.” Taking a page from Alice’s journey, we can look at this line from several angles—drugs destroy one’s ability to reason or, alternatively, drugs happily obliterate our limited worldview. The line might also indicate disillusionment with a society gone very wrong. The loss of balance in the song seems associated with the failure of the White Knight, who is the trope of heroism but seems incapable of lucidity, and the evocation of the Red Queen, who is the murderous embodiment of hegemony in the novel and the song. Using the Red Queen in this context—the character in the Carroll book most likely to seek Alice’s death—is foreboding and smacks of larger issues such as war and violence. It could reference what Kramer describes as, “the dehumanizing violence of ‘the System’ of American consumer and military empire as epitomized by the war in Vietnam” (Kramer 1994: 5, Perry 2005). But, the song ends on a profound exclamation—“Feed your head!” This could be ingestion of mind-expanding drugs and it could also be educating oneself as a form of countercultural awareness—it could be both.

I read the news today, oh boy

Like the Beats, psychedelic rock bands offered insightful and intense countercultural critiques of the evils of their day “like prophets emerging from the community to address its deepest concerns” (Perry 2005: 53). One of the most pressing issues in the era was the war in Vietnam—the quagmire overseas that was costing so many thousands of lives (Farber 1994, Perry 2005, Kramer 2013). Psychedelic rock bands entered the scene firmly grounded in back-stage performances that provided “members of the dominant group an insightful critique of their own culture” (Goffman 1959, Mitchell and Feagin 1995: 69).

The song “Uncle John’s Band” by The Grateful Dead does not at first glance look to be an anti-establishment song let alone an anti-war song, but there are some hints in the lyrics that point to just such a message. Throughout the song, there are intimations of grave and imminent threat, including references to the U.S. government’s predilection for war—perhaps allusions to the war in Vietnam. This foreboding is balanced by suggestions that there are means of escape.

The intimations of danger in “Uncle John’s Band” are at times obvious, as in the line “there is danger at your door,” but there are also more subtle, opaque warnings that deserve unpacking. The reference to a “buck dancer’s choice” is one such opaque warning and may refer to a poem of the same name by James Dickey. In the poem, a man’s mother is dying of a respiratory illness while whistling a song called “Buckdancer’s Choice” about the “buck-and-wing men”—freed black men who performed solo tap dances, originating in the South (Dickey 1965: 21, see also *The Old Farmer’s Almanac* 2020). Dickey suggests they are dying out—“the last dancers of their kind”—as is his mother. The fairly profound implication of the lyric is that the listener could be in grave danger if they don’t “take my advice.” The lyrics further suggest that the listener knows what is going on—the “fire from the ice”—perhaps a reference to Robert Frost’s poem “Fire and Ice” in which the end of the world is described as coming through either the destructive force of fire or ice (Frost 1920: 67). Again, another foreboding image.

In the third verse, the cause of all the danger seems suggested by the lyrics, “Goddamn, well I declare, have you seen the like?/Their walls are built of cannonballs, their motto is ‘Don’t tread on me.’” This lyric seems unquestionably a critique of the U.S. government—the motto “Don’t tread on me” was part of the Gadsden flag, designed during the American Revolution (Leepson 2007:10). The reference to “their walls” and “their motto” disavow support of said government. The lyrics

suggest that war is an old story told by the crow—"the only one he knows" involves death and feasting on remains. There is also a reference to the ephemeral nature of life in the line "like the morning sun you come and like the wind you go"—lives of soldiers in wartime are so fleeting. Then the lyrics assert, "Ain't no time to hate, barely time to wait"—when hundreds of young men are dying each month, "where does the time go?" The lyrics could also be referencing the Emily Dickinson poem, "I Had No Time to Hate," in which the protagonist of the poem finds life too short to spend on the "ample" enmity of hate, but can find time for love, which exacts only "a little toll" (Dickinson 1960: 478, see also Adams 2017). Finally, there is an opaque reference to living in a silver mine that is also called a "Beggar's Tomb"—again, an intimation that life is fleeting, but perhaps also an admonition against materialism with the implication that one should be focused on what matters most.

Which brings us to the counternarrative within the song—the answer to the wars and rumors of wars the song describes. The lyrics assert that the response to "Don't Tread On Me" is to come away and "hear Uncle John's Band" who will "take his children home." It is implied the children are away from home and need help and guidance to come back—perhaps young men away overseas at war. The song ends with chorus after chorus—four in all—that plead with the listener to leave behind the walls of cannonballs, the murder of crows, and the silver mine to hear Uncle John's Band "by the riverside." Uncle John has "got some things to talk about" and he has "come to take his children home"—a place, it is suggested, that offers comfort and peace. There is one thing more. The lyrics include a significant question raised earlier in the song, but that carries weight throughout the song—"what I want to know is, are you kind?" In many ways, this is the summation of the song and suggests that the only thing that matters is how we treat each other. As Kramer suggests, psychedelic rock

...offered great fun and a chance to enjoy the pleasures of sound, light shows, psychotropic substances, spirituality, erotic encounters, and communal fellowship. At the same time, escaping into the music also led back to engagement. Rock allowed listeners to probe the nature of human individuality, liberty, freedom, community, commitment, and coercion.

(2013: 11)

Take a sad song and make it better

As Calonne suggests, "the nation's gross injustices... made it impossible for the Beats to avoid rebelling against their society's

hypocritical ‘values’ (2017: 6). Instead, they searched for beatitude—for some form of “heavenly connection”—through various approaches, including mind-expanding drugs but also Zen Buddhism, Tarot, shamanism, and even Catholicism (Calonne 2017). Just so psychedelic rock bands rejected the materialism and hypocrisy of their parent’s generation as they searched for “heavenly connections,” offering an alternative countercultural worldview and spirituality. These artists grounded their intrepid back stage performances within an alternate identity that was critical of the dominant mainstream culture (Goffman 1959, Mitchell and Feagin 1995).

The song “Ripple” is another collaborative piece from Jerry Garcia and Robert Hunter. The song practically “glows with the gold of sunshine” even on a first read, establishing a countercultural ethos in direct contrast to the “new car/TV/suburbs” that were so much a part of their parents’ generation (Jackson 2015: 171). Leaving aside the chorus for the moment, the verses unpack like a stream of consciousness-raising that speaks to life, adversity, moral choices, and what matters.

There are several allusions and suggestions in the lyrics of the song “Ripple” that indicate the vacuous nature of a materialistic world, which is contrasted with the significance and meaning of a world that has rejected materialism. Music glows with “the gold of sunshine”—not the hard, cold, heavy bars that pass for substance in a society hitched to affluence. Music is played on a “harp unstrung”—not those featured in posh salons. An unstrung harp is perhaps a reference to the human voice, a harmonica—known as the French harp—or, as one scholar asserts, “changing contexts and cultural expression” (Bender 2015). The listener is part of the process in a song’s own unfolding and has the capacity to take the song in and “hold it near as it were your own,” much as psychedelic rock bands embraced audiences as family—but once again in contrast to their parents’ generation with “an audience viewing the musician-elite from distant fixed seating” (Friedlander 2006: 188-89, see also Farber 1994). Further, songs themselves, according to the lyrics, are very human and flawed creations, a “hand-me-down” made up of broken thoughts that may have been “better left unsung”—not a picture-perfect part of their parents’ middle-class suburban world. Regardless, the lyrics suggest that this is immaterial—“don’t really care”—the song will be sung perhaps for the very reason that it is human, flawed, and messy, so “Let there be songs to fill the air.”

At the same time, there is a distinct ethic of caring and interdependence in the song as well as an intimation that what is of real value is open to all. The lyrics offer concrete support to those in need, asking the listener to reach “out your hand if your cup be empty,” while offering words of encouragement even if the listener’s cup is full—“may

it be again.” Then, perhaps more tellingly, there is mention of a “fountain that was not made by the hands of men” that implies some sort of universal—perhaps a natural spring or a spiritual place, or simply a state of mind where people can find solace and peace. Whatever, the implication is that the “fountain” is there for everyone and not bound by the “plastic death culture that organized life around a workable lie of Cadillac dreams, prime-time TV, and a forty-hour week” (Farber 1994: 170).

Beyond the references to the nature of music and the ethic of caring, allusions to significant life choices frame the last part of the song. The lyrics reference a road that is “no simple highway,” not easily traveled, that lies somewhere “between the dawn and the dark of night.” The road could perhaps be a reference to the narrow gate of the New Testament whose sacrifices lead to heaven (The Holy Bible: King James Version 1976), or perhaps the eightfold path to enlightenment that is part of Buddhist teachings (Okawa 2002: 335). Whatever the road is, it falls in the light of day where we often make the individual choices that define our character as human beings—“that path is for your steps alone.” The lyrics further state that “you who choose to lead must follow,” which is perhaps a reference to leadership from Buddhist or Christian teachings in which humility is paramount (The Holy Bible: King James Version 1976). The lyrics further state, “But if you fall, you fall alone,” then ask, “If you should stand, then who’s to guide you?” and further state, “If I knew the way, I would take you home.” There is an indication that taking a stand on anything is a difficult and lonely road that each individual must choose within their own heart.

Finally, the chorus that winds through this spiritual journey seems a sort of riddle, affirmation, and benediction in one about the nature of life and perhaps the song itself:

Ripple in still water
When there is no pebble tossed
Nor wind to blow

(The Grateful Dead 1970)

The chorus is uniquely brief and is suggested to be a 17-syllable *haiku* that attempts to explain an altered state of being (Dodd 1995-2006), or alludes to the “still waters” in the 23rd Psalm (Dead.net 2013). In any case, what does seem apparent is that the chorus is describing what is essentially indescribable, because neither human beings nor nature are causing the ripple “in still water when there is no pebble tossed nor wind to blow.” Perhaps the ripple is a spiritual essence or entity, affirming the significance of things we cannot see but know to be

significant nonetheless. As the Beats sought for “heavenly connections,” so the Dead grasped for what could not be explained with a song that takes the listener along a journey of enlightenment. Kramer suggest that artists like the Grateful Dead, Jefferson Airplane, and other psychedelic rock artists

...generated a radically pluralistic spirit of democratic belonging...by connecting everyday life to grand-historical transformations. This is why participants and observers alike have often emphasized the spiritual dimensions of rock...The Grateful Dead, the Airplane...played the music that was our hymnal.

(Kramer 2013: 20)

The foregoing analysis focuses on psychedelic rock bands in the Bay Area whose music was part of a countercultural ethos, tackling the use of mind-expanding drugs, the evils of their day, and a movement toward a spiritual life. The bands framed their performances in the back stage for all to see who they were and what they believed in (Goffman 1959), and each rendered a construction of identity in direct opposition to and critique of the mainstream of their day (Mitchell and Feagin 1995).

Conclusion

In his preface to Charles Perry’s spectator history of the Haight-Asbury scene, Bob Weir, founding member of the Grateful Dead, writes

We haven’t seen the end of what happened in the Haight. Actually, we’re seeing a backlash from it now, forty years later, which confirms how powerful it really was. The dark minions who can’t abide natural buoyance or the notion of self-generated enlightenment never tire of trying to stamp out the fire we got started there, but that won’t happen.

(Perry 2005: 4).

Weir is reflecting on a time when the youth of the counterculture raised their voices to challenge the white, middle-class, suburban lives of their parents—a world that was “settled, compartmentalized and devoid of high deeds and adventures” (Perry 2005: 4). These youth drew outside the lines with the effect of changing the nature of things—from hairstyles and communes, to physics and the internet, and finally perhaps to “a greater tolerance for deviant behavior and...alternative lifestyles” (Perry 2005: 266). The literature on the psychedelic era documents and

interrogates these profound changes. More tellingly for the current study, the sociohistorical landscape that produced the psychedelic era created some of the most memorable and lasting music of the 20th century and even today—artists like the Grateful Dead and Jefferson Airplane, to be sure, but also other artists that were not covered in the interest of space.

The present study explored the sociohistorical context of the psychedelic rock era while drawing on lyrical analysis of selected artists—psychedelic bands who embraced bold back-stage performances for audiences that were like family. These artists brought lessons to bear from their Beat mentors as they critiqued, challenged, and renounced the starched, straightjacketed, suburban materialism of their parents' generation. The songs unpacked in the analysis reflect on the era and articulate the nature and consciousness of the counterculture—speaking to journeys of transformation and experimentation as well as spiritual growth and enlightenment, while utterly repudiating their parents' conspicuous consumption and the slaughterhouse of wars, Cold or otherwise. It is a music and a generation that is present anytime someone questions authority, searches for truth, or advocates for peace. As Bob Weir suggests, once envisioned, once created, the counterculture has never left us.

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Abstracts

ARTS

Switching Channels: Information Theory and the Rise of Contemporary Art

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By the mid-20th century, it seemed the visual arts had achieved the ideal plateau that Clement Greenberg and other theorists had predicted for nearly thirty years. Abstract and nonobjective, it shunned narrative and representation for the universal expression and experience of the painter's mark. Pollock, de Kooning, Rothko were the benchmarks of the era. Yet within a decade, the gestural drips and color-fields of Modernism would be supplanted by an odd assortment of soup cans and comic panels; performances, new media, installation and conceptual art. This wave of disruptive innovation overwhelmed the art world, and Modernism, ironically, became so associated with the past, that a new term, Contemporary, had to be coined. As shocking as this revolution was, it might not have caught art critics and theorists off guard, had they been aware of the work of Claude Shannon. The founder of Information Theory, Claude Shannon was concerned with information systems and telecommunications, but his theories have since found broader application in the fields of economics and even biological evolution. The current study attempts to demonstrate that the never-ending hunt for novelty and innovation in Contemporary Art is related to the field of Information Theory. My paper attempts to see Contemporary Art as a classic information system, with its own signals, noise and channels. Moving to new media or experimental forms in contemporary art fits the classic archetype for dealing with "noise" that is disruptions in messaging in information systems by switching to a channel that is quieter or overlooked. The first generation of contemporary artists, overcome by the noise of modernism, switched channels, and thus changed the paradigm for art, and the art world has been switching channels ever since.

ARTS

The Holocaust, Sigmund Freud, and Anna Sokolow

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World War II. The Holocaust. These cultural touchstones have permeated the general consciousness of the global populace, infiltrating the unconscious minds of millions of people even today, namely, the Jewish population. This research will demonstrate that Anna Sokolow, an influential modern dance choreographer in the mid-20th century, was one such Jew. Her piece *Dreams* (1961) has been lauded as an important Jewish choreographic work showcasing the horrors of the Holocaust that was realized from the nightmares Sokolow was experiencing at the time. Current scholarship in dance research has concluded that dance reflects culture. Researchers can assume that dance, whether that be a general dance form or a specific choreographic work, is reflective of the culture at large and an individual's cultural microcosm. Sokolow's vivid nightmares, which served as the motivation behind her piece, according to Freud's dream theory, are a direct reflection of her repressed emotions. This psychoanalytic perspective originated from Sigmund Freud's concept of psychoanalysis as a way of talk therapy. Now, it is used as a frame of analysis to critically interpret the choices made when a creator is in the creative process to discern their unconscious motivations which will provide a fuller understanding of *Dreams*. Freud's dream theory offers a means to interpret one's dreams which explains a person's behavior through revealing their internal drives, motivations, and emotions. A critical analysis of *Dreams* and a synthesis of peer-reviewed source material through a psychoanalytic perspective utilizing Freud's dream theory will demonstrate the implications the Holocaust had on Sokolow's unconscious mind, as revealed through her dreams, resulting in her masterwork: *Dreams*.

ARTS

Classical Persian Art: Toward an Ecological Perspective

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Utah Valley University

The classical arts of Persia, meaning the arts of the region now known as Iran from roughly the 10th to 16th centuries, are renowned for their

combination of technical excellence and a strongly decorative aesthetic. Mosques and other buildings are clad in tiles forming intricate arabesques, geometric patterns, and calligraphic inscriptions; manuscript illustrations feature minutely detailed figures in shadowless landscapes of saturated colors; carpets, ceramics, and other utilitarian objects are ornamented with overall designs featuring floral, geometric, and occasionally figural decoration. In this paper, I suggest a novel way to think about these arts, along with the issues and questions raised thereby. The perspective from which I approach these arts may be termed “ecological,” as it is inspired by the branch of biology that studies organisms in relation to their environment. Understanding the creation of manuscript paintings, architectural decoration, and other arts in ecological terms, i.e., as a living being’s survival-directed modification of its environment, opens up interesting new possibilities and challenges of interpretation. For example, if Persian architectural decoration is to be explained on the same lines as we explain other animals’ interaction with their natural surroundings, the survival significance of such an activity has to be accounted for, including the apparent inutility of an effort seemingly aimed solely at pleasing the sense of sight. My analysis will suggest some answers to this and related questions, with the ultimate goal of forming a coherent methodology and research program.

ARTS

Ballet and Bonaparte: Understanding Napoleon Bonaparte's Lasting Influence on the Art of Dance

Golda Dopp

Utah Valley University

The purpose of the presentation is to explore Napoleon Bonaparte’s influence on the physical and fleeting art of ballet. His role as master choreographer of war has been studied extensively, with an exhaustive field of research relating to his manipulation of power. The intricacies of how he used dance for personal and national gain, and what lingering effects survive to this day, have been relatively untouched by scholars. This presentation outlines the political peregrinations of ballet surrounding and during the Napoleonic years from 1790–1815. Organization is chronological, with four main parts: how the Enlightenment helped ballet survive the 1789 Revolution and The Terror; what role dance claimed in the Revolutionary festivals and national fêtes of the Directory and Consulate; how Napoleon’s cultural

admiration of antiquity influenced ballet; and finally, how Napoleon's militant approaches shaped the discipline and pedagogy of ballet. The argument is made that the Enlightenment, combined with Napoleon's strategic adoption of ancient regime characteristics, were necessary in perpetuating ballet as an art form. Napoleon's military defeat against Russia enabled the rise and popularity of Russian ballet and marked a shift in French dance culture. The presentation is based on a written, 20-page essay article and targets a professional audience with little ballet experience. Brief demonstrations of ballet movement will be shown, and visual cues such as photos and diagrams utilized.

ARTS

Healing Trauma: Exploring a More Just Future & Working Towards Joy Through Artmaking

Audrey Reeves

Utah Valley University

Many students are experiencing trauma, including physical abuse, sexual abuse, emotional abuse, physical or emotional neglect, exposure to domestic violence, household substance abuse, household mental illness, parental separation or divorce, and incarcerated household members. Furthermore, they may be also experiencing societal oppression, such as inequality and discrimination based on race, ethnicity, gender, sexual orientation, social class, and disability. Art teachers regularly design projects that engage students in meaningful and relevant art experiences by encouraging students to interrogate and critique social problems, which may overlap with students' trauma. This may lead to art teachers hearing stories of trauma every day in the classroom. Art teachers wrestle with how to help students with trauma looking into a seemingly unhopeful future. The purpose of this paper is to provide curricular considerations for K–12 art teachers with students with trauma. It is important for an education curriculum to allow student choice and enable students to voice their narrative that may be intertwined with trauma and societal oppression. Although looking at students' past and present is useful, teachers should also empower students to create and imagine a more just and joyful future. Art education curriculum should not solely focus on the pain students experience but should allow students to escape and give room for fun within the art classroom. A curriculum should balance expression and working through and critiquing students' traumatic circumstances with imagining joy and escape.

BIOLOGICAL SCIENCES

Gluconate Metabolism by *Lactobacillus wasatchensis* Is Another Risk Factor for Late Gas Production in Aging Cheese

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Weber State University and Utah State University

Lactobacillus wasatchensis, a nonstarter lactic acid bacteria, can cause late gas production, splits, and cracks in aging cheese when it metabolizes a 6-carbon sugar, particularly galactose, in cheese to a 5-carbon sugar, resulting in the release of CO₂. Previous studies have not explained late gas production in aging cheese when galactose is not present. Based on the genome sequence of *Lb. wasatchensis* WDC04, genes for potential metabolic pathways were mapped using Knowledgebase Predictive Biology software (KBase). Modeling predicted that *Lb. wasatchensis* WDC04 could metabolize gluconate. Gluconate contains six carbons and *Lb. wasatchensis* WDC04 contains genes to decarboxylate it to ribose-5-P and CO₂ using phosphogluconate dehydrogenase. This study's purpose was to determine whether sodium gluconate, often added to cheese to reduce calcium lactate crystal formation, could result in gas production when metabolized by *Lb. wasatchensis*. Carbohydrate-restricted MRS (CR-MRS) was mixed with varying ratios of ribose, sodium gluconate, and/or D-galactose (1% total sugar content). Oxyrase (1.8%) was also added to create an anaerobic environment similar to aging cheese in the CR-MRS tubes. Tubes were inoculated with a 4-day culture of *Lb. wasatchensis* WDC04 and incubated at 30°C, and results were recorded over 8 days. Of the 10 ratios used, gas was produced in 6, with the highest gas production resulting from 1% sodium gluconate with no added ribose or galactose followed by the ratio of 0.3% ribose/0.7% gluconate (1% total sugar concentration). Assuming other strains of *Lb. wasatchensis* have the same genes for metabolizing gluconate and producing CO₂ gas, adding sodium gluconate during manufacture of cheddar cheese is another risk factor for growth of *Lb. wasatchensis* during cheese aging and subsequent unwanted gas production resulting in the formation of splits and cracks in cheese.

BIOLOGICAL SCIENCES

Structural Characterization of Junctional Adhesion Molecules

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Brigham Young University

Tight junctions are proteic structures in the apical portion of endothelial and epithelial cells. Their function is to create a barrier for tissues that protects them from unwanted substances. One of the strongest barriers maintained by tight junctions is the blood–brain barrier. Several membrane proteins are integral parts of tight junctions: claudins, occludin, tricellulin and junctional adhesion molecules (JAMs). Much has been researched about them except the small family of JAM proteins. There is a lack in understanding as to the role of these proteins in tight junctions. A proper characterization of these proteins is needed to understand their adhesion properties and protein–protein interactions with other members of the tight junctions. Here we report for the first time in the literature, the oligomeric state of each member of the JAM family, their constants of affinity for self-association and for association with other JAM proteins and other tight junction proteins. We resourced synthetic biology and surface plasmon resonance to obtain our results. With this information, we describe a possible mechanism of assembly and maintenance of tight junctions.

BIOLOGICAL SCIENCES

The Effect of Urbanization on Genetic Diversity in Southern Utah Ant Populations

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Southern Utah University

Urbanization can have profound effects on habitats and the plant and animal species found within them. The increase of urbanized areas worldwide can have limiting effects on genetic and species diversity by reducing gene flow and disrupting ecosystem functions. Ants (Formicidae) are found worldwide and are considered indicators of ecosystem biodiversity and health. This research characterized the population genetic structure of ant populations in urban and nonurban areas of southern Utah. We collected ants from several locations in Cedar

City (Canyon Park, Lake on the Hills, along Main Street; urban), Southern Utah University Mountain Center (nonurban), and Three Peaks Recreation Area (mixed-used public land). Ants were classified to their genus with morphological characteristics using a modified dichotomous key. Biodiversity was highest in Cedar City (Shannon Diversity Index, $H' = 1.503$; evenness, $E = 0.840$) and lowest in Three Peaks Recreation Area ($H' = 0.817$; $E = 0.589$). DNA was extracted and amplified at 10 microsatellite loci for 201 ants. Population genetic parameters were compared among urban, nonurban, and mixed-use areas to investigate the effect of urbanization on ant genetic diversity. Ants in the genus *Formica* were moderately diverse in Cedar City (gene diversity was 0.764) and SUU Mountain Center (gene diversity was 0.689). Ants were more inbred in Cedar City ($FIS = 0.607$) than at the Mountain Center ($FIS = 0.488$). Similar patterns were estimated in *Dorynomymex* and *Lasius*. Ants in each genus were more related than expected in all localities, which suggested that ants within a locality may have been collected from one colony. Our results suggested that urbanization may not have a large effect on species and genetic biodiversity in ant populations in southern Utah. A longer-term study may provide more insight into how urbanization impacts ant biodiversity.

BIOLOGICAL SCIENCES

Reduction of human cytotoxicity by the brain-eating amoeba *Naegleria fowleri* due to drug and complement inhibition

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Naegleria fowleri is a free-living amoeba that is capable of parasitizing the human central nervous system. *N. fowleri* is the causative agent of primary amoebic meningoencephalitis (PAM), which has a fatality rate of ~98%, with diagnosis often only revealed postmortem. It is hypothesized that *N. fowleri* possesses a protein similar to that of human CD59 complement regulatory protein, the CD59-like protein. The CD59-like protein is believed to play an important role in the infection process by preventing the amoeba from being lysed by the complement system. *N. fowleri* were treated with combinations of anti-CD59 antibody and the experimental drugs amphotericin, azithromycin, and miltefosine. Measurements of cell death in *N. fowleri*, as well as the survival of infected human cells, revealed that the CD59-like protein was

neutralized by antibody and the relative effectiveness of these drugs. These findings provide initial steps toward effective treatment of devastating PAM infections.

BIOLOGICAL SCIENCES

Fermentation of Plant-based Extracts by Dairy Lactic Acid Bacteria

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Weber State University

Plant-based fermented foods to replace milk-based fermented foods, such as yogurt and cheese, have become a growing cultural necessity. These products are currently being produced using dairy fermentation cultures and processing equipment. Therefore, it is necessary to determine whether dairy-derived lactic acid bacteria (LAB) cultures can effectively ferment plant-based milk substitutes. Initially, selected dairy bacterial strains were profiled for carbohydrate utilization using API CH50 carbohydrate panels to determine whether they can ferment the types of sugars available in plant extracts. Three plant-based extracts (almond, coconut, and oat) were incubated with specific LAB cultures at 3 inoculum levels, and the pH was monitored over 420 minutes of incubation at 37°C. Results showed that fermentation (acid production) is LAB strain-dependent based upon the type of plant extract being fermented. Only two LAB strains could ferment coconut and almond extracts (YFL01 and YFL02), while most LAB tested could ferment oat extract especially at the lower inoculum levels required for commercial production.

BIOLOGICAL SCIENCES

Microbial Load Reduction in Athletic Locker Rooms Using Ozone Treatment

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Weber State University

This research was conducted to determine whether a commercial ozone generator was effective in reducing *Staphylococcus aureus* and *Escherichia coli* in an athletic locker room and to determine its

limitations. Petri plates (TSA media) inoculated with a nonpathogenic strain of either *S. aureus* or *E. coli* were put in strategic locations in triplicate in collegiate locker rooms. Lids were removed from the inoculated petri plates, and 2 ozone generators (Extreme Ozone Co.) were run for 120 minutes (trial 1) or 180 minutes (trial 2). Inoculated plates were placed from 3 to 70 feet from each ozone generator. Distance from the ozone generator, height of the plates, time exposed to ozone, and whether the plates had obstructed airflow were measured. After ozone infusion, petri plates were incubated for 48 hours at 37°C. Two hours into the run cycle, average ozone readings increased from a background of 17 ppb to 1042 ppb at ground level and 1344 ppb 1.5 m above ground level. Results for trial 1 showed an overall *S. aureus* reduction of $78.7 \pm 8.3\%$, while trial 2 showed an increase in the overall reduction to $93 \pm 1.8\%$. In trial 2, results for *E. coli* survival showed an overall reduction of $89.6 \pm 3.0\%$. On average, a plate in an obstructed location such as a cabinet or foot locker had a 24% decrease in kill rate compared with similar plates, which increased to 38% when looking exclusively at *E. coli*. Plates at a higher elevation trended toward higher kill rates than those at low elevations. These results show that ozone can reduce *S. aureus* and *E. coli* in locker rooms and that increasing the run time from 2 hours to 3 hours significantly decreases survival rates regardless of distance.

BIOLOGICAL SCIENCES

Can Automatic Hand Dryers Serve as a Microbial Reservoir for Contamination?

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Weber State University

Our purpose was to determine whether the hand dryers in public restrooms are antiseptic or if they are a source of contamination to hands during drying. The first phase was to determine restroom areas at Weber State University that had a high frequency of foot traffic, making them good locations for sampling. Testing was conducted by swabbing a 5-cm² area of the top, middle, and bottom of the hand dryers using a 3M Quickswab. Pour plates using TSA were made to enumerate samples. Testing was done in men's and women's restrooms in three buildings on campus, testing four bathrooms in each building. Plate counts were determined at 48 hours after incubation at 37°C. Results showed that the

bottom of the dryers in both the men's and women's restrooms had the most contamination, with an average of 311 CFU/5 cm² in the men's restrooms, and an average of 299 CFU/5 cm² in the women's restrooms. The middle section was the second most contaminated for both men's and women's restrooms, averaging 144 CFU/5 cm² for men and 145 CFU/5 cm² for women. The top was the least contaminated for both men's and women's restrooms averaging 107 CFU/5 cm² for men and 51 CFU/5 cm² for women. Both *Staphylococcus* (MSA plates) and coliforms (VRBA plates) were isolated from selected dryers. Results showed that these dryers serve as a source of contamination after hand washing, and the levels of contamination in the dryer can be correlated with the amount of foot traffic through the restroom and with men (higher levels of CFU) versus women. As a preventative measure, the inside of these dryers should be cleaned on a daily basis to prevent people from contaminating their hands immediately after washing them.

BIOLOGICAL SCIENCES

An Analysis of ITS1 in Two *Equisetum* Subgenera: Secondary Structure and Nonmetric Multidimensional Scaling

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Salt Lake Community College

ITS1 sequences were used to evaluate relationships between 19 *Equisetum* specimens representing 9 (of 15) species plus three hybrid taxa from subgenus *Equisetum* and subg. *Hippochaete*. Most of the sequences examined had comparable lengths (231 to 232 bp). However, *E. sylvaticum* (subg. *Equisetum*) had a 62-bp deletion, making it only 170 bp in length. Secondary structures were similar except that for *E. sylvaticum*. Nonmetric multidimensional scaling ordinations were conducted for 1) uncoded nucleotide sequences, 2) numerically coded sequence data, and 3) in silico-derived restriction site (presence/absence) data. In general, the ordinations tended to distinguish the two subgenera, although conspecific specimens did not always group together. The interspecific relationships obtained were at times inconsistent with other studies. Furthermore, *E. myriochaetum* (subg. *Hippochaete*) was placed quite close to, though distinct from, the subg. *Equisetum* specimens in some of restriction site data ordinations. Unrooted UPGMA and NeighborNet trees (networks) using GeneContent distances were used to further analyze the restriction site data. This study suggests that ITS1,

while useful in delimiting the subgenera, may not be as useful in elucidating relationships within or between closely related *Equisetum* species.

BIOLOGICAL SCIENCES

A Comparison of the Perceptions of Genetically Modified Organisms among Differing Religious Beliefs and Educational Backgrounds

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The perception of genetically modified organisms (GMOs) is an important and controversial topic today, particularly with information and misinformation coming from vastly different sources. Identifying perceptions of GMOs is pivotal to public health education and GMO implementation. Previous research of public perception is either outdated or is not correlated. This, along with a changing ecosystem, indicates an increased need for genetic modification of organisms to grow in different environments in order to meet the needs of the changing ecosystem. The objective of this research is to identify possible correlations in perception of GMOs among educational backgrounds and religious beliefs. The results of the study can be used for further application by public health officials in addressing educational needs among the correlated results. We will be using a survey with set questions to identify demographics and individual perception of GMOs. We will then use standard statistical analysis to identify correlations between educational backgrounds and religious beliefs. The results of this research can be used to further educate the indicated populations on GMOs and aid in the overall acceptance of GMOs in the United States.

BUSINESS

Plugged-In: Rural Readiness for Technology Industry

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Many rural Utah communities face major problems with declining economies. Rural communities in Utah may be an excellent place for

technology companies to expand. Adding to the problem, median incomes in nine rural counties is \$48,306 while the statewide median income is \$62,961 (US Census Bureau, 2017). Rural areas seem to be an untapped well of potential to help both the state's economy and technology companies themselves. This research explores how to effectively use that potential. The research identifies needs and limitations that currently exist in rural communities that can prevent or be seen as obstacles for technology industry growth in these areas. Research was conducted by looking into the viability of technology companies being able to expand and/or start up in rural Utah by exploring whether those areas are ready for the technology industry. Specifically, the research examines: 1. current educational opportunities related to technology in rural area school systems; 2. interest among potential workforce in technological fields; 3. presence of skilled workforce in these rural areas; 4. potential to form partnerships between higher education and high schools to offer better education and generate interest; and 5. infrastructure of rural areas to support growing technology industry. Additionally, obstacles that are preventing these areas from being able to support technology industry are found and examined. This research constitutes the first step in helping bolster rural economies through an increase of jobs and industry into those areas. By conducting extensive research and getting in on the front-lines of the problem, current situations are more understood and potential suggestions can be developed.

BUSINESS

A Pedagogical Model for Teaching Data Analytics in an Introductory Information Systems Python Course

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Brigham Young University

In this paper, we answer the call of Sheppard (2012) and Brunner & Kim (2016) and present a model for teaching data analytics in an introductory information systems class using Python programming language. The pedagogy follows an active-learning strategy in which students are assumed to have no statistical or Python programming training prior to class. the learning outcomes include: 1) data: write code to import and manipulate data; 2) visualization: write code to generate useful and theoretically sound data visualizations; 3) feature engineering: write code to generate, condense, or recombine variables (i.e., “features”) of

any type (numeric, categorical, ordinal, text) to provide the best possible predictive performance; and 4) prediction: write code to estimate the effect/weight of a set of feature variables on a label variable. The first portion of the course covers fundamental programming in Python similar to Frydenberg and Xu (2019), focusing on the specific areas of: variables and data types; input/output; flow control; functions; packages (installing, accessing); data sources (reading/writing); and data mining (CRISP-DM). The second portion of the course consists of students using their newly-learned Python programming skills to apply statistical data analytics. Empirical analysis includes student feedback from the Fall 2019 semester, the first time this course has been taught. We compare and contrast the feedback with Holman (2018) who covers similar material with differing pedagogy.

BUSINESS

The Impact of Video Games on College Academic Performance: An Empirical Analysis of an Introduction to Information Systems Class

Heber C. Brau, Finnegan McKinley, James C. Brau, James Gaskin
Brigham Young University

We extend our previous work along two dimensions. First, we include video game and social media factors to the portfolio of independent variables. Second, we use a dataset of information systems students as an alternative to marketing and finance students. To these variables shown to have explanatory power in the extant literature, we add over 40 additional questions that involve video game activity and social media activity. We conduct a survey with 197 respondents of college students in an introductory (200-level) information systems class. The survey provides our independent variables for our subsequent empirical tests. The dependent variable for our study is the total semester course grade each student earned. Example descriptive statistics from the data indicate that 74% of the students in the class played video games during the semester. The average age they started playing video games was 6.7 years, with a standard deviation of 3.2. In addition, 79.6% of student respondents who played video games indicated that their parents attempted to regulate their playing time before they left for college. Preliminary results indicate that students who played video games (indicator variable set equal to one if they played and zero otherwise) during the semester did no worse and no better than those who did not.

Additionally, the length of time students played video games (for those who played) indicated no significant impact on their course grade.

BUSINESS

Utah State Capital Resource Allocation: A Proposal for Increasing the Transparency of Capital Expenditures, Including Facilities

Nathan G Caplin, R. Neil Walter

Snow College

Capital expenditures are a unique challenge in state budgets because subdivisions of the state are rarely charged for using the state's debt or equity for facilities, equipment, and other investment needs. In an effort to take advantage of the current resource allocation process, state subdivisions lobby for capital expenditure appropriations. The result is an inefficient distribution of resources for capital expenditures within state budgets where the most-connected, best-funded lobbying efforts frequently win. This paper proposes changing the capital resource allocation processes by attaching a cost to state-appropriated capital expenditures in an effort to increase accountability and efficiency while improving the long-term credit strength of the state.

BUSINESS

Teaching Python Data Analytics Through External Object-Oriented Game Design

Heber C. Brau

Brigham Young University

The current practice of teaching data analytics typically begins by introducing Python code in the context of statistics. The author's experience of teaching the material under this pedagogical flow suggests that a superior approach is available to teach students Python data analytics. My observation has been that when trying to jointly learn Python and statistics, students are often confused by either the code, the statistics, or both. To help ameliorate this confusion, I introduce a method for teaching Python coding in the first part of a Python Analytics

class by first focusing on Python syntax and logic (and not statistics). The approach is based on online tutorials that walk students through programming a video game in Python. Through the video game, students efficiently learn proficiency in Python code in a fun way. This paper details the video game, Python code, and pedagogy involved in the process. I introduce an external and unique game-building framework of proprietary architecture. The second half of the course is similar to our previous work teaching statistical concepts that are operationalized in Python. An experiment is conducted with students, randomly assigned to either the traditional way of instruction or this new game design approach. Student feedback is used as qualitative data, and coding performance is used as quantitative data.

BUSINESS

Attitudes and Perceptions of White Collar and Street Crime

Jill O. Jasperson, Ronald M. Miller, Thomas Dearden

Utah Valley University; Virginia Tech University

The incidence and severity of white-collar crime (WCC) and awareness in the public has only increased since being defined and operationalized in 1940. To date, researchers have not explored attitudes and perceptions of WCC among residents in the state of Utah, which is the only state to have a WCC registry, which may indicate public awareness of its severity. In this study, researchers explored the attitudes toward and perceptions of WCC among students from the largest university in the state of Utah. This study is unique in the WCC literature as the research is the first to leverage self-report measures of perceived probability of crime victimization to explore attitudes and perceptions toward WCC. Our findings show that over 80% of participants rated WCC as affecting some to a major portion of the population. The results indicate, interestingly, that the neither ethnic background, sex, religious background, amount of education (high school through advanced degrees), nor personal views on social or economic issues (conservative through liberal) had any statistical differences in rating the self-assessed probability of being a victim of WCC. Although not typically related in US public perception, participants who feared WCC also feared street crime. Those who felt that WCC was difficult to investigate and prosecute also had increased fears of WCC. Additionally, blue-collar workers had significantly less fear of WCC than white-collar workers or

those whose main occupation was student. Divorced persons had a significantly greater fear of WCC than those who were currently married, single, or engaged. Overall, we also found support was high for the WCC registry across ethnic backgrounds, job category, and political views.

BUSINESS

Business Ethics Education in Utah: How Are We Teaching Ethics and Why?

Chelsea M Dye, Charlotta Farr, Dara Hoffa, Ron Mano

Westminster College

In an article on why business ethics need to receive greater prominence, Clayton Browne noted that although the study of general business topics like marketing, accounting, finance, and management are important to business education, it is equally important to have a real understanding that how you operate your business reflects not just on you, but impacts your neighbors and the larger community (Browne, C. "The Reasons for Studying Business Ethics." Small Business - Chron.com. Retrieved from <http://smallbusiness.chron.com/reasons-studying-business-ethics-18877.html>) Although higher education for business looks to agree that ethics education is important, the method by which we impart this education varies greatly. This paper examines the business programs at each of the eight institutions included in the Utah System of Higher Education in addition to the three nonprofit private institutions in Utah and looks at the extent to which ethics is included in the business curriculum and the importance each institution places on business ethics curriculum.

BUSINESS

Did the Global Financial Crisis Have an Impact on Credit Unions Risk Performances? Evidence from Utah

Abdus Samad, Duncan Chritensen

Utah Valley University

Credit unions are different breed of financial institutions distinguished from other financial institutions because they are small, not-for-profit, and tax-exempt cooperatives. They provide financial services to their

members who have common bonds with associations. By law, credit unions' loans are limited only to their members, not to corporations or institutions. They have small capitals but are large in numbers. They are basically small community banks. Credit unions, being community banks, play an important role in mobilizing households' savings and channeling them to meet the needs of their members in buying cars, homes, tools, and equipment. In Utah, there are 119 credit unions operating side by side with other commercial banks. They provide a variety of services to meet the common needs of the community. Among important services, credit unions provide a variety of loan services. Based on the purpose of the loan consumers borrow for or type of loan they need, loans from a credit union can be classified into either residential loans or nonresidential loans. Residential loans and nonresidential loans of credit unions are the important source of income of credit unions, but they also provide sources of risk to credit unions. Loans suffer from various risks. Loans default risk, nonpayment of loans in due time, is very common. Credit risks, nonpayment of loan, affect profit performances of credit unions. The global financial crisis (GFC) of 2008–2010 had serious impact worldwide. The GFC had a catastrophic impact on the U.S. financial institutions and the economy. There were large bank failures. In the U.S., the numbers of bank failures were 140 and 157 during 2009 and 2010, respectively. In the context of such a large U.S. bank failure, it is worth exploring the risk performance of Utah credit unions—small credit unions (SCUs), medium credit unions (MCUs), and large credit unions (LCUs) in particular. A Google search finds no evidence of study of the impact of the GFC on Utah credit unions' risk performances, particularly the GFC comparative impact on the SCUs, MCUs, and LCUs. As there were no studies on the impact of the GFC, the study of the GFC impact on the risk performances provides an important contribution in the literature of credit unions, at the state level in particular.

BUSINESS

An Empirical Examination of the Marketing of Initial Public Offerings

Whitney Holman, James C. Brau

Brigham Young University

Whereas prior literature extensively documents the initial and long-run performance of initial public offerings (IPOs), the marketing of IPOs is

rarely covered in prior literature. The principal focus of this study is to identify statistically significant factors associated with artificial demand created by the marketing of IPOs that affects the short- and long-term returns of IPO issues. We examine the selling efforts of brokers and dealers (Push hypothesis) and the use of offer price adjustments (Impresario hypothesis) as marketing tools in small and large issues, respectively. In the Push hypothesis, brokers and dealers may experience incentives to sell shares to less informed, unsophisticated investors, creating excess short-term demand. In the Impresario hypothesis, an increase in the offer price of the issue may be an alternate selling mechanism that creates the appearance of strong aggregate demand. We use the data drawn from SDC's New Issues database with offer dates between 1981 and 2016 as well as corresponding first-day, one-year, and three-year returns drawn from CRSP. We then use a portfolio approach and a series of OLS regressions to test the impact of artificial demand from the Push hypothesis on small issues with unsophisticated investors, as well as from the Impresario hypothesis on large issues with sophisticated investors. Our empirical results support both hypotheses in the presence of these marketing mechanisms, specifically for selling efforts in small issues with unsophisticated investors and for increased offer price in large issues with sophisticated investors. Our results are also consistent when these marketing mechanisms are absent: Small issues that are not pushed into the market and large issues that do not raise the offer price experience less first-day return and do not experience poor long-run performance.

BUSINESS

Integrating Scrum Methodology Principles into Undergraduate Marketing Course Design

Nelson Altamirano, Benjamin Hart

LDS Business College

The aim of this paper is to set forth in detail the experiences developed in undergraduate marketing courses from LDS Business College, where Scrum methodology principles were adapted as the primary teaching approach. These principles include a team-based, power-balanced, and goal-oriented framework, self-organized teams, transparency, inspection, adaptation, and values of commitment, courage, focus, openness, and respect. This methodology has been used successfully in software development and has lent itself in various other fields including

education where the inherent iterative and interactive approach of the methodological principles may facilitate learning. Since 2018, LDS Business College has integrated Scrum methodology principles into two marketing courses: Digital Marketing Strategy and Digital Marketing Analytics. Data from students in those courses are collected at the end of each semester through voluntary surveys about how students viewed their experiences. Although student responses varied, most students expressed that they would take similar courses in the future. Additionally, instructors who taught using the Scrum methodology principles have expressed that their experience has been primarily positive and shows potential as a teaching approach. These results suggest that there is an opportunity to refine how the Scrum methodology principles effectively engage students in the learning process. We provide recommendations to other educators about how to effectively integrate these principles in the instruction of courses in marketing, business, and other disciplines.

BUSINESS

Modeling and Predicting the Underpricing of Initial Public Offerings using Machine Learning Algorithms

Noah T. Brown, James C. Brau, Craig Thorsen

Brigham Young University

Initial public offerings (IPOs) have historically demonstrated three phenomena that continue to persist as puzzles. They are the initial underpricing of issues on average; the cyclical nature (or hot markets) of both volume and underpricing; and negative risk-adjusted long-run stock returns persisting for at least five years. Much research has been published on these financial phenomena, with initial underpricing perhaps drawing the most attention. To date, however, no research that we know of has used machine learning to model and predict IPO underpricing. In this paper, we use advanced machine learning methods to first fit, then train, and then out-of-sample test the prediction of IPO underpricing. The equation for the initial underpricing is: Initial Underpricing = $[(\text{Closing stock price on the first trading day})/(\text{IPO offer price})]$. This equation is dynamic in nature in that both the numerator and denominator can change up until the moment the IPO goes effective. The tools of machine learning allow us to train our model to predict both parts of the ratio and to achieve a predictive accuracy confidence interval that is significant in within sample testing. We use a sample of IPOs drawn

from the SDC New Issues Database and supplement it with CRSP and Compustat data for a period from 1980 through 2019.

BUSINESS

The State Treasurer Needs an Intermediate Maturity Fund: A Discussion of Investment Options Needed to Compliment the Public Treasurers' Investment Fund

R. Neil Walter, Nathan Caplin

Snow College

The Treasurer's office has focused on the performance of the Public Treasurers' Investment Fund (PTIF) while its participants have been depositing long-term cash in the in the Treasurer's short-term investment vehicle. Sophisticated state entities invest longer term on their own. It is time for the Treasurer to put together an intermediate maturity fund that would create a higher return investment option for counties, cities, school districts, universities, charter schools, and other entities of the state that do not have the ability to manage a similar long-term investment strategy. The combination of the existing PTIF and a new intermediate maturity fund could materially increase cash dividends to the fund participants without requiring the Treasurer to take on additional credit risk.

BUSINESS

Earnings Management Surrounding Seasoned Equity Offerings: A New Method for Measuring Abnormal Accruals

Paige Perkins, James C. Brau

Brigham Young University

In this paper, we propose a new metric for measuring abnormal accruals to determine whether the findings of Teoh, Welch, and Wong (1998) still hold validity. Because of the construction of our new abnormal accrual metric, we are constrained to use seasoned equity offering or secondary equity offering (SEOs) to operationalize our hypothesis. In studying SEOs rather than initial public offerings (IPOs), we also address the

conjecture of Ball and Shivakumar (2008) that “upward-biased estimates of discretionary accruals occur in a broad genre of studies on earnings management around similar large transactions and events.” The essence of our new metric is that instead of using other firms in the same industry to measure the normal amount of accruals (e.g., Jones (1991) and its perturbations), we use the same firm’s earlier nonevent years to serve as the benchmark. In this regard, our measure is similar to the market model for stock return event studies (e.g., see Fama, Fisher, Jensen, and Roll (1969)) for a seminal article). When abnormal returns are desired for event studies, it has become common to estimate a single factor asset pricing model in a pre-estimation period and then to use this model to estimate the normal return for the stock. In the market model approach, the normal measure is subtracted from the observed measure, and the residual is considered either over- or underperformance. In much the same manner, we estimate expected accruals for each firm during a pre-estimation period that is not confounded by equity issuance. We then subtract this estimate from the observed accruals and compute abnormal accruals. Using our new approach, for a sample of 3,874 SEOs, we document that, on average, firms inflate their earnings immediately prior to the offering. In addition, our new measure displays the best predictability of future long-run returns when compared with industry-matched benchmark approaches.

BUSINESS

The Effect of State Disclosure Status on Housing Markets

Spencer Evans, Barrett Slade

Brigham Young University

The western United States presents an interesting case in analyzing the effect of disclosure status on residential real estate markets. Idaho, Utah, and New Mexico are nondisclosure states, meaning real estate agents are not required to disclose transaction data. The multiple listing service (MLS) controls access to transaction data, and in these nondisclosure states the data is. Alternatively, Arizona, Colorado, and Nevada are disclosure states, meaning all real estate transaction data is public. This creates a natural test of market efficiency because buyers are acting on imperfect information and real estate agents are not incentivized to provide market transparency. We hypothesize that homes cannot be priced correctly in nondisclosure states, representing a market

inefficiency. This asymmetric information could be detrimental for buyers and have serious implications for household wealth. The National Association of Realtors (NAR) is the organization that develops and maintains the MLS. The NAR is also the second-largest lobbyist in the United States. One potential source of data to start to understand the setting of the effect of disclosure status on real estate markets is to look at lobbying expenditures in nondisclosure states by the NAR. We expect to find that the NAR has significant lobbying presence in non-disclosure states because transparency is not beneficial to the NAR.

BUSINESS

Work-Life-Balance Characteristics as a Predictor of Job Satisfaction across Generations

**Danielle Hardy, Annie Arvizu, Jace Johnson, Spencer Powell,
Jonathan Westover**

Utah Valley University

Objective: The purpose of this paper is to explore work–life balance predictors of job satisfaction across various generations, using an international sample of workers across 37 countries. The four generational cohorts included in the analysis include the Silent Generation, Baby Boomers, Generation X, and Millennials. **Design/methodology/approach:** This study provides a comparative analysis of work–life balance indicators of overall job satisfaction across generational cohorts, using data from the 2015 Work Orientations IV Wave of the International Social Survey Program (including stratified random samples of employees across 37 different countries). **Findings:** Initial analyses indicate statistically significant differences in work–life balance–related indicators of employee job satisfaction across generational cohorts. Additional analyses will be performed to clarify these relationships and further explore the causes behind the differences. **Originality/Value:** Although thousands of studies have been performed on job satisfaction, very few studies have explicitly examined job satisfaction levels and its indicators across generations. Additionally, although many studies have examined the role of work–life balance saliency on job satisfaction across generational cohorts, no research has previously been done examining these relationships cross-nationally.

BUSINESS

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Spencer Evans, Barrett Slade

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EDUCATION

Facilitating Engaged Student Learning: Seven Principles for Instruction in Undergraduate Marketing Courses

Benjamin Hart

LDS Business College

Can marketing instructors influence their students' desire to learn? Can we identify how to use student–teacher interaction in a classroom environment to affect their motivation? From 2018 through 2019, students in 18 marketing courses at LDS Business College anonymously answered questions about their learning experience. Their responses

revealed what events occurred during their classroom instruction that they felt motivated them to learn. Responses were organized into categories based on the nature of the events they described. Each category suggested a common theme for the responses. These themes were organized into seven principles supported by existing research in education and learning: incentive, inclusion, immersion, integration, interaction, iteration, and inspiration. It is suggested that adapting these seven principles as a foundation for curriculum design will positively influence a student's desire to learn. Recommendations on how to implement each of the seven principles in a classroom environment are provided. Further research in this area is needed to demonstrate the effectiveness of the seven principles to increase student's desire to learn in other disciplines.

EDUCATION

Networks of Solidarity in College Housing for Indigenous Youth

Elhom Gosink

Westminster College

College is a different experience for indigenous students, especially at predominantly White institutions (PWIs), so the solidarity networks that students of color create become a major part of their success. Currently, there is a lack of interdisciplinary discussion on how culturally relevant housing and support networks in PWIs could benefit indigenous students. Indigenous students have some of the lowest retention and graduation rates; in fact, a study conducted in the 1990s found that only 1% of university degrees conferred in the US were to indigenous peoples and that indigenous youth have the highest dropout rates of any ethnic group. Institutions of higher education have paid little attention to recommendations for support, partly because of structural coloniality and the neoliberal capitalist economy. Research has shown how campus housing can support college-wide retention efforts, so it follows that institutions must pay more attention to the experiences of indigenous youth, listen to their complex histories, and value their culture in order to create more supportive programming. This paper synthesizes some of the existing literature to construct a critical, interdisciplinary examination of college housing requirements; synthesize the recommendations made by indigenous scholars that are explicitly concerned with the success of indigenous students; and examine the

structural challenges to institutions of higher education by utilizing currently isolated research from land-based pedagogy, communities of self-selection, and the importance of peer networks for students of color in higher education.

EDUCATION

A Comparison of Experiential Project and Learning Outcomes for Students in an Online Organizational Development and Change Course

Jonathan Westover

Utah Valley University

In the fall of 2019, I launched a new fully online version of my Organizational Development (OD) and Change service-learning class, which includes an intensive, semester-long service-learning consulting project that teams of students complete with a community partner. I have been teaching this class for 9 years, in both the traditional F2F and hybrid modalities, but I decided to design an online version to provide more options for our students. The challenge has been to find ways to retain the heart of the course, a meaningful and effective service-learning OD team project consulting experience, within a fully online course. This research compares student learning reflections and various service-learning project outcomes in this new fully online course versus the previous hybrid version of the class. Personal learnings and reflections on how to improve future versions of the online course will be shared.

EDUCATION

From Start to Finish: The Implementation of Campus-Wide Integrative Equity Training and Programs

Lianna Manibog

Snow College

We will begin with a platform presentation establishing the distinct student environment at Snow College, which is a rural, predominantly white, predominantly Latter-Day Saint student demographic. In doing so, we will demonstrate the unique profile and history of our college,

even within the state of Utah. We will use data and personal experiences to illustrate the marginalized status of first-generation, financial-need, as well as certain minority and racial groups of students, and we will end with an argument for how campuses can better support these students from the moment they set foot in our classrooms to the day they depart. Furthermore, we will discuss a campuswide plan of integration that allows for better communication between faculty, administration, advisement, and service-learning groups on campus. We will include a list of programs and structures that are currently being discussed as solutions to issues these students face. We will also make the case for our responsibility to prepare diverse students to the best of our ability and give the resources they need for success. As Ta-Nehisi Coates argues, “No one directly proclaimed that schools were designed to sanctify failure and destruction. But a great number of educators spoke of ‘personal responsibility’ in a country authored and sustained by a criminal irresponsibility. The point of this language of ‘intention’ and ‘personal responsibility’ is broad exoneration. “Good intention is a hall pass through history, a sleeping pill that ensures the Dream.” Finally, we will conduct an interdisciplinary workshop targeting faculty who are seeing firsthand the DFWI (D, Fail, Withdraw, Incomplete) rates being problematic in their courses. We will encourage attendees to work together to identify needs and methods to create equitable practices within their own discipline with an opportunity to brainstorm what these practices might look like and how they might function.

EDUCATION

Creating a Successful Secondary Dance Program in Any Community

Nichole Ortega

Utah Valley University

Through the study of dance education and dance advocacy, the relevance and importance of successful secondary dance programs has been proven time and time again, especially concerning the positive outcomes for participants and school communities. These same programs can also be used as an extremely effective learning tool for future dance educators, specifically in navigation of diverse learning environments. As a result of several years of observation and evaluation of Dance Education majors during their student teaching assignment, it became evident that students were aptly prepared to teach dance curriculum in the secondary

schools but often struggled with the diverse situations and/or environments they were assigned. Every secondary school requires modifications of best pedagogy practices for optimal learning in that specific environment. As a result of my 10 years as a secondary dance educator and 13 years as a university faculty member involved in a Dance Education program, I am aware of several successful secondary dance programs throughout the state of Utah and some in surrounding states, all with distinct environments. In this presentation, I will be sharing my research based on interviews of over 20 secondary teachers with successful dance programs and the specific elements of these diverse programs. The goal of this research is to provide helpful information for enhanced Secondary Dance Education pedagogy practice at the university level, allowing future dance educators more success in their student teaching and professional teaching assignment.

EDUCATION

Greater Rudeness: Interruptive Behavior in the Graduate School Classroom

Thomas C. Terry

Utah State University

Professor Fiona Draper surveyed the classroom filled with M.A. and Ph.D. students, ignoring vocal outbursts by two men. She gestured to a woman. "Studies have shown that men interrupt women more often than women interrupt men," she said, "and are more forceful and loud in classroom situations. So, Sandy, you go right ahead." Draper provided the premise for this study exploring whether male graduate students do attempt to dominate and interrupt female graduate students in classroom situations. Interruptions are defined as speaking without raising a hand, blurting out comments or questions, "stepping on" those speaking, and talking over others, as well as similar behaviors. Research was conducted in a southern university's research methods class of 16 men and 11 women taught by a female professor over two 75-minute periods. In this preliminary study, results were mixed. Percentage-wise, men and women interrupted others without raising their hands at virtually the same rate. However, men did talk over others in the class nearly twice as often but were also twice as likely to raise their hands and wait to be called on by the professor. Women

half-raised their hands before interrupting far more often than men. Overall, men's approach to the class seemed informal, and they appeared less engaged. A third were not closely following the flow of classroom discussion. In sharp contrast, women seemed connected and always fully aware of the flow of conversation. However, women made fewer comments, percentagewise. When women left the classroom during class, they did so quietly and closed the door carefully, unlike the men, who let the doors slam shut behind them. The researcher concludes that further research is indicated to create a more nuanced and comprehensive answer to the study's hypothesis that men's classroom behavior is more interruptive.

ENGINEERING

Heat Transfer Analysis of Water During Liquid-Solid Phase Change

Kelly Lou Pelicano, Colton Robinson

Southern Utah University

To better understand the heat transfer through materials undergoing a phase change, experiments were conducted using eicosane as it went through the freezing process. Liquid eicosane at 50°C was placed in a cylindrical test vessel and cooled from the outer surface of the vessel utilizing a counterflow heat exchanger. The heat exchanger provided constant temperature cooling by means of a constant temperature bath system. An initial analysis of the data showed that a steady fusion temperature of ~35.6°C was achieved before the eicosane solidified. Analyzing the temperatures recorded by the thermocouples, detailed quantitative time-dependent volumetric temperature distributions, freeze-front motion, and shape were obtained. Under idealized conditions, the phase-change material (PCM) behaves as a thermal lumped capacitance, providing cooling (or heating) for a wide range of heat transfer rates at a single temperature corresponding to its melting-point (fusion) temperature. In practice, this temperature exists only at the solid/liquid interface. As the PCM freezes, the interface moves away from the surface of the heat source, and a thermal resistance layer is built up, resulting in a reduced heat transfer rate and/or increased temperature difference between the system to be cooled and the PCM. Results have been generalized to apply to any low-Stefan number PCM. By examining the data collected from this experiment, the phase change behavior of eicosane was characterized.

ENGINEERING

Mechanical and Thermal Properties of Concrete

Craig Olson, Nathan Tyler

Utah Valley University

Concrete is a popular building material used in all types of structures such as roads, bridges, homes, and other structures. Knowing both the mechanical and thermal properties of concrete is very crucial to the construction of structures in various environments. In this undergraduate research performed at Southern Utah University, the mechanical (failure stress at several periods of times after pouring) and thermal (heat generation rate and thermal heat capacitance) properties of type IV concrete were experimentally evaluated from a premixed bag purchased locally. The experimental values were compared with the published values. The compressive strength of concrete specimens depends highly on slumps and also relates to the heat generation rate (heat of hydration) and thermal heat capacity associated with the initial curing process. In this research, for the heat transfer evaluation, a cylinder (10-in diameter $\times$ 10-in height) was used, and the cylinders used for the compression testing were standard 4-in diameter $\times$ 8-in height. Cylinders were placed in “hot,” “ideal,” and “cold” environments to mimic the real pouring environments. The compressive strength of the concrete was evaluated to be higher when the initial curing process was ideal rather than hot and cold. The experimentally evaluated heat generation of the concrete to be evaluated to be 57.89 cal/g, which placed it as type IV concrete when compared with other published data.

ENGINEERING

Analytical Solutions to Predict the Thermal Conductivity of a Phase-Change Material in a Cylindrical Coordinate System

Kelly Lou, Pelicano, Emmanuel Navarro, Vicki Krull, Ali Siahpush

Southern Utah University

In authors' previous research, inward freezing of eicosane was investigated. Experimentally radius of fusion and calorimetric heat transfer analysis were performed. In this paper, we analytically predict the inward freezing of a phase change material system, eicosane ($C_{20}H_{42}$), in

a cylindrical enclosure. A quasi-steady-state heat transfer analysis was conducted, and the experimental results were compared with theoretical predictions. The heat transfer analysis consisted of (1) implementing a calorimetric heat transfer measurement with eicosane to ensure that the system was functioning properly; (2) using mathematical heat balance integral method to present a detailed quantitative heat transfer analysis and radius of fusion location; and (3) predicting the eicosane thermal conductivity. We also will discuss how the analytical and experimental results support one another by presenting mathematical models that yielded time-dependent volumetric temperature distribution and freeze-front motion distribution plots. Predictions from previous experimentation are also presented to further validate the results of this work.

ENGINEERING

Thermoelectric Devices: A Study of Material-based Efficiency and Operation

Spencer Bain, Ryan Dungan, Nate Hirst, Kaiyuan Sun

Southern Utah University

The purpose of this experiment was to determine the performance of different thermoelectric devices by comparing efficiency based on material selections and device configurations. Dissimilar semiconductors create a relation between heat flux and electricity in the thermoelectric junction based on the Peltier Effect. The most common materials are bismuth alloy (BiSn), bismuth telluride (Bi_2Te_3), antimony telluride (Sb_2Te_3), and bismuth selenide (Bi_2Se_3). An apparatus consisting of two cooling blocks, two thermoelectric devices, and two heaters was used to conduct the experiment. A steady-state temperature differential was maintained by ceramic plate heater on the hot side and an aluminum cooling block on the cold side. Multiple configurations were tested for power generation at a variety of temperatures. The maximum efficiency of the thermoelectric generator was measured to be around 5.6%, and the published maximum efficiency from the manufacturer was listed as 5.03%. Multiple devices were tested in an attempt to draw connections between material combinations and efficiency for the thermoelectric coolers or generators. Although the test apparatus provided consistent and relatively accurate data, the raw material combinations and manufacturing methods used for thermoelectric devices are proprietary. However, a comparison between

different thermoelectric devices showed a correlation between the intended application of the device and the efficiency when used for power generation. When used for power generation, the thermoelectric devices intended for heating and cooling were consistently less efficient than the devices that were purpose-built for power generation.

ENGINEERING

Material Properties of Photopolymer Resin, Polylactic Acid, And Other 3D Printing Materials

Austin Rohrer, Teigen Jewkes, Zach Jensen, Jacob Pastorik
Southern Utah University

In this experiment, we tested and studied the mechanical and physical properties of thermoplastic PLA (polylactic acid) filament and thermoset photopolymer resins by exercising the material bonds in the form of tensile stress evaluations. The 3D filaments used in the primary dogbone tests were all PLA material. For comparison, secondary tests were run on PLA, ABS, PETG, and carbon-fiber PLA strands of unprinted 1.75-mm diameter wire. For additional comparison, tie wire and braided-steel cable were also used in the secondary test. These secondary tests were conducted to study the difference between unprinted and printed materials and how the bonds change the mechanical properties of the sample materials.

ENGINEERING

Tensile Properties and Thermal Conductivity of Fused Polylactic Acid Polymers

Anthony Cole, Aaron Dockins, Kyler Reinhold, Austin Banks, Ali Siahpush
Southern Utah University

The study performed in this paper is part of the undergraduate research performed at Southern Utah University. The research includes evaluating the basic mechanical and thermal properties of the common printing material PLA (polylactic acid). The tests include tensile strength in the three orthogonal orientations and experimentally evaluate the coefficient of thermal conductivity for the material. The samples were strongest

when printed with layers parallel to the direction of the applied load. The thermal conductivity for the material is $0.134 \frac{\text{W}}{\text{m.K}}$ where, according to the SD3D Technical Data Sheet, the published thermal conductivity is $0.13 \frac{\text{W}}{\text{m.K}}$.

ENGINEERING

Experimentally Evaluating Solar Flux and Absorptivity of a Plate through Radiation Heat Transfer

Landen Measom, John Webster, Inoa Wahinehookae, Chris Zeman

Southern Utah University

The first objective of this project is to evaluate the solar flux in Cedar City, Utah, by conducting radiation heat transfer tests with aluminum and steel sheets. This information is then utilized to calculate the absorptivity of the two metals. The results are compared with published values. The solar flux values calculated using the aluminum and steel sheets are within 4.23% and 4.48% of the values reported by a solar field approximately 10 miles west of the test location. From these solar flux values, the absorptivity of each material was approximated using numerical methods in MATLAB. The calculated absorptivity of each fell within the published values.

ENGINEERING

Applications of Knowledge Management in Construction Companies to Improve the Performance Indicators

Mohamed Askar, Mason Timmerman, Bryant Ward

Southern Utah University

Knowledge management is the identification, optimization, and active management of intellectual assets to create value, increase productivity, and gain and sustain competitive advantage. Knowledge management is essential in the construction industry, but there is a dramatic gap between rhetoric and reality, highlighting mistaken expectations of technology. The construction industry depends on human knowledge, with limited systems support. A significant obstacle to the broader acceptance of knowledge management in most of the construction companies is that

the management of these companies finds it difficult to recognize any concrete benefit for their day-to-day business to be gained from applying existing knowledge management concepts. It is vital for construction companies to win orders in a competitive environment and to execute these orders profitably for the company and satisfactorily for the customer (project success). The study aims at evaluating the current knowledge management situation of the construction industry, recommending the next steps in implementing knowledge management that can be taken by construction companies and studying how they can benefit from the existing resources of knowledge management. The fundamental prerequisite to enable this approach is to activate their success factors. The paper proposed an applicable Knowledge Management System (PKMS) for construction companies that covers inputs, processing, and outputs. The PKMS aims at increasing the value of the intangible assets of construction companies.

ENGINEERING

Problems Facing Parties Involved in BOT/PPP Projects in the USA—Case Study: Cedar City, Utah

Mohamed Askar, Jared Baker, Gray Christian, Tyler Ercanbrack
Southern Utah University

One of the newest financial schemes for the infrastructure projects is the BOT (Build, Operate and Transfer) concept, which is being used increasingly nowadays all over the world as a project delivery system, by which governments deliver the infrastructure projects through private sector after a concession period free of charge. The United States has been committed to the free-market economy principle since its establishment, and it has guaranteed freedom of economic activity to its people. The policy of transferring government enterprises and corporations into private sector ownership and management has gained substantial significance in recent years in the US. The state of Utah is encouraging the private sector to participate (Private Participation in Infrastructure Projects, PPP) in the development of infrastructure facilities such as railway, airports, power plants, water supply facilities, ports, etc. In an attempt to reduce its spending, the State is attracting private capital in increasing volumes to overcome the financing limitations. Increased private sector participation will help in the realization of large-scale infrastructure projects with minimum burden on the State. The study aims to investigate the potential for implementing

the BOT approach in Utah. This can be achieved by giving a clear view of BOT, its problems, risk areas, and features found in Utah to maximize the benefits and minimize the risks as much as possible. Data about the required critical success factors to achieve BOT projects in Utah were collected, analyzed, compared with the actual risks.

KINESIOLOGY AND HEALTH SCIENCES

Intermittent Fasting as an Alternate Method of Fat Loss: Altering Body Composition in Competitive Physique Athletes

Kasey Giles

Brigham Young University

Physique athletes (e.g., bodybuilders and bikini competitors) are judged on aesthetics, which is why they aim for a low body-fat percentage and a lean, hard appearance. After a few months of muscle building, known as the “bulking” period, competitors follow a strict regime to “cut” body fat. Men usually try to drop anywhere from 3% to 6% body fat for competitions, and women aim for an 8–11% body fat range. Bodybuilders and bikini competitors must rely on nutritional habits to edge out other competitors and bring themselves to a lower body-fat percentage. These athletes often rely on continuous energy restriction (CER) to alter body composition by cutting more calories out of their diet every few weeks. CER, while being able to recompose body structure, has also led to decreases in performance and energy levels. Athletes will push their bodies to the limit in the “cutting” stage; CER will often bring caloric intake to unhealthy levels (often a sub-500 caloric deficit) to decrease body fat in a short amount of time. Not only does CER cause athletes to lose energy while in the preparation of a competition, but it also causes them to rebound after competition (potentially destroying them psychologically). Intermittent fasting (IF) has recently gained a lot of traction in the media as a nutritional habit that leads to increased fat burning while maintaining energy levels. IF, or intermittent energy restriction, alternates times of energy restriction (fasting) with times of energy consumption (feeding). Athletes who chose to replace CER with IF can lose fat and maintain muscle while maintaining a healthy and consistent daily caloric intake. IF aids athletes in body composition by increasing the human growth hormone, decreasing insulin spikes, and maintaining basal metabolic rates.

KINESIOLOGY AND HEALTH SCIENCES

Factors that Increase the Effectiveness of Active Rehabilitation in the Treatment of Postconcussion Symptoms: A Review

Alexa Katrena Bowns

Brigham Young University

The treatment of ongoing postconcussion symptoms with active rehabilitation is a complex and multifaceted topic. Past studies recommend physical and cognitive rest as the most effective treatment for postconcussion symptoms. Current emerging studies show the benefits of active rehabilitation treatment. This review focuses on the specific factors that make active rehabilitation the most effective in the treatment of postconcussion symptoms. Awareness of circumstantial factors that increase symptom recurrence with exercise is of importance when prescribing active rehabilitation as a post-concussion symptom treatment. Treatments that begin 2 to 3 weeks after injury that include light to moderate intensity-graded exercise regimens are most beneficial. Additionally, treatments that include a variety of exercises such as aerobic, strength, and skill training are likely to be advantageous.

KINESIOLOGY AND HEALTH SCIENCES

The Relationship between Physical Activity and Smokeless Tobacco Use among Adults in the United States: A Systematic Review of the Literature

Linnette Wong

Weber State University

Objective: To synthesize published literature that has tested the relationship between physical activity and smokeless tobacco use. **Data Source:** A systematic review of literature published between January 2007 and December 2017 was conducted by searching the databases: PsychInfo, Medline, and CINAHL Complete. **Study Inclusion and Exclusion Criteria:** Inclusion criteria: study must have tested for the relationship between physical activity and smokeless tobacco use; adult samples in the US. Exclusion criteria: study utilized samples from outside the US, adolescents, or tobacco-dependent and heavy smokers. **Data Synthesis:** The search captured 81 unique articles, 6 of which were

included in the final systematic review. Results: 40% of the studies reported a positive relationship between physical activity and smokeless tobacco use. Conclusion: Research published in the past decade implies a positive relationship between physical activity and smokeless tobacco use. Findings have important implications for the design of health promotion programs targeting physical activity and smokeless tobacco use.

KINESIOLOGY AND HEALTH SCIENCES

Lactate Threshold Analysis: Statistical and Practical Analysis—Pilot Study

L. Nathan Thomas, Kylie Cox, Angee Thomson, Teresa Taylor, Miliena Mitre, Jenny Pham

Salt Lake Community College

Objective: The objective was to perform a pilot analysis of lactate threshold analysis protocols, identify lactate threshold, and compare statistical and practical differences between protocols and potential application of data for exercise prescription in nonathletic populations. **Methods:** In this research, 6 subjects underwent a LT, HR Def, and CP assessment. Recovery from CP to LT test was 3 days, while recovery between LT and HR Def was 8 hours. Data were collected and analyzed by the group. **Conclusions and Findings:** The use of LT is important for exercise prescription and adaptation for health.

KINESIOLOGY AND HEALTH SCIENCES

Serotonergic Hallucinogens' Antidepressant Potential: A Comparative Review of Serotonergic Hallucinogens and Ketamine

Ethan Ouzts

Brigham Young University

Ketamine was recently approved by the U.S. Food and Drug Administration as a therapeutic approach to treat individuals with treatment-resistant depression. This approval opens the door for other hallucinogens to be approved for psychiatric use. This review compares the antidepressant potential and safety of serotonergic hallucinogens,

such as lysergic diethylamide acid (LSD), with those of ketamine, the standard of comparison in this review. Serotonergic hallucinogens demonstrate similar short- to mid-term reductions in depressive symptoms for patients with depression, and these drugs may be safer than ketamine. Researchers should conduct additional randomized, controlled experiments to better establish the antidepressant potential of serotonergic hallucinogens. Despite limitations in current research, serotonergic hallucinogens warrant serious consideration for potential antidepressant treatment.

LETTERS—LANGUAGE AND LITERATURE

Poetic Shape: How Enjambment in Gwendolyn Brooks's "We Real Cool" Evokes Visual Metaphor and Deeper Meaning

Megan Alyse

Weber State University

Gwendolyn Brooks's poem, "We Real Cool," is often one of the first poems we think of when discussing her work. The purpose of this paper is to explore the poem's functions of enjambment through the minimalist and cubist movements associated with visual arts. The poem originally appeared in Brooks's collection *The Beans Eaters*, a collection of ballads, sonnets, and near-sonnets outlining both fictional and imagined characters. Within this context, the poem's enjambment creates a musical embrace of culture despite the larger collection's resistance. My concern is with how minimalist and cubist impulses shape the poem, visually and musically, and enable its becoming a celebration of black language and culture.

LETTERS—LANGUAGE AND LITERATURE

Lab Lit: What Happens to Character When Contemporary Science and Literature Cross Paths?

Olga Pilkington

Dixie State University

Up through the beginning of the 21st century, there was no name for the genre of fiction that deals with science in its present state, unembellished

by the brilliant possibilities of the future. Only within the last two decades has this genre been named—"science-in-fiction" or "verification" (by Carl Djerassi) or "fiction about science" (by Charles Sheffield). The name that has stuck, however, and that is allowing the genre to flourish and gain scholarly recognition is "LabLit," a name coined by Jennifer Rohn. Focusing on two recent LabLit texts, Susan Gaines's *Carbon Dreams* and Jennifer Rohn's *The Honest Look*, I will show how elements of contemporary, nonfuturistic science (including lab apparatus) expand or modify traditional characterization in English-language fiction.

LETTERS—LANGUAGE AND LITERATURE

Creative Fiction: Address Trauma Through the Surreal Fictions

Lisa Christensen, Dallin Hunt, Chanel Earl, Madalyn McRae

Brigham Young University

Four readers will read short pieces fiction in which magical realism is used as a means of examining how people respond to trauma, pain, and grief. These pieces are: "Moths of a Feather," a short story about tattoos and friendship beyond the grave; "Cheating," a series of flash fictions where death doesn't win; "One Boy's Death," a ghost story featuring multigenerational connections and lighting; and "The Corpse's New Clothes," in which an obsessive distance runner finds an unusual trainer.

LETTERS—LANGUAGE AND LITERATURE

Creative Nonfiction and Poetry: The Truth of Beauty and the Beauty in Truth

Kalli Abbott, Carma Hilland, Thew Curtis

Brigham Young University

Three readers will share original creative nonfiction and poetry employing lyrical memoir and quasiconfessional modes to explore how these sister genres explore and generate beauty in truth. The pieces are: "On Fishing," a nonfiction essay; "Nuclear Folly," a nonfiction essay; and "Epistolary Poems."

PHYSICAL SCIENCES

Using Silver Nanoparticles to Detect Early Onset of Disease

**Porter Wilkes, Payton Riggs, Hayley Phillips, Jonah Babbel,
Payden Harrah, Christopher F. Monson**

Southern Utah University

Silver nanoparticles are of interest because of their chemical, antimicrobial, and other properties. We have developed a method to fabricate silver nanoparticles using a microfluidic device made of polydimethylsiloxane. Through this method, we can consistently form high concentrations of nanoparticles of the same size and shape using common reagents for silver nanoparticle fabrication (silver nitrate, sodium hydroxide, ascorbic acid, and a specific capping ligand, which coats the outside of the nanoparticle, determining its final size and shape). Citric acid is commonly used as a capping ligand, but we have tested several nonconventional ligands, including common biological molecules. Specifically, we have compared a lipid (1,2-dioleoyl-sn-glycero-3-phospho-L-serine), a vitamin (vitamin B), and several proteins (bovine serum albumin (BSA), casein, and IgG) and have observed differences in the nanoparticles produced when using these capping ligands. We can identify these differences by examining the nanoparticles' abilities to fluoresce using fluorescence spectroscopy. Furthermore, we have compared the nanoparticles fabricated using three significantly different concentrations of both BSA and casein. We observed that the nanoparticles made from different concentrations of BSA fluoresced identically to each other and that the nanoparticles made from different concentrations of casein did likewise, although, as found previously, the nanoparticles made from the distinct proteins fluoresced differently. We have also examined the nanoparticles formed from mixtures of BSA and casein and have observed that these nanoparticles fluoresce differently than nanoparticles formed from each of the pure capping ligands, at a level between BSA and casein. Our objective is to identify distinguishing features between the fluorescence of nanoparticles derived using different biological samples as capping ligands, with the vision that this research could lead to new methods of identifying diseases at early stages by comparing the fluorescence of nanoparticles fabricated from samples of subjects believed to have a disease to those who do not.

PHYSICAL SCIENCES

Lead Levels in the Wing Bones of Utah Eagles, Measured by X-Ray Fluorescence

Michelle Arnold

Weber State University

Lead is a known toxin for which adverse effects have been detected in both humans and animals, even at very low exposure levels. Eagles and other raptors are primarily exposed to lead through the presence of lead shot within game they ingest. There is only minimal data for lead levels of eagles in the United States or studies that have evaluated the resulting effects of exposure. Because of the long biological half-life of lead within bone, a measurement of bone lead levels can be used to assess lifetime exposure to the element. The noninvasive technique of x-ray fluorescence (XRF) was used to assess the bone lead levels for 10 eagles found dead in Utah (4 bald eagles and 6 golden eagles). Seven of the 10 eagles measured had elevated bone lead levels, $>20 \mu\text{g/g}$ of bone mineral. Four of the six golden eagles had levels in excess of $30 \mu\text{g/g}$, with the greatest measured bone lead concentration being $78.2 \mu\text{g/g}$.

PHYSICAL SCIENCES

A Microfluidic Device for Oxygen Quantitation in Anoxic Environments

Mariah Clayson, Madison Evans, Christopher Abraham

Southern Utah University

Anoxic environments provide a challenge for measuring dissolved oxygen concentration. Currently, the only commercially available method that has sufficient sensitivity to quantify the dissolved oxygen concentration in anoxic waters ($<1\%$ oxygen saturation) is the STOX Electrode. Using a three-dimensional design, we have developed a microfluidic device for measuring low levels of dissolved oxygen. The device is fabricated using a sacrificial magnesium wire to form a channel through polydimethylsiloxane, which allows the electrodes to be exposed to solution. Our initial design involved nine separate electrodes and three independently controlled applied voltages. To simplify our design, our new device allows for a three-electrode set-up, allowing the working electrode to reduce noise by acting as its own guard. A new

pumping mechanism is also employed, allowing for a larger volume displacement at faster rates.

PHYSICAL SCIENCES

Biological Molecules—Separation by Charge and Microfluidic Devices

Ruthie Cicotte

Southern Utah University

Microfluidic devices may be used to separate biological molecules by charge. The device being built in this experiment is intended to aid in separating DNA from a matrix of molecules quickly and efficiently. The method in which the device was constructed allows the analyte to flow through a narrow channel, with positive and negative charges on either side of the channel divided from the analyte by a frit. It is intended that the charges will pull DNA and other molecules towards them, in magnitude related to the molecules charge, essentially separating them from one another. It is anticipated that these devices may be used with raw samples of biological material and separate any DNA within the raw sample in the same manner it would isolated DNA, allowing biological material to be analyzed without DNA being isolated first. This could save an incredible amount of time in analysis and could potentially be used in criminal investigations, genetic research, and other related fields.

PHYSICAL SCIENCES

Ultrafast Laser Spectroscopy Probes of Macromolecules and their Solvent Environment at Electrified Solid-Liquid Interfaces

Rodrigo Noriega, Sasha A. Moonitz, Noah Shepard

University of Utah

Probing electrochemically active interfaces with spatial selectivity and temporal resolution is a challenge that requires the combination of complementary experimental tools. To enable the spectroscopic and electrochemical characterization of macromolecular species at electrified interfaces in the condensed phase, our group is extending surface plasmon probes into the time-resolved mid-infrared domain.

These new probes are designed to be compatible with in-situ electrochemical measurements and ultrafast fluorescence experiments. We demonstrate the ability to detect electric field-mediated adsorption of polypeptides at a semiconducting electrode, as well as subsequent pH- and electric field-dependent conformational changes in the adhered peptide layer and its solvation environment.

PHYSICAL SCIENCES

Continuous Trajectories in the Quantum Harmonic Oscillator

Matthew Lawyer, Jean-Francois Van Huele

Brigham Young University

Bohmian mechanics is a formulation of quantum theory that describes particles having continuously defined trajectories. These trajectories give an intuitive picture of the dynamics of a quantum system; however, they are highly nonclassical. Numerically calculated trajectories for several states of the simple harmonic oscillator are shown, and nonclassical effects are explained in terms of an additional potential, called the quantum potential. The method of obtaining these trajectories is discussed, and a possible application of these results is explored.

PHYSICAL SCIENCES

Designing a Universal Quantum Logic Gate: Deutsch Gate Circuitry with Two Quantum Dots and a Flying Qubit

Paul Bailey

Brigham Young University

The Deutsch gate is a three-qubit universal quantum logic gate, meaning that any quantum computing task can be completed using a combination of Deutsch gates. To our knowledge, no Deutsch gate has been experimentally realized so far. We store two qubits in the spins of two electrons confined to GaAs/InAs quantum dots and the third qubit in the polarization of a photon. This photonic qubit interacts with the quantum dots by travelling through the designed circuitry, thereby achieving the

Deutsch gate. We discuss the challenges and feasibility of realizing these quantum gates.

PHYSICAL SCIENCES

Investigation into the Dynamics of Lipid Membrane Remodeling

Abhimanyu (Abhi) Sharma, Henry Nguyen, Nathaniel Talledge, John McCullough, Frank Moss III, Janet Iwasa, Michael Vershinin, Wesley Sundquist, Adam Frost

University of Utah, University of California San Francisco

Lipid membranes play a key role in biology, enclosing entire living cells as well as intracellular compartments. Cellular processes such as endocytosis, virus budding, and cytokinesis involve changes in membrane shape and connectivity. Membrane remodeling is essential, common, and tightly regulated. A variety of pathways, including the endosomal sorting complexes required for transport (ESCRT) machinery, are involved in locally changing membrane curvature (both invagination and evagination), tabulation, and scission. However, the mechanics of many of these remodeling events are still poorly understood. We have used an in vitro giant unilamellar vesicle system and investigated the details of membrane reshaping under local mechanical load and in several ESCRT protein backgrounds. We will discuss our results, which demonstrate how protein-based regulation can help remodel bilayer membranes.

PHYSICAL SCIENCES

Robustness of a Quantum Algorithm in the Presence of Noise

Scott Johnston, Jean-Francois Van Huele

Brigham Young University

Quantum algorithms offer efficient solutions to computational problems that are expensive to solve classically; however, their implementation on quantum computers requires dealing with inevitable errors such as noise and decoherence. We present a quantum implementation of Simon's algorithm for a simple toy problem whose quantum algorithmic solution

enjoys an exponential speed-up over any classical solution and use noise simulation to analyze the effect of noise on the algorithm's effectiveness. We also compare results of noise simulations with implementations on a real quantum computer.

PHYSICAL SCIENCES

Numerical and Stability Analysis of the Lengyel–Epstein and Brusselator Systems

Parker Evans

Southern Utah University

We study a Lengyel–Epstein and Brusselator system, which are used to describe the reaction of chlorite-iodide-malonic acid (CIMA) and the Belousov–Zhabotinsky reactants. These reactions are commonly found in nature, describing certain patterns such as the recurring stripes in a zebras and leopards and other cyclic patterns. The stability of the steady-state solution of these systems are analyzed. We develop some numerical schemes that guarantee the positivity of solutions. The numerical solutions, from the numerical schemes we have developed, verify the theoretical results for the system.

PHYSICAL SCIENCES

Solvatochromic Properties of Novel Molecules Structurally Related to Brooker's Merocyanine Dye

Jacob Newey, Kyler White, Mackay Steffensen

Southern Utah University

Solvatochromism is a chemical property of some compounds that can change color, depending on what solvent they are dissolved in. Solvatochromic compounds can be used to predict the colors of solutions or predict suitable solvents for particular uses. Theoretically, they can also be used in sensors or molecular electronics to construct molecular switches. The most well-known solvatochromic compound is an organic dye called MOED or Brooker's merocyanine. MOED's color changes depending on the solvent and its polarity. In general, the more polar the solvent, the shorter the wavelength of light it will absorb. This is referred to as a bathochromic shift. The solution will appear as the

complementary color of the light it absorbs. This is because the molecule can exist in neutral and zwitterion resonance forms. We have synthesized MOED using an expedited route and tested its solvatochromic properties in various solvents. Our future goals are to synthesize novel solvatochromic compounds, similar in structure to that of MOED, and compare their properties.

PHYSICAL SCIENCES

Developing Selective Absorbers for Solar Water Heating; Undergraduate Materials Research at Weber State University

Kristin Rabosky, Colin Inglefield, Corey Collatz

Weber State University

The materials group at Weber State University has been working with undergraduates primarily from the physics and chemistry departments on research projects that combine recipe design for materials growth, multiple characterization methods, and device testing. We present an example of cermet-based selective solar absorbers (SSAs) of SiO_2 with Mo incorporated through sputtering growth. The SSA layers and prototype water heating device were tested, and the growth method was refined in a scaled-down version of the iterative cycle of materials development. This exemplary project demonstrates the type of opportunities available to students in the materials program and opportunities for collaborative efforts with other Utah institutions doing materials research.

PHYSICAL SCIENCES

Concentration Variation of Reagents on Silver Nanoparticle Production via a Microfluidic Device

Cade Christensen, Brittany Christensen

Southern Utah University

Microfluidic devices are devices that contain micrometer-scale channels through which liquids flow. These liquids behave differently on these scales than they do in everyday life. One example is that the liquids flow in defined sheets, called laminar flow, which means two liquids flowing

next to each other will not mix until they are forced to. These flow properties can be utilized to mix solutions at a very specific time during the chemical process, such as during the synthesis of nanoparticles. Nanoparticles are particles, often of metals, that are typically between one and several hundred nanometers in size. On this scale, the nanoparticles behave differently than the bulk metal does. Forming a desired size of nanoparticles requires specific conditions, and this project aims to show how varying the concentrations of the reactants in a microfluidic device can improve or detract from the formation of silver nanoparticles.

PHYSICAL SCIENCES

Low-Temperature Deviations from Arrhenius Behavior of Kinesin-1

Flo Doval, Kassandra M. Ori-McKenney, Richard J McKenney, Michael Vershinin

University of Utah

Kinesin-1 is a mechanochemical enzyme that is essential for executing long-distance transport of cargos in eukaryotic cells via processive motility along the microtubule network. KIF5A is a conventional kinesin in the Kinesin-1 family. The temperature dependence of enzymatic activity for several kinesin-1 motors has been reported to follow a simple Arrhenius trend. The range for this observation has been gradually extended to higher temperatures, as it became possible to circumvent and, more recently, control kinesin degradation. However, both biophysical and biochemical measurements to date have been limited down to $\sim 5^{\circ}\text{C}$. We investigated the enzymatic activity of KIF5A at even lower temperatures and have observed a break in the Arrhenius trend, corresponding to higher activation energy at lower temperature. We will report our investigations of this phenomenon in different biochemical backgrounds and discuss its cause as it relates to the nature of the rate-limiting step of kinesin's enzymatic cycle.

POSTER

Undergraduate Student Research Conducting DNA Extraction, Sequencing, and Assessing Quality from Angiosperm and Gymnosperm Herbarium Specimens

Ethan M. Rosati

Utah Valley University

The goal of this project is to gather and collect the genetic information to lay the groundwork for future engaged learning opportunities. The DNA sequences collected will create a reference collection, building a valuable student resource for future phylogenetic work. DNA was collected from angiosperms and gymnosperms from exsiccate herbarium specimens, by way of destructive method of grinding. After material collection, DNA extraction kits were used, and isolates were evaluated for quality and quantity of extracted DNA. DNA was amplified via PCR, then PCR products were observed for quality and quantity though gel electrophoresis and nanodrop spectrophotometry. To investigate success in amplification of the target DNA sequence, the ITS region was sequenced. Geneious software was used to edit DNA sequence data and measure DNA sequencing quality. Ultimately, the goal is to add our DNA sequencing data to the barcoding body of knowledge to help biologists have intellectual control and to conserve and protect the biota of Utah and the world.

POSTER

Prevalence of *Batrachochytrium dendrobatidis* in *Hyla arenicolor* in Washington County, Utah

Dagny Hunt, Seth Collins, Curt Walker

Dixie State University

Amphibian species worldwide have been faced with decline and extinction due to chytridiomycosis, a lethal infection caused by the fungus *Batrachochytrium dendrobatidis*. A small number of species have been found that do not experience detrimental effects following exposure to the fungus. One such species is *Hyla arenicolor*. It has been speculated that these frogs are capable of preventing infection by basking in the sun. Fluorescently labeled antibodies were used to determine the prevalence of chytrid in wild populations of *H. arenicolor* in Washington

County, Utah, and to diagnose captive specimens held at the optimal temperature range for *B. dendrobatidis* for six months without any symptoms of chytridiomycosis. An ex vivo assay using skin secretion samples was used to determine *H. arenicolor* immune response to *B. dendrobatidis*. The captive specimens were determined to be positive for *B. dendrobatidis* and the growth of *B. dendrobatidis* was inhibited in the plates containing diffusion discs saturated in *H. arenicolor* skin secretions. These results may provide insight into the mechanism by which wild *H. arenicolor* survive the cooler months when infected.

POSTER

Determining the Physiological and Morphological Effects of Nutrient Removal on *Brassica rapa*

Heather Moon, Sarah van Dijk

Utah Valley University

Nutrient deficiencies have various effects on plant growth and health in different species. Depending on the nutrient deficiency, plants may exhibit unique physiological and morphological symptoms. Knowing the response in specific species is useful for farmers, because it enables them to discover and rectify a nutrient deficiency before the damage becomes permanent. They can also use the knowledge to adjust the nutrients and correct potential deficiencies that can affect the physiology of the plant. The purpose of this experiment is to observe the effects of isolated nutrient deficiencies in the species *Brassica rapa*. Evaluation in this species is important because various *B. rapa* subspecies are cultivated worldwide for oil and vegetable crops. The observed nutrients will be phosphorus (PO_4^{3-}), nitrogen (NO_3^-), potassium (K^+), magnesium (Mg^{2+}), and iron (Fe^{2+}). Our objectives are to evaluate whether there is a difference among plant performance upon depletion of each nutrient and to determine how the depletion affects different physical and morphological traits of the plant, including the effect on roots, shoots, leaves, and flowers. *B. rapa* is a flowering plant with a 2- to 3-week growing cycle. We will first sterilize our seeds, and let them germinate in Petri dishes for 1–2 days. Following germination, seedlings will be transferred to styrofoam containers filled with vermiculite and then placed onto our watering systems. To test the effect of the various nutrients, watering treatments will be applied, each lacking a different nutrient and one with all the nutrients present. These will each be replicated 4 times with 6 plants in each replicate. Water treatments will

stop after 2 weeks of growing, and we will evaluate water potential, size, and physical traits of the plants, including dry mass of shoots and roots.

POSTER

How Do Endophyte Communities Change in *Juniperus osteosperma* Tissue after Wildfire?

Reagan Dodge, Mackenzie Jones, Nick Owen, Sam Smalley

Utah Valley University

Juniperus is a common woody genus endemic all over the West Coast, with *Juniperus osteosperma* (common name Utah Juniper) found abundantly in the state of Utah. Junipers play key roles in pinyon–juniper forest complexes, which are commonly susceptible to wildfires. The aftermath of a wildfire appears devastating and desolate, but studies have shown that fungal communities help break down these large biomasses of charred plant life via decomposition and help replenish the soil by promoting microbiome formation in these areas. This plays a key role in regrowth after these events because plants rely on symbiotic relationships with bacteria and fungi to improve nutrient uptake, enhance pathogen resistance, and resist stress. Therefore, it is critical for those ecosystems first to rebuild their microbial community. These fungal communities typically start from endophytes, which may persist within the tissue of trees killed by fire. This study will assess the role of endophytes present in *J. osteosperma* wood samples in the aftermath of the aforementioned wildfire ecosystems and how these fungal communities persist and change in dead tissue over time. We will be able to evaluate the impacts those fungal endophytes may have had on the physiology of their host and as members of a new soil microbiome.

POSTER

Evolution of Wood Warbler (Parulidae) Song

Sierra White, Marggie Glenn, Nicolas Gasparro, Jungyun Huh, Rachel Bolus

Southern Utah University

The Parulidae, or Wood Warblers, is a family of birds found in the Americas. The song behaviors vary among species, particularly in

repertoire size (i.e., how many unique song types each individual sings), the context in which different song types are sung, and whether one or both sexes sing. The variation in these traits could have been affected by variation in morphology (i.e., beak size and mass), habitat, or migratory behavior. To test these relationships, we collected data on these characteristics from the literature and mapped them using a published phylogenetic tree of 107 species in this family. We will also measure the frequency and modulation of archived songs using Raven bioacoustic software. Using these data, we will produce analyses to formulate and test new hypotheses on the evolution of song in this group and publish an updated review.

POSTER

The Impacts of Cannabis Use on Medical Conditions, Drug Use, and Financial/Academic Success

Tyler M. Hacking, Alex Johnson, Meshel Patten

Utah Valley University

Cannabis use is categorized into two types: medical and recreational. These are general terms used to describe the way it is used. The recreational user is classified as someone who uses cannabis outside of medical prescription. This, however, could be inaccurate because some of these individuals could be in a location where the legislature does not allow medical cannabis use, or someone who does not have insurance, or someone who does not have a doctor who is willing or able to write a recommendation or prescription for cannabis use. Because animals seek out molecules that provide physical and mental medical treatments, perhaps, in reality, the recreational user is extremely rare. Is it possible that a majority of these recreational users are actually medicating themselves for untreated medical conditions? We aim to find correlations between recreational use of cannabis and pre-existing medical conditions, to determine whether cannabis is a gateway drug toward or away from other drugs and financial/academic success. We will distribute anonymous surveys with questions targeted towards cannabis use and its intended purpose as well as potential consumers. The online survey responses will be collected anonymously via SurveyMonkey. The in-person surveys will be collected using a black box. This will ensure there will be complete anonymity when collecting data from informants.

POSTER

Perceptions of GMO vs. Organic Foods among Different Education Levels and Backgrounds

Mackenzie Jones, Nanasi Sekona, Miles Beck, Matthew Olsen

Utah Valley University

Genetically modified organisms (GMOs) are defined by the US Department of Agriculture as any organism whose genome has been altered using any form of genetic engineering techniques. Modern-day agriculture has turned to using GMOs to increase crop yield and improve crop efficiency. This study examines the perceptions of participants with regards to GMOs as a food source compared with organically grown food. Organically grown foods are defined in the US by growing organisms without the use of synthetic pesticides, genetically engineered seeds, and petroleum-based or sewage-sludge based substrates. For a company to be legally certified organic by the USDA, they must comply with the aforementioned stipulations. According to research, GMOs are typically portrayed in a very negative light in the media, which tends to influence the population's personal opinion on the subject matter. Other studies have demonstrated that there are no real risks involved with consuming genetically modified foods; furthermore, studies also have shown that organic foods do not show a large nutrition gap between them and GMOs. Anonymous structured surveys will be electronically given to a wide range of participants to assess demographics with the participants views on GMOs. Conducting this research provides valuable insight on the interaction between producers and consumers, through goods sold and product preference in correlation with educational background.

POSTER

Differences in Salt Tolerance of *Spinacia oleracea* when Inoculated with Fungi from the Rhizosphere of *Atriplex canescens*

Ethan Darby, Aubrie Bogle, Steven Kelty, Dasha Horton

Utah Valley University

Atriplex canescens is a native Utah plant with the ability to withstand halophytic environments because of a complex relationship with

microorganisms such as fungal communities in the soil. *Spinacia oleracea*, spinach, is a commonly grown crop with halophytic potential and similar tolerances to cold and heat as *A. canescens*. *S. oleracea* and *A. canescens* are also in the same plant family, Chenopodiaceae, which makes them closely related in terms of phylogeny. This can reveal similar relationships between the *S. oleracea* and *A. canescens*. The purpose of this study is to evaluate how an inoculation made of the fungi complex in the roots of *A. canescens* affects the salinity tolerance of *S. oleracea* through a comparison of 4 treatments of inoculated *S. oleracea* plants and 4 noninoculated control treatments (25 replicates for each treatment). Previous studies have shown success of bacterial rhizosphere inoculation of *S. oleracea* in increasing salt tolerance as well as multiple experiments with other halophytic fungi inoculants to plants not specific to the Utah region. The inoculation of agriculturally important crops was able to increase salinity tolerance and not create noxious secondary compounds or endangering conditions for other species associated with the crop. Climatic change is predicted to increase the salinity in certain Utah regions and water sources. This research is intended to test the effects of this soil salinity change to benefit agricultural endeavors and will provide important information applicable to agricultural crops.

POSTER

Perception Analysis of CBD at Utah Valley University

Michael Lacerda, Matthew Carter, Christopher Gowans, Kaina Payan

Utah Valley University

Cannabidiol (CBD) is often given a poor reputation because of the perpetuation of false information concerning its effectiveness, addictiveness, and legality. We believe these stereotypes persist because of a lack of education on the subject and the associations and negative perception of cannabis (marijuana). As of 2019, 14% of Americans use CBD for medicinal uses. This research aims to gather information about the perception of CBD among people at Utah Valley University. It will examine the perception in conjunction with significant demographics: ethnicity, sex, area of study, education level, age, religious affiliation, income, political affiliation, and current knowledge of CBD. Randomized participants will take a survey using a Qualtrics survey administered on an iPad throughout the 20 main buildings of the UVU campus. Through the publication and presentation of this research, we

aim to clarify misconceptions and false information surrounding CBD and its use as a medicinal remedy.

POSTER

Predicting the Presence of *Juniperus osteosperma* Using Niche Modeling Techniques at the Three Peaks Recreational Area

Justin D. Mickelson, Rachel T. Bolus, R. Matthew Ogburn

Weber State University

We conducted a study in the Three Peaks Recreational Area using niche modeling techniques to predict the presence of *Juniperus osteosperma* in the area. Sampling included 506 plots (132 containing *J. osteosperma*) with radii of 3 meters. Plots were tested for soil composition and evidence of plants and animals. Sampled plots were analyzed with R and MaxEnt. An analysis of the plots found that the most important factors, both biotic and abiotic, in determining the presence or absence of *J. osteosperma* were the presence of a rocky terrain, total plant count, total plant species, habitat type, and soil type. In plots where the soil was not rocky, and the plant count was less than 31.5, juniper was absent in 82% of the 274 plots. The model was weakly predictive of the presence of juniper (CCR=0.74, Kappa=0.43, n=506, $p<0.01$). More research may be done by using these variables to predict the possible migration of *J. osteosperma* into new ecosystems as local climates change. It is anticipated that this project will continue by sampling the plots again to obtain more consistent data collection methods and accuracy, in addition to analyzing more focal species from the sampled areas.

POSTER

Can Little Changes Kill You? Using Great Salt Lake Brine Shrimp to Examine Developmental Mortality

Hannah Adams, Tanner Allgaier, Ashleigh Jackson, Jonathan Wasden, Paul Dunn

Utah Valley University

Many organisms exhibit a “bathtub”-shaped mortality curve, with high but decreasing mortality risk early in life (ontogenescence), a bottoming-

out around age of first reproduction, and then a gradual increase in mortality risk with age (senescence). The evolutionary implications of senescence have been studied extensively because of its direct implications for human health and society. Ontogenescence, however, has remained largely understudied despite its immense importance to all organisms that exhibit this life-history trait. The question that demands an evolutionary explanation is why ontogenescence would evolve in the first place since the disadvantages of dying before reproduction should be strongly selected against. One possible explanation is the Transitional Timing Hypothesis, which claims that increases in mortality are associated with transitional events (e.g., hatching) and that the most dangerous of these events are concentrated early in life. Prior studies have shown links between increased mortality and the major transitions of an organism's life cycle, such as hatching and metamorphosis of barnacles. The goal of this study is to look at the potential mortality risks of less drastic, but still necessary, transitions such as molting events in brine shrimp (*Artemia*). To accomplish this, individual brine shrimp were hatched from cysts and then monitored throughout their development until maturation. The timing of molts and deaths were recorded to look for links between timing of death and transitional stage. Pilot experiments for determining ideal culturing conditions that allow for the collection of individual-level data with this model species are ongoing.

POSTER

Exploring the Synergistic Effects of Vancomycin and Electrohydraulic Shockwaves against *Staphylococcus aureus* Biofilms

Ashley Roach Escarate, Bryce Brunetti

Utah Valley University

Medical device-associated infections can lead to serious complications affecting the health of patients. Electrohydraulic shockwave treatments have shown bactericidal activity in some microorganisms. Biofilms are structures formed by microorganisms enclosed in an extracellular matrix. They form on a variety of surfaces, protecting the microorganisms from antibiotics and facilitating their growth. This can result in a high rate of drug resistance and in many cases results in chronic bacterial infections. Previously determined MIC₅₀ concentrations of vancomycin had little effect on biofilms at 12 hours of treatment when not paired with

shockwave therapy. This research evaluates the synergistic effect of different concentrations of vancomycin and shockwaves after 12 and 24 hours of treatment, given that vancomycin has shown time-dependent activity. Biofilms were grown in 96-well plates and the corresponding treatments were applied. XTT and Crystal Violet assays were used to quantify and qualify the presence of the biofilm and the antibiosis effect. The results of this experiment will be discussed in detail. A better understanding of the synergistic effects of antibiotics and shockwave therapy may lead to more effective treatment of biofilm and device-associated infections.

POSTER

Identifying Conservation Needs of Dwarf Bear-Claw Poppy Populations

Spencer Douglas Thatcher

Dixie State University

Dwarf bear-claw poppies (*Arctomecon humilis* Coville) are an endemic species of wildflower in Washington County, Utah. These poppies only flower for about a month during the summer. There are currently seven known locations where these poppies are found. Conservation efforts to protect these populations include research to understand the reproductive success of each site. Populations with low reproductive success may indicate the need for additional efforts or interventions to save this unique species. Four specific locations were monitored over a three-year period. Poppies in these areas were tagged and studied during their flowering seasons, and individual inflorescences were bagged and collected to determine struggling locations and their correlating issues related to population decline. Seeds were split into two groups—immature and mature—and were weighed and counted. A large percentage of immature seeds may indicate a resource or pollinator issue for the population. A low overall seed production may indicate that a resource limitation or other stressor is reducing the population viability.

POSTER**Tracking Professional Development through Creation of Culturally Appropriate Educational Materials****David R. Byrd, DeeDee Mower, Penée Stewart, Richard Fry, Nadia Wrosch***Weber State University*

Teacher candidates bring with them knowledge, experiences, values, memories, and beliefs that are culturally and socially determined when they enter their teacher education programs. Some of these factors will align well with the ideas and experiences they gain in their program, both through coursework and practical experiences. However, when this knowledge, experiences, and so on are challenged, the candidate can feel some significant disequilibrium. Both types of learning can provide growth. Whereas the former can reinforce and add to existing beliefs, the latter can create instances where the teacher candidate must reevaluate and reconsider their stance and find ways to come to terms with the discordant knowledge. One area in teacher preparation where this situation can take place is in materials development. The present study examines the professional development of three US teacher candidates creating culturally appropriate stories and accompanying educational materials for Thai orphan students. Using grounded theory, the researchers triangulated philosophy statements, journals, and interviews to track how developing materials for students in a different culture than their own provided opportunities for professional growth for the participants. Initial results indicate that the candidates were able to change their teaching beliefs as they considered for whom they were creating the materials and what concepts needed to be addressed in the stories and other materials and how they could accomplish these goals. The greatest struggle and growth came as they reflected on what they created and why. The results provide implications for both teachers and teacher educators.

POSTER**Synthesis of Halohydrins by Epoxide Ring Opening****Sydney L. Rowley, Nathan S. Werner***Southern Utah University*

A need exists for reactions that produce new products under mild conditions with high efficiency and selectivity throughout all fields of chemistry. Many reactions use harsh conditions that can decompose sensitive molecules. For example, hydrobromic acid can be used as a reagent to open an epoxide to create a useful halohydrin functional group. However, hydrobromic acid is a very reactive reagent that can also react with many other functional groups. We have studied the synthesis of halohydrins from epoxides using a ruthenium catalyst and visible light. The necessity and stoichiometry of all reagents was evaluated. The regioselectivity of the epoxide opening was studied.

POSTER**Methylene Blue Derivatives as Potential Photosensitizers in Photodynamic Therapy****Jeffrey Brenton Bushnell, Jacob Dean***Southern Utah University*

Methylene blue (MB) is used in photodynamic therapy, a technique used to treat cancer, such as skin, lung, and esophageal. Photodynamic therapy requires a photosensitizer molecule, like MB, that becomes excited by light and can transfer that energy to oxygen in target tissues. This singlet oxygen then attacks nearby cells, providing the therapy. Although MB is effective for this treatment because of its ability to absorb light in the visible region, derivatives of the MB, i.e., those with heavier atoms, may be able to sensitize oxygen species more efficiently because of their expectedly larger spin-orbit coupling constants. In this work, a series of chemical derivatives that utilize the MB framework were investigated using time-dependent density function theory. The absorption spectra were simulated and compared against MB, and the operative triplet state energies were compared to determine possible efficacy for photodynamic therapy. Calculations from these heavy atom substitutions show that their absorption spectrum can change, at times allowing for a wider range of light and enhanced absorption to excite

more molecules. The results of this work suggest that several of the compounds studied would likely be even more effective than MB.

POSTER

Reactivity of B-Keto Radicals with Halogens

Garett Ruesch, Nathan Werner

Southern Utah University

The Ru(bipy)₃²⁺ catalyst has received a lot of attention from researchers because of its ability to oxidize or reduce organic substrates in its photoexcited state. The catalyst is known to form reactive b-keto radicals from α,β -unsaturated ketones. The focus of our research is the study of the reaction of halogen electrophiles with the b-keto radical formed through visible-light photoredox catalysis. Various halogen electrophiles and reaction conditions were evaluated in this study. By targeting the electrophilic capture of the radical, we hope to discover more about the reactivity of this intermediate and develop novel chemistry that can be used in the synthesis of pharmaceuticals and fine chemicals.

POSTER

Exploring the Behavior of Bilin Subunit N-Methyl-Dipyrinone Upon Photon Excitation

Taime Clark, Jacob Dean

Southern Utah University

Chemical compounds have many pathways by which they can process, release, and transfer the energy obtained by photon absorption, whether it is via a relaxation mechanism or a photochemical process. The photobilins, or photosynthetic pigments in cyanobacteria and some algae, are especially efficient at moving and preserving this light-generated energy to use for biological processes. To research how these tetrapyrrole photo pigments behave upon photon excitation, this investigation will focus on a bilin subunit, N-methyl-dipyrinone in the solvents methanol and dichloromethane, individually. This compound will specifically be tested without the presence of protein binding/interactions, which can affect the energy transferring capabilities of the molecule. To perform this experimentation, ultraviolet–visual absorption

spectroscopy and fluorescence spectroscopy will be used to observe the excitation of the molecule and obtain relevant data such as the molar extinction coefficient, the fluorescence quantum yield, and rates of relaxation from the excited state. These quantities will aid in the observation of rapid molecular behavior such as torsional relaxation and isomerization. The goal of this research is to find a chemical connection between biological function and better understand the exceptional energy transferring capabilities of light-harvesting bilins.

POSTER

Isomerization of (E)- β -Bromostyrene

Trace Wilson, Nathan S. Werner

Southern Utah University

Isomerization reactions are an important method for the synthesis of geometrically defined alkenes. Cis-alkenes are less stable than the corresponding trans-isomers because of the steric interactions that occur when the large groups are located on the same side of the double bond. Therefore, cis-alkenes are typically more difficult to prepare than trans-alkenes. This can pose a significant problem when a method to prepare the cis-alkene is required. Here we present our discovery of a novel trans-to cis-isomerization reaction of (E)- β -bromostyrene.

POSTER

Fourier Analysis of Ultrasound Signals for Identification of Scatterer Diameter in Agarose Microbead Phantoms

Brandon Jolley, Alex Johnson, Whitney Parry, Olivia Johnson, McKenna Parr, Clayton Rawson, Tyson Hoyt, Vern Hart

Utah Valley University

Early cancer detection requires identifying the disease at a cellular level, by distinguishing cancer cells from healthy cells at low concentrations (<0.1%). Cancerous cells typically have larger nuclei than healthy cells and can be distinguished using a variety of optical techniques, but this process is complicated when the fraction of malignant cells is extremely low. As such, high-precision detection requires highly accurate measurements of cell confluence and the ratio of healthy to cancerous

cells. Techniques such as machine learning and Fourier analysis have been used to autosegment cells in microscopy images; however, these techniques often lack a ground-truth standard to validate the segmentation results. We present a methodology for producing agarose tissue phantoms embedded with mixed polystyrene microbeads of varying diameters. These phantoms were imaged using a two-dimensional translational stage and a microscope camera, collecting hundreds of images for input to an artificially intelligent neural network for training and classification. The ability of this binary classifier to identify and quantify microbeads in the images was assessed by comparing the automated results to manual counts, producing accuracies above 90% for bead sizes of 50–200 microns. A 50-MHz ultrasound transducer was used to collect scattering patterns from each agarose phantom. Fourier analysis of these signals showed variations in the attenuation of 52–60 MHz. Results will be presented for 5 different bead diameters, which were accurately distinguished from the accompanying power spectrum.

POSTER

Scouting Friends Will Always Be: Communities in the Boy Scouts of America

Amanda McFarlane

Brigham Young University

The Boy Scouts of America has recently encountered several financial problems that have led many to believe that the organization will go bankrupt and cease to exist. In the light of criticism from both sides of the political spectrum—conservatives typically disliking policies accepting gay and transgender leaders in 2015 and then girls into the Scouts, BSA program in 2019 and liberals typically believing it promotes toxic masculinity and nationalism—some have argued that the Progressive-era organization has nothing left to offer the divisive environment of 21st century America and that the establishment's end is inevitable. However, this paper will argue that Scouting does have something vital to offer. Exploring research done among staff working at Camp Maple Dell in Payson, Utah, during the summer of 2019, this paper will show how Scout Camp creates communities among the staff and fosters a sense of connection with other people that is imperative for healthy social development. Despite it becoming increasingly rare to find this mode of sociality in modern American society, communities at camp

are foundational to the daily functioning of Maple Dell. Communities are centered around the unexpected and often inexplicable events that are simultaneously unique to and extremely common at Scout Camp. Through mutually experiencing these events and perpetuating them, staff members create relationships that border the ranges of kinship. Beyond an enjoyable summer job, this environment fosters relationships that can provide a support network years after having worked at camp. Despite the criticism it faces, Scouting provides a unique atmosphere for these relationships to form, which serves to fill an important social need for young adults that otherwise are not often being met.

POSTER

How Do You Like Your Eggs?

Aubrielle Atkinson, Sarah Applegarth, Kole Graper, Teran Sorensen

Snow College

How do you like your eggs? In the movie, *Runaway Bride*, the main character, Maggie, changes the way she likes to eat her eggs every time she gets into a new relationship. In the article entitled, "The Psychology of Romance: The Impact of Personality Traits on Romantic Relationships," Amanda Glynn cites authors, Buss and Watson, who say that, "One leading theory is active assortment, where people prefer partners whose personalities resemble their own." This may explain why many times it seems as if people will change who they are or what they are interested in based upon their significant other and their interests and opinions. We will conduct research to see whether there is a personality that changes more in romantic relationships based on the domains of the Big Five Personalities, which are extroversion, agreeableness, conscientiousness, neuroticism, and openness. Our research will be mainly focused on personality change within romantic relationships and the gender of the person in the relationship. To test these factors, we will present a survey to a variety of different people including 50 men and 50 women in relationships, 100 people who have close friends in relationships, and 100 parents who have children in relationships. The survey will be made up of questions that reflect and demonstrate each domain of the Big Five Personalities. These questions will have the survey participants rate, on a scale, the personality of the individual in the relationship before and after the relationship began. The answers to these surveys will then help us see how much the individual's

personalities changed and what aspect of their personalities changed the most. We will also be able to compare men and women and see whether gender plays a key role in personality change within a romantic relationship.

POSTER

What Makes You Jump: Can a Brief Auditory and Visual Stressor Cause a Measurable Stress Response?

**Maren Payne, Claudia Jorgensen, Tyler Barton, Peter Williams,
June Perez, Mandie Stephen, Jessi Hill**

Utah Valley University

Research conducted in various animal species including humans has led to evidence suggesting that stress in excess can be physiologically and psychologically harmful. Researchers have found a correlation between chronic exposure to stress and the development of anxiety and major depression disorders. Stress is an inevitable aspect of human life and can vary in duration and intensity depending on the individual. Experiencing a stressful stimulus leads to the activation of the hypothalamic–pituitary–adrenal (HPA) axis, which causes the release of stress hormones (such as cortisol). Furthermore, the activation of the HPA axis leads to an increase in heart rate and blood pressure. The current study assesses whether a brief stressful visual and auditory stimulus can elicit a measurable physiological stress response in college students. The participants watched a 32-minute video clip of a television show containing a 1-second stressful visual and auditory stimulus. The stressful stimulus had been spliced into the television show and occurred halfway through the video clip, allowing for comparison of physiological measures prior to stressor (baseline), during stressor, and during recovery (after stressor). Throughout watching the video clip, participants' physiological measures were recorded using an electrocardiogram associated with BioPac software. Subsequently, the participants' heart rate and heart rate variability prior and immediately after the stressor were compared by repeated measures ANOVA to assess whether the stress response was measurable. The successful completion of this experiment will guide future studies to assess various conditions that might shorten or prolong the recovery period after a stressful experience. Obtaining knowledge about the factors that can shorten the recovery period after a stressful experience will allow us to promote healthy coping techniques. Indeed, developing healthy coping

mechanisms to deal with stress could positively influence the academic performance of college students and improve their psychological and physiological well-being.

POSTER

Observing Healthy Progression in Relationships Throughout Generations

**Avery Whitaker, Haleigh Chester, Jackson Bird, Kiersten Strat,
Kloie Park**

Snow College

Most people have experienced a romantic relationship in their lifetime. As a group of curious students, we hope to gain a deeper insight into relationships. The study being proposed is that of observation through different types of physical progression in relationships, whether there is a healthy or unhealthy way. This will be achieved by comparison and analysis of what individuals define as so. The anticipated outcome is to gain an understanding of how individuals have progressed in their personal relationships to create an outline for what constitutes different types of relationships. This project will provide an opportunity for individuals to observe what deems a healthy or unhealthy relationship. Many studies and articles have been published in relation to the psychology of relationships. The National Center for Injury Prevention and Control suggests that “respect for both oneself and others is a key characteristic of healthy relationships. In contrast, in unhealthy relationships, one partner tries to exert control and power over the other.” This article gives a basis for comparing relationships. To observe healthy and unhealthy relationships, a survey will be conducted. The survey consists of three parts where questions will be asked to determine how each relationship model progresses according to the individual. First, participants will be asked what influences their views or relationships. Second, each participant will be asked to put a specific list of various physical actions to specify a healthy relationship. Third, each participant will be asked to put the same list of physical actions to identify an unhealthy relationship. Online dating terms will be included in the second and third surveys. The conclusion will be to compare results and see how demographics play a role in the results.

POSTER

“Selfie” Self-Esteem

**Hayley Hightower, Sarah Chipman, Adeline Frank, Quincy Kunz,
Abigail Spackman, Danielle Noorda**

Snow College

There are many ways to alter yourself or your pictures to post on social media, including filters, digital editing, using make-up, and posing. In a sample survey of US adults, 93% said they believe photos are edited before they are posted. For our research, we want to know how posting uncurated, natural selfies on social media affects a person's self-esteem. Our research is going to measure the self-esteem of our participants by administering a survey before and after our experiment, as well as by tracking the participant's posts/comments on social media. We will collect as many participants as we can to randomize into two groups that will allow us to gather enough data about posting on social media and its effects on self-esteem. The control group for our experiment will be posting to social media as much as the experimental group, every other day for two weeks, and will be posting the same content to social media as they normally do. The experimental group will be posting selfies they take of themselves first thing in the morning: puffy eyes, no make-up, no altering or editing their photos in any way. We will observe the comments and reactions of others on their posts, which will allow us to compare the change in self-esteem of the experimental group with the control group. If this study shows that after posting uncurated photos their confidence goes down, then it justifies people in editing their photos and making themselves look good online. However, if they find their self-esteem goes up, then there will be evidence to show it is unnecessary to alter every photo of themselves.

POSTER

Reflexive and Sustained Attention: Identifying Individual Variability in Children

**Brian Farstead, Tanner Williford, Hunter Schow, John
Muldowney, Victoria Stewart**

Brigham Young University

Reflexive and sustained attention are important components of daily functioning, and those who exhibit attention deficits typically have

problems in school, work, and relationships. Previous studies have measured sustained and reflexive attention using different tasks with disparate stimuli. Because the stimuli are different, it is unclear how reflexive and sustained attention are related. There are some indications in the literature that individuals tend to be better at one or the other type of task. We measured reflexive and sustained attention in a sample (N=185) of children who completed two computer tasks that recorded response time and accuracy. We developed the two tasks so that all stimuli were identical, but the reflexive attention task used peripheral stimuli and the sustained attention task used central stimuli. Parents also completed questionnaires reporting demographics (e.g., age and sex) and the child's usual sleep habits, behavior at home, and behavior at school. Asking about sleep, home behavior, and school behavior allows us to identify predictors of individual variability in computer-task scores. We anticipated that children who have a better reflexive attention (lower response times and higher accuracy) would score lower on sustained attention. Furthermore, we expect the relationship between reflexive and sustained attention would be moderated by aspects of behavior related to sleep, home life, and school. Determining the relationship between different components of attention is important because it will help us to understand the underlying factors that contribute to different deficits in attention. Furthermore, it is important to understand how these different components of attention manifest by age, sex, behaviors at home and behaviors in school. Understanding the relationship between reflexive and sustained attention and their association with child characteristics could potentially contribute to interventions in individuals who have symptoms of attentional deficits.

POSTER

The Role of Parental Control on Childhood Anxiety

Natalie Merrill, Jennifer Shubert

Utah Valley University

Anxiety is a growing epidemic among society today, and the age of onset is becoming increasingly younger. Control over one's environment is a major contributor to anxiety; thus, research on childhood anxiety revolves around parenting styles related to acceptance and autonomy-granting behavior. It is hypothesized that children of parents who lack autonomy-granting behaviors are more likely to suffer from anxiety due to their perceived lack of control. The primary aim of this study is to

assess the development of anxiety in youth through addressing two factors—parental control and child’s perceived control—and how these factors relate, thus leading to the development of anxiety. Data for this study comes from Wave 6 of the Schools and Families Educating (SAFE) Children Study. The study consists of 338 children ages 9–10 (mean age=9.11, SD=0.31; % female=53.4%), 339 parents, and 305 teachers. Linear regression analyses revealed parental involvement significantly predicted social anxiety, $\beta=.181$, $t(338)=2.77$, $p<.01$. Results support the hypothesis that excessive parental involvement contributes to the development of childhood anxiety. Prior literature found that over-reactive parenting encourages the child’s dependency on their parents, resulting in an underdeveloped sense of self and fearful perspective of the world. When children lack opportunities for independence, they do not develop proper decision-making and coping skills, thus leading to anxiety. Informing parents on the importance of autonomy-granting practices during early childhood and educating children on positive decision-making skills and healthy coping mechanisms for stress will decrease the child’s likelihood of developing anxiety.

SOCIAL SCIENCES

“Ripple in Still Water”: Psychedelic Rock Resistance

Theresa A. Martinez

University of Utah

Psychedelic rock music sprang from a fascinating amalgam of influences. The sound perhaps first emerges from a pioneer boomtown mentality of free-thinking and Barbary Coast–mindedness found in the San Francisco Bay Area. Wedded to this was a history of campus and community political activism—from trade unionist movements to student organizing at the University of California at Berkeley. In addition, the Beat Generation had a hand in the mix as some of its members settled in San Francisco in the 1950s for a time, sowing the seeds of countercultural dissent against the quintessential American status quo, privileged white work ethic in the throes of materialistic and conspicuous acquisition. Moreover, the music of this era would be itself guided by the folk rock of its day but also a revival of interest in African American blues and jazz. Psychedelic rock referenced the interests and concerns of countercultural artists in the Bay Area and often focused on critiques of the establishment. This paper is an exploration of

psychedelic rock through a theoretical framework that builds on dramaturgical approach as well as oppositional culture and resistance theories' performance as resistance or oppositional performance. Through a content and thematic analysis of the lyrics of selected psychedelic rock artists, we will reveal a wealth of oppositional performance.

SOCIAL SCIENCES

Toxic Friendship Scale

Emily Arrington, Maya Howell, Avery Hansen, JD Myers

Snow College

Multiple assessments exist to evaluate different relationships. The Marital Satisfaction Inventory, developed by Douglas Snyder in 1997, assesses marital satisfaction and quality. Another study created a friendship inventory to assess positive and negative friendship qualities in young adolescents. Many of us have friends with whom we spend much of our time. How do we know whether the friends we make are influencing us in good ways? Are our friends toxic? Do females stay in unhealthy friendships more than males? We decided to conduct research to create a Toxic Friendship Scale and to assess which gender is more willing to stay in an unhealthy friendship. There are many scales to evaluate intimate relationships, but there is a lack of serious scales to assess friendship quality. There is a lack of friendship assessments that determines the quality of a friend and how healthy the relationship is. Our assessment will focus on assessing these aspects of friendship, specifically for ages 25 and under. We chose this age range because at this time we are developing socially and have a dependence on our peers. The assessment will only assess interpersonal relationships and will assess whether the friendship is emotionally and mentally damaging. There is a lack of information on unhealthy friendships; we are aiming to assess toxic relationships but also whether or not a male or a female is more likely to stay in a toxic friendship. We plan to create an assessment to evaluate unhealthy friendships in adolescents to young adults. We will do this by giving males and females a survey to find whether they have unhealthy friendships. We will be assessing students at a small college in rural Utah. We aim to assess which gender has more toxic friendships with this assessment.

SOCIAL SCIENCES

The Influence of Pressure on Decision Making

Shayla Howe, Charly Pace, Ryker Erickson, Demi Contreras

Snow College

The average adult makes a whopping 35,000 decisions per day, ranging from something as simple as deciding to brush your teeth to the complexities of planning a birthday party. Several factors influence how much time and thought is involved in decision making, and there are studies that research further into these factors. One variable that clearly has an impact yet has not been adequately researched is the impact of pressure on the ability and time it takes to make a decision. To gain insight on how the pressure of a situation inhibits or encourages the ability to make decisions, two tasks will be measured: planning a date and creating a school presentation. Four variables within each task will be tested: first as an individual with high pressure, second an individual with little pressure, third with a group facing high pressure, and fourth in a group completing a task with low pressure. This will be done through task simulation and observation combined with survey questions during and after the experiment. Questions will be administered in intervals throughout the task to gauge stress levels, derived from the State-Trait Anxiety Inventory. The pressure felt will be measured both by self-report in the survey as well as visual observation for signs of distress by the researchers during the experiment. This will be compared with the concluding choice that was made and the time it took for the group/individual to come to that conclusion. The anticipated outcome is that individuals who face high-pressure decisions will feel more stressed and take longer to make decisions. This study is beneficial in understanding how to address and potentially relieve unnecessary pressures.

SOCIAL SCIENCES

Can't Buy Me Friendship

Arielle Brooks, Rubie Hernandez, Zamera Male, Alexi Hernandez

Snow College

Research shows how one's socioeconomic status with race or ethnic groups to which they belong can have an effect on the way that they are perceived. But just how does socioeconomic status alone affect these

perceptions and affect a friendship? The current research does not show exactly whether one's socioeconomic status affects the way one perceives their friends' social status and how it affects their relationship. A major hole in the research is that there is scarce research specifically with socioeconomic status and the effects it may have on friendships. This may add new insight to the current research because it will solely focus on the socioeconomic status and its effects, rather than focusing on different variables such as race or ethnic background and educational background. With this research, it may help provide answers to other questions such as what condition a friendship is in, what conditions people need to become friends, and what other conditions people need to continue friendships. A method of getting the sample for the research will consist of sending out surveys to college students that consist of various questions, such as what is their net income, their parent's net income, what social class they are in, what social class they believe their friends are in, and how they perceive their relationships. This method would only focus on college students because of the way college students tend to be diverse and their relationship status and their socioeconomic class. The results may show how friendships are perceived based on socioeconomic status and whether it affects the relationship.

SOCIAL SCIENCES

Dismantling Speciesism through Ecofeminism

Kiana Avlon

Westminster College

"Speciesism," the belief that human animals are superior to nonhuman animals, results in the domination and violence of othered bodies and the environment. This belief system is underpinned by root causes including, but not limited to, anthropocentrism, patriarchy, and rationalism, which hierarchically arrange one type of identity or way of knowledge as superior to others. This presentation investigates these root causes to shed light on the historical context and the current implications in the animal liberation movement. Whether it is Francis Bacon's description of nature as the common harlot or Kant's ideal of rationality devoid of emotion and intuition, these ideologies continually shape the prevalent view that humans, specifically white, cishetero males of European origin/descent, have dominion. Furthermore, anthropocentrism, patriarchy, and rationalism inform dominant economic and political systems fueled by the commodification and assault of nature and bodies.

Ecofeminism offers a powerful framework to counter the root cause of speciesism as this theory studies the overlap of the oppression of women and nature. Understanding the role of ecofeminists, who center their work on the inclusion of nonhuman animals, is crucial to unlearn hegemonic beliefs and to adopt alternative ways of coexisting with other beings within ecological systems at large.

SOCIAL SCIENCES

Climate Justice and the Human Rights of the Subaltern: A Dire Need for a Treaty

Giancarlo Panagia

Westminster College

This paper analyzes the human rights and lack of political recognition of residents within the Global South and those countries, specifically in the central Pacific Ocean, where the impacts of climate change are already being seen and felt. This research focuses on the application of theories and concepts of political recognition and status to the bio- and necropolitics of those doomed to live bare lives in those islands. Some authors already provide, as a solution, the drafting of a new treaty for the protection of climate refugees, given the inability of the international community to provide any form of rescue to these islands. We suggest the use of the tool of actor-network theory as a foundation for the drafting, signing, and ratification of this new treaty.

SOCIAL SCIENCES

Leadership: A Protean Institution of the Mind and of Civilization

Pierce Bassett

Brigham Young University

As the inherent nature of leadership is continuously redefined in contemporary society, there is accentuating emphasis placed on its utilization and comprehension. The primary objective of this research paper is to examine this emphasis on leaders in the 20th and 21st centuries, analyzed from the perspective of a university student. This research explores the study of specific styles, differences, and examples of leaders

within community and throughout history. Further studies into the development of leadership processes have the potential for the synthesis of ultramodern techniques in the advancement of ethics, diversity, and communication in all facets of leadership positions.

SOCIAL SCIENCES

Has the World Failed Us? Social Sickness in Utah County

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There is a long tradition in anthropology of examining nonbiomedical or “native” forms of healing. This paper contributes to this anthropological dialogue by critically assessing why people gravitate to more holistic practices. If anything, anthropology teaches us that a holistic view of what constitutes health and the body is the norm rather than the exception. My research was conducted in Utah through ethnographic data collection. My methodology was participant observations, interviews, and focus groups. I present my data based on actual conversations and personal experiences I had with eight individuals who practice complementary and alternative medicine, specifically using gemstones and crystals. Recently, there has been a resurgence of the recognition individual trauma may play in the receptivity of more alternative forms of health care. Although I think trauma provides a narrative structure, it cannot be the sole explanation of why people seek nonbiomedical treatments. This paper will argue that the social practice of alternative healing through gemstones and crystals cannot be explained away as a coping mechanism for personal failure. My evidence will show this by introducing my readers to four of my key informants who have experienced trauma and participated in crystal healing as they sought meaning and purpose in their suffering. Finally, I will show an example of an informant that uses alternative medicine although he has not experienced traumatic life experiences. My results showed that people often feel alienated by their families, social groups, or medical doctors. My informants found comfort, health, and purpose in alternative health care practices. This study emphasizes the need to take into account the impact of social systems and the growing concern in the United States with impersonal and expensive health care systems.

SOCIAL SCIENCES

Understanding Us Programing

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Salt Lake Community College student researchers collaborated with Understanding Us, a local nonprofit organization, to collect demographic information among people experiencing homelessness in downtown Salt Lake City. This organization currently provides several programs, including a Tai Chi program at the downtown library. Student researchers have collected preliminary demographic survey data to help the organization better understand the population they are serving to best meet the needs of participants. This information will help to measure program efficacy, educate the broader community about homelessness, and help to provide data that can be used to further Understanding Us programing.

SOCIAL SCIENCES

Peeking through the Palisade at Palmares: A Composite Social History

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This paper analyzes the history of Palmares, a 17th-century maroon community located in the hinterlands of colonial Brazil with a population of between 10,000 and 20,000 escaped slaves, indigenous tribes, exiled Dutch colonists, and Portuguese deserters. Currently, very little is known about the inner workings of Palmares, including its social institutions or its political structures. Existing colonial sources portray the community as an inherent foe, but the relationship between colonists and Palmares was more nuanced and complex, involving mutual benefits. The complete lack of sources from within Palmares has forced historians to paint the community with broad brushstrokes, resulting in conflicting portraits of Palmares. This paper utilizes a three-pronged methodology to better understand Palmares and its society: a critical analysis of official colonial records dealing with Palmares, comparisons with other contemporary maroon communities, and an evaluation of the published archeological record from the area. The society uncovered by this

approach refutes previous characterizations of Palmares, revealing a portrait of a complex, trans-Atlantic community.

SOCIAL SCIENCES

Article 9: Japan's Constitutional Conundrum

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Pursuant to Japan's defeat in World War II, the United States rewrote Japan's Constitution, modifying Japan's style of governance and imposing restrictions on the country's military capabilities. Article 9 (known colloquially as the "peace" or "pacifist" clause), one of the clauses promulgated in Japan's post-war Constitution, exemplifies the U.S. mission at the time: destroying any chance of Japan resurging to power by forcing the country to demilitarize and relinquish its military capabilities. It also prohibits Japan from ever maintaining a standing army again. Thereafter, the U.S. and Japan ratified the Treaty of Mutual Security, which obligates the U.S. to commit a portion of its troops and weapons to defending a demilitarized and defenseless Japan. This arrangement still holds today. Althoughs Article 9 and the U.S.–Japan treaty were arguably conducive to Japan's post-war recuperation and economic revitalization, as well as symbolically significant to many Japanese of their country's eternal commitment to peace, the modern political climate has diminished their ability to adequately protect Japan's security. This paper explores two questions, the first of which asks whether Article 9 should be revised. Given rising tensions with China and North Korea, wavering U.S. commitment, the evolving nature of U.S.–Japan relations, and doubts about the constitutionality of Japan's important Self Defense Forces, this paper concludes that Article 9 must be revised to reflect Japan's contemporary realities and the challenges it faces. The second question asks what risks, if any, that a revision of Article 9 would incur. This paper proposes two considerations towards this end: Revision may result in domestic unrest and a deterioration of relations with neighboring and enemy states. Despite these proposed perils, this paper ultimately concludes that such risks are mitigated by the necessity of revising Japan's Constitution to protect national security, the integrity of the Constitution, and Japan's independence.

SOCIAL SCIENCES

Blue-Collar Workers' Perceptions of Queer Individuals

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The perceptions of blue-collar workers are an underexamined part of understanding queer identities in the social world. Those perceptions influence people's views; views influence voting and legislation. This study used a survey to measure various comfort levels for interacting with queer individuals. The hypotheses predict that more people are comfortable with homosexuality than gender identity, that they are more comfortable working with queer people rather than being friends, and that there will be a lack of support for queer legislation.

SOCIAL SCIENCES

A Longitudinal Test of Law Enforcement Officer Training to Prevent Citizen Suicide

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Law enforcement officers (LEOs) frequently act as community gatekeepers, linking community members with resources such as mental health services. This is the result of LEOs acting in their role as first responders to calls for service. LEOs often arrive to a call before mental health professionals. For example, Cerel et al. (2018) found that 95% of LEOs surveyed had acted as a first responder to mental health crises involving suicide, with an average of 30.9 career responses to suicide. LEOs are increasingly the first line of service for people facing mental health challenges and, based on government data sources, this trend seems likely to increase. This article examines LEO mental health training focused on suicide. We review the literature on training of LEOs to respond to mental health crises, with specific focus on suicide. We conduct a longitudinal test of effective LEO interaction with citizens during calls for service. Our main dependent variable of interest is LEOs use of questions about suicide. Additionally, controls for LEO attitudes about mental illness, self-efficacy beliefs, as well as knowledge related to mental health issues and suicide were specifically included in our analysis. Findings suggest several important factors useful to guide

police departments as they seek to better serve citizens during LEO interactions involving suicide. For instance, based on our longitudinal design, we find that on-the-job training increases LEO effectiveness while off-the-job training has no statistically significant impact on LEO use of questions aimed at awareness and prevention of suicide. Additional results shaping LEO effectiveness as well as limitations will be presented.

SOCIAL SCIENCES

Housing and Autism Spectrum Disorder: Insights from Individuals and Families

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Background: Autism is one of the fastest-growing disabilities in the country. Housing for autistic adults remains elusive for many, and access to funding and supports is often nonexistent. The aim of this project was to better understand the current and future housing needs of autistic adults in Utah from the perspective of autistic individuals and their caregivers. Methods: Two surveys, one provided to autistic individuals and one to parents/guardians of autistic individuals, were developed and disseminated among a sample of convenience using social media and email. Descriptive analysis of the survey responses was undertaken for all respondents. Results: The majority of autistic respondents still live with their parents, and housing options are limited. The majority of autistic respondents stated that employment was funding their housing needs, and the majority of parents/guardians indicated that family funding was the primary source. The majority of autistic adults wanted to live independently. A clear dichotomy was present between parent/guardian responses and autistic adult responses. Conclusions: The data received from the survey provide evidence that appropriate housing options for autistic individuals in Utah have been and continue to be an ongoing struggle. There are many individual organizations trying to offer solutions, but working together to synthesize research, outcomes, and lessons learned is imperative to finding optimal housing support for adults on the autism spectrum.

SOCIAL SCIENCES

Utah's High Suicide Rate: What College Students Say about the Causes

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Per the requirement of Weber State University that all the general education courses need to assign a Signature Assignment (SA) relevant to the course subject to each student, in my Introduction to Sociology class, my SA topic is to use sociological concepts and theories to explain why Utah is ranked very high in teen suicide and suicide in general and why the suicide rate is on the rise in the United States. Each student was assigned to answer 5 to 6 questions in their portfolio essays throughout the semester. By the end of the semester, they need to combine all their portfolio entries and finish a final paper, the SA. This paper is a summary of what my students have written in their SA in the fall semester, 2019. Each student signed a consent form that their papers can be cited for public purposes. The categories in the summary include using Durkheim's suicide theory, cultural and religious values, labeling theory, bureaucracy, economic poverty, and gender role to examine the causes of suicide, and it is a multifaceted issue. Curbing the suicide rate is not a singular matter, and it needs more complex methods to deal with this social phenomenon.

SOCIAL SCIENCES

The Use of Digital Folklore to Reduce Internalized Stigma Related to Civilian PTSD

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For over twenty years, folklore has been used in conjunction with traditional health care assessment methods as a way to assess community health care misinformation, which may not be captured through traditional medical research. The folklorist's approach to gathering and analyzing vernacular communication allows for the discovery of misconceptions on the part of the community that may have potentially detrimental effects on the health of people who suffer from, or risk transmitting, illnesses. Until recently, the majority of this research has

been done on issues such as the AIDS virus or the antivaccination movement. This study builds on those concepts, using digital folklore (specifically memes on Facebook) to explore the ways that civilians with post-traumatic stress disorder (PTSD) are resisting internalized stigma by reaching out to their friends and family members through social media. To examine how the stigma of PTSD is portrayed in digital environments, I will be following the guidelines of a “folkloric approach to stigma” recommended by Amy Shuman in her 2012 article, “The Stigmatized Vernacular.” In summary, these guidelines as they relate to my research are: 1) to determine what is considered normal; 2) to observe of the facets of stigma; 3) to analyze both digital folklore and comments to identify how stigma is enacted by people inside and outside the PTSD community; 4) to explore cultural expectations of narrative norms; and 5) to determine how stigmatized groups position themselves with regard to normal. After gathering data in a random distribution from public Facebook groups over a six-month period and then applying a close rhetorical analysis of both the images and the words chosen to portray PTSD, I have determined several ways in which digital folklore is being used to resist the internalized stigma of PTSD using an adaptation of William Benoit’s image repair theory applied to self-image.