The Journal of the Utah Academy of Sciences, Arts, & Letters Volume 98 • 2021

Includes selected and refereed articles from the 2021 Annual Conference held virtually March 20, 2021

Editor Kristin L. Kraus

Copyright 2021, Utah Academy of Sciences, Arts, & Letters. Copyright reverts to authors after publication. Printed in the United States of America by Brigham Young University Academic Publishing, Provo, Utah. Neither the editors nor the sponsoring organization assumes responsibility for statements of fact or opinion made by the contributors.

ISBN-13: 978-0-9988268-5-1 All Rights Reserved

Board of Editors

Arts: Angie Banchero-Kelleher, Utah Valley University Biological Science: Daniel Clark, Weber State University Business: Taowen Le, Weber State University Education: Nichole Gearing, Utah Valley University Engineering: Ali Siapush, Southern Utah University Kinesiology and Health Sciences: L Nathan Thomas, Salt Lake Community College Letters-Humanities, Philosophy, Foreign Language: Craig Bergeson, Weber State University Letters-Language and Literature: Keith Lawrence, Brigham Young University Physical Sciences: Chris Monson, Southern Utah University Social Sciences: Emily Putnam, Salt Lake Community College Posters: Jacque Westover, Utah Valley University 2020-2021 Utah Academy of Sciences, Arts, & Letters Officers President: Daniel Poole, Salt Lake Community College President-Elect: Angela Banchero-Kelleher, Utah Valley University Past President: Rachel Keller, Snow College Secretary: Colleen Boam, Weber State University Treasurer: **Ryan Boam**, Weber State University Members at Large: Erin O'Brien, Dixie State University; Jonathan Westover, Utah Valley University Technology Officer: Vern Hart, Utah Valley University

Cover Photo: Matthew Bayreder, Mako Bennett, Tanya Jones, Ali S. Siahpush, "Semi-Translucent Concrete: Thermal, Structural, and Optical Properties," p. 195.

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 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.

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

Publication Policy

The Journal of the Utah Academy of Sciences, Arts, and Letters publishes works in all of the fields of study encompassed in the Academy's mission. Papers published in *The Journal of the Utah Academy 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.

The Journal of the Utah Academy of Sciences, Arts, & Letters—2021

AWARDS

Distinguished Service Award	11
Academy Fellow 2022	13
O.C. Tanner Lecture	14
John and Olga Gardner Prize	15
2021 Best Paper Awards	16

ARTICLES

ARTS

Ballet and Bonaparte	19
Golda Dopp Ovalles, Utah Valley University	

BIOLOGY

A Determination of Evolutionary Relationships among	
Specimens of the Genus <i>Equisetum</i> Using ITS1 Sequences	
and Sequence Motif Secondary Structures	35
William D. Speer, Salt Lake Community College	

BUSINESS

Self-Efficacy, Emotional Intelligence, Self-Determination, and Self-Regulated Learning: Student Survey Results and Relationship to Practice CPA Exam Scores in an Auditing Course	61
Jefferson T. Davis, Weber State University	
EDUCATION	
Greater Rudeness: Interruptive Behavior in the Graduate School Classroom Thomas C. Terry, Utah State University	79
ENGINEERING	
Analysis of Electrical Resistivity and Conductivity of Materials	97
Noah M. Swenson, Zachery N. Isaac, Ali S. Siahpush, Southern Utah University	
Calibration and Testing of Budget Extensometer To Accurately Evaluate The Modulus of Elasticity of Steel	
Wire Alicyn Astle, Collin Cutler, Cameron Pepi, Trayson Maxwell, Owen Telford, Jacob Bishop, Ali S. Siahpush, <i>Southern Utah</i> <i>University</i>	111
Direct Evaporative Cooling: Simple Analysis Skyler Ipsen, Matt Bennion, Colby Thorton, Andrew Logan, Austin Banks, Ali S. Siahpush, <i>Southern Utah University</i>	125
Heat Transfer Analysis of Eicosane During Melting Sabrina Kim, Bill Maxwell, Ali S. Siahpush, Southern Utah University	143
Lumped Capacitance Method: Analytical and Experimental Evaluation Collin Cutler, Kyler Reinhold, Owen Telford, Ali S. Siahpush, Southern Utah University	157

Effectiveness of Plane Wall Radiation Shielding	169
Collin Cutler, Owen Telford, Cierra M. Salcido, Rebekah	
Yamashita, Ali Siahpush, Southern Utah University	
Cost-Effective Solar Water Heater	181
Kyler A. Reinhold, Omar R. Campos, Noah A. Mollner,	
Aaron J.G. Dockins, Ali S. Siahpush, Southern Utah University	
Semi-Translucent Concrete: Thermal, Structural, and	105
Optical Properties	195
Matthew Bayreder, Mako Bennett, Tanya Jones, Ali S. Siahpush, Southern Utah University	
HUMANITIES, PHILOSOPHY, AND FOREIGN LANGUAG	E
"Something Large and Old Awoke": Ecopoetics and Compassion in Tracy K. Smith's Wade in the Water Kaitlin Hoelzer, Brigham Young University	213
KINESIOLOGY AND HEALTH SCIENCES	
Drinking Pattern Differences between Men and Women during the COVID-19 Pandemic: A Review of the Literature Linnette Wong, Weber State University	229
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	235
LANGUAGE AND LITERATURE	
Selections from Death Kindly Stopped	245
Chanel Earl, Brigham Young University	
PHYSICAL SCIENCES	
Synthesis of Merocyanine Compounds	253
Jacob Newey, Kyler White, Mackay B. Steffensen, Southern Utah University	

Phosphatidylserine in Supported Lipid Bilayers Binds	
His-Tagged Proteins	263
Ryan S. Koch, Christopher M. Reynolds, Sydney J. Williams,	
Dylan J. Keiser, Christopher F. Monson, Southern Utah	
University	
Evaluation of Superfund Removal Action at the King	
Edward Mine	275
J. Andreas Lippert, ¹ Charles F. Davidson, ¹ Robert A.	
Davidson, ² Tori L. Schaffer ¹ , ¹ Weber State University; ² Utah	
Valley University	
A Homebuilt Laser Light Scatter Particle Sizer for Use	
with Microfluidic Devices	287
Stephen K. Smith, Christopher F. Monson, Matthew B.	
Rowley, Southern Utah University	
3D-Printed Cell Phone Spectrophotometer and	
Spectroscope	301
Brittany Christensen, Saselah Goulding, Carrigan Holt,	
Christopher F. Monson, Southern Utah University	
Optimizing Theta Pinches for Outreach Demonstrations	313
Theodore S. Lane, Thayne Hansen, Shaun Cluff, Southern	
Utah University	
SOCIAL SCIENCES	
Making Silicon Places: Regional Entrepreneurialism and	
the Technology Economy on the Silicon Slopes	327
Jeremy Bryson, Melissa Jensen, Weber State University	
From "My Guy" to "Inner City Blues": A Spectrum of	
Resistance in Motown Music	335
Theresa A. Martinez, University of Utah	
ABSTRACTS	353

DISTINGUISHED SERVICE AWARD

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

F. Ann Millner, PhD

Dr. F. Ann Millner was the 11th president of Weber State University from 2002 to 2012. She was appointed to this role after 20 years of serving the university as an educator and administrator.

She is currently serving as the Majority Whip in the Utah State Senate. She has previously served as the Assistant Majority Whip in the Senate, the Chair of the Higher Education Strategic Planning Commission of the state legislature, and the Chair of the Senate Ethics Committee. As the Majority Whip in the Senate, she currently sits on ten legislative committees, including the Executive Appropriations Committee, the Senate Education Committee, the Senate Education Confirmation Committee, the Higher Education Appropriations Subcommittee, the Public Education Appropriations Subcommittee, the Senate Management Committee, the Economic Legislative Development and Workforce Services Committee, the Senate Economic Development and Workforce Services Confirmation Committee, the Senate Ethics Committee, and the Senate Transportation, Public Utilities, Energy, and Technology Committee.

She received a B.S. in Education from the University of Tennessee, an M.S. in Allied Health Education and Management from Southwest Texas State University, and an Ed.D. in Educational Administration from Brigham Young University in 1986.

She then worked in a variety of positions at educational institutions. She was Education Coordinator of the Medical Technology Program at Vanderbilt University, Instructional Developer in Medical Technology at Thomas Jefferson University, a Lecturer at the School of Health Professions, Southwest Texas State University, and Associate Director of Continuing Education at the Edmonda Campus of Gwynedd Mercy College. She began employment at Weber State College in 1982 and held such positions as Director of Outreach Education in the School of Allied Health Sciences, Assistant Vice President for Community Partnerships, Associate Dean of Continuing Education, and in 1993 she became Vice President for University Relations.

Millner has been involved in various community and academic organizations. She is the current chair of the Utah Campus Compact and a board member for Intermountain Health Care, the Ogden/Weber Chamber of Commerce, the Weber Economic Development Corporation, and Coalition for Utah's Future. She has been a member of the NCAA I-AA/I-AAA Presidential Advisory Group, the Council of State Representatives for the American Association of State Colleges and Universities, and the Ogden Rotary Club.

ACADEMY FELLOW 2022

Nichole Ortega, MA

Nichole Ortega began her classical ballet training in 1975 with Sandra Allen. From 1984 to 1990, she continued her training with Jacqueline P. Colledge, as a member and soloist with the Utah Regional Ballet Company. Nichole completed her undergraduate degree in Health Education and Dance Education at Brigham Young University and earned a Master of Arts in Dance, from California State University, Long Beach. For ten years, Nichole acted as a secondary dance educator, developing the dance program and Dance Company at Payson High School in Payson, Utah. Currently, Nichole is in her 18th year at Utah Valley University where she is an Associate Professor and served for six years as Chair of the Department of Dance. She is currently the Ballet Program Coordinator and teaches Ballet and other core courses. Nichole has served as President of the Utah Dance Education Organization and the Utah Academy of Science, Arts, and Letters. She served two years as the Secondary Endorsement Dance Representative for the Utah State Office of Education and has choreographed for Synergy Dance Company, Contemporary Dance Ensemble, Utah Regional Ballet, Utah Regional Ballet II, Boise State College, Body Logic, and Scera Shell Outdoor Theater. Nichole has been published twice in the Journal of the Utah Academy of Sciences, Arts, and Letters and once in The Journal of the International Arts in Society and has shared her research at several national and international conferences. She was awarded the UVU Presidential Fellowship for her research, "Dance Loops," along with UVU Behavioral Science Associate Professor, Barton Poulson. Nichole just finished two years as the Director of Undergraduate Research and Creative Works in the UVU Office of Engage Learning and is a Faculty Fellow in the UVU Center for the Study of Ethics.

O.C. TANNER LECTURE "The Academy's Role in Contemporary Society"

John Mukum Mbaku, PhD, JD

Weber State University

Throughout the world, many countries look to the United States for guidance on how to deal with at least two issues: how to develop and adopt (1) a governance system that enhances and guarantees peaceful coexistence, minimizes impunity, and significantly promotes the recognition and protection of human rights; and (2) an economic system that advances entrepreneurship, innovation, and the creation of the wealth that can be used to alleviate poverty and improve the quality of life for all citizens. While the republican system of government that was created by the Founders in the late 18th century has faced several challenges, it has been and remains robust and resilient enough to withstand these challenges, as well as adapt and grow. In addition, the country's economic system has the world's most enabling environment for entrepreneurship, innovation, and the creation of knowledge and wealth. The success of both the economic and political systems in the United States has been due to its virtuous, robust, and politically active public (i.e., civil society). Members of the Utah Academy of Sciences, Arts, and Letters are part of that civil society, which has served, not only as a check on the exercise of government power, but as a major contributor to the creation of conditions in Utah and the nation that advance critical objectives, such as the protection of human rights, peaceful coexistence, eradication of poverty, prevention and treatment of disease, promotion of civility, creation of knowledge to minimize human suffering, maintenance of values (e.g., hard work, fidelity to the rule of law, respect for one another), and the cultivation and sustenance of ethical forms of conduct. Knowledge created by Members of the Academy adds value to our lives and makes this world a better place to live.

JOHN & OLGA GARDNER PRIZE

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

John Mukum Mbaku, PhD, JD

Weber State University

Dr. John Mukum Mbaku is a Brady Presidential Distinguished Professor of Economics and John S. Hinckley Fellow at Weber State University. He is also a nonresident senior fellow at the Brookings Institution in Washington, D.C., and an attorney and counselor at law, licensed to practice in the Supreme Court of the State of Utah and the U.S. District Court for the District of Utah.

He is a consultant to several domestic and international news organizations, as well as multilateral organizations (e.g., the African Development Bank), on governance issues in Africa and has appeared on several domestic and international news programs to discuss elections, corruption, and other governance-related issues in Africa. He is also a consultant to the United Nations.

Mbuaku received his Ph.D. in economics from the University of Georgia and his J.D. in law and graduate certificate in natural resources and environmental law from the S.J. Quinney College of Law at the University of Utah. He is a resource person for the Kenya-based African Economic Research Consortium.

His research interests are in public choice, constitutional political economy, sustainable development, law and development, international human rights, intellectual property, rights of indigenous groups, trade integration, and institutional reforms in Africa.

He is the author of *Corruption in Africa: Causes, Consequences,* and Cleanups (Lexington Books, 2010) and (with Mwangi S. Kimenyi) of *Governing the Nile River Basin: The Search for a New Legal Regime* (The Brookings Institution Press, 2015) and *Protecting Minority Rights* in African Countries: A Constitutional Political Economy Approach (Edward Elgar, 2018).

On May 22, 2017, he was admitted and qualified as an Attorney and Counsellor of the Supreme Court of the United States.

At Weber State University, he teaches courses in principles of economics, intermediate microeconomics, international trade, business calculus, and economic development. He also engages with community groups and helps them understand issues such as globalization, outsourcing, and immigration and how they affect economic activities in the United States.

2021 BEST PAPER AWARDS

Biological Sciences

A Determination of Evolutionary Relationships Among Specimens of the Genus *Equisetum* ITS1 Sequences and Sequence Motif Secondary Structures

William D. Speer Salt Lake Community College

Business

Self-Efficacy, Emotional Intelligence, Self-Determination, and Self-Regulated Learning: Student Survey Results and Relationship to Practice CPA Exam Scores in an Auditing Course

Jefferson T. Davis Weber State University

Engineering

Lumped Capacitance Method Analytical and Experimental Evaluation

Collin Cutler, Kyler Reinhold, Owen Telford, Ali Siapush Southern Utah University

Humanities, Philosophy, and Foreign Language

"Something Large and Old Awoke": Ecopoetic and Compassion in Tracy K. Smith's *Wade in the Water* Kaitlin Hoezler

Brigham Young University

Language & Literature

Selections from "Death Kindly Stopped"

Chanel Earl Brigham Young University

Social Sciences

Making Silicon Places: Regional Entrepreneurialism and the Technology Economy on the Silicon Slopes

Jeremy Bryson and Melissa Jensen Weber State University

Ballet And Bonaparte: Napoleon's Lasting Influence on the Art of Dance

Golda Dopp Ovalles

Utah Valley University

Abstract

Napoleon Bonaparte's role as master choreographer of war has been studied extensively, with exhaustive biographical research that details his political strategies and national legacy, as well as his military conquests. 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 paper outlines the political peregrinations of ballet surrounding and during the Napoleonic years, from 1790 to 1815, illuminating Napoleon Bonaparte's influence on the physical and ephemeral art of ballet. The organization is chronological, with four main parts: how the Enlightenment helped ballet survive the 1789 Revolution; the role of dance in the national fêtes of the Directory and Consulate; how Napoleon's cultural admiration of antiquity influenced ballet; and finally, how Napoleon's militant approaches shaped balletic pedagogy. The argument is made that the Enlightenment, combined with Napoleon's strategic adoption of certain ancien regime characteristics, were necessary in preserving ballet as an art form.

Ballet and Bonaparte

Napoleon Bonaparte was an excellent choreographer of war. His military genius enabled him to rise to power after crucial upheavals in France, irrevocably changing the nation. The global repercussions of his victories, in addition to contemporary fascination for 'Napoleon the Man' prove just how prolific and charismatic he was. Seizing control of a land he was not born nor would die in, Napoleon ruled with a deliberateness that extended to the arts, and in significant ways. Napoleon's comprehensive refashioning of France's zeitgeist necessarily influenced dance. As historical stages were set for the Revolution and characters clamored for power afterward, Napoleon climbed the ranks for a stunning 15 years in the spotlight. And ballet would never be the same.

The purpose of this essay is to explore Napoleon Bonaparte's influence on the physical and ephemeral art of ballet. His motivations for artistic impact were clear: to maximize power in a uniquely comprehensive manner. Yet, the intricacies of how he did so, and what lingering effects survive in classical ballet, have been relatively untouched by scholars. This essay will outline the political peregrinations of ballet surrounding and during the Napoleonic years, from 1790 to 1815. The paper's 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.

To fully understand the implications of the Napoleonic years on ballet, a brief history is necessary. Ballet began in the 1400s in Renaissance Italy. Catherine de Medici, an Italian noblewoman, brought ballet to the French courts after her marriage to King Henry II, King of France.¹ In the court of Louis XIV, ballet training was used as political leverage. An aspiring politician's reputation and future depended largely on his presentation in court, specifically his grace and deportment in social dancing. Dance training became a crucial component of elite French education.² The aristocracy of pre-Revolutionary France claimed divine right to the throne, requiring an almost deistic demeanor of rulers. The control, beauty, pageantry, and tradition of ballet not only distinguished nobility and asserted their God-given earthly inheritance, it also served to stratify social classes. Evidence of these aesthetics lives on in modern

 $^{^1}$ Zoë Anderson, The Ballet Lover's Companion. (New Haven: Yale University Press, 2015): 2

² Jennifer Homans, Apollo's Angels. (New York: Random House, 2010): 12

ballet: the elaborate costumes, dancer rankings, lift of the upper body and head, and hundred-year-old choreography.

The potential political power of ballet was used by the French even before Bonaparte. *Balli* preceded ballet and was done in the Italian courts during the Renaissance. However, with the union of Catherine de Medici and King Henry II, *balli* entered French dominion and began to evolve at the hands (or feet) of French royalty. During the Enlightenment, Louis XIV bestowed a terminology and vocabulary for what had by then become the French version of *balli*. Under Louis's rule, artist Raoul Feuillet created a system of dance notation. The names of steps were assigned, and the most basic positions of ballet were set. Five foundational positions recorded then still structure the training and choreography of 21stcentury ballet. Louis's instruction to record and organize the mechanics of ballet was an incredibly auspicious move; ballet carries immense power, for a myriad of reasons, and this amalgamation was a cause for nationalistic pride. The legacy of balletic tradition now had specifically French roots.

Setting the Stage for the Survival of Ballet

The royal roots of France turned out to be less perennial. Of the innumerable and convoluted catalysts that led to the French Revolution, the Enlightenment bears a weighty significance in the final tipping point. Enlightenment thinking led to the creation of a new type of ballet: the *ballet d'action*. This breed of ballet was narrative in nature, which meant inventing and utilizing a complex system of language through movement. The storytelling aspect carried significant nuance within semantics.³ The merit of ballet's narrative potential garnered commentary from the likes of Cahusac, Diderot, and Voltaire. Cahusac was a playwright and librettist, but Diderot and Voltaire were philosophers and writers, proving how interdisciplinary Enlightenment thinking was surrounding the performing arts. The *ballet d'action* offered the art form redemption: separating it from the royal courts, a change the aforementioned writers championed.

The following quote from Louis de Cahusac demonstrates the intentionality of balletic changes during this period:

The dance of our theater needs some guides, some good principles, and some light, like a fire that will never go out. Let us be

³ Judith Chazin-Bennahum, "Cahusac, Diderot, and Noverre: Three Revolutionary French Writers on the Eighteenth Century Dance." Theatre Journal, vol. 35, no. 2, 1983: 170

persuaded that the century which produced L'Esprit de Lois, L'Henriade, L'Histoire Naturelle, and l'Encyclopedie can go even further in the Arts than the period of Augustus.⁴

Cahusac states that ballet needs its own set of lasting ideals, emphasizing that need by citing the time period's most excellent literary works. It is also interesting to note his use of personal pronouns in "our theater." The rise of humanism had invited innovative perspectives on the individual and the collective whole. Humanism also increased and validated a public interest in secular entertainment. The royal connections to Catholicism would not be uprooted until 1905 with the Separation of Church and State law, but Humanism spotlighted the thoughtful citizen, casting shadows on kings and queens and Catholicism in general. Content diversified and became more relevant to the French population.

As ballet expanded into theaters, first in royal stages for only elite entertainment, then more broadly into lavish opera houses, the *corps de ballet*, literally the "body" of the ballet, formed. The corps is composed of a group of dancers, and their collective purpose is to support the leading roles. Before the corps, ballet had three types of dancers: *noble, demicaracter*, and *comedie*. Entire works of ballets were sometimes categorized within these three archetypes.⁵ There were clear distinctions, just like royal hierarchies and noble titles. During the Napoleonic years, the corps began to symbolize harmonious citizenry, maidenly purity, and ethereal mysticism. Ballet safely identified outside targeted regency. The more nuanced ballet structure also served well Napoleon's visions for societal structure. Gone were queens and peasants.

Instead, Napoleon's people referred to one another as *citoyen* and *citoyenne*. There was a feeling of equity and national pride, of a group acting as individual players but in a cohesive group that promoted primary players.

When the guillotine was in use, the public widely participated in "La Carmagnole." Charles Dickens penned a lengthy description of this dance and condemned it for its chaotic, wild nature.⁶ Instead of courts or theaters, it was done in the streets, sometimes circling the guillotine! Instead of royal persons or students under masterful tutelage, it was danced by peasants. La Carmagnole was opposite in characteristics from ballet.

⁴ Ibid., 172

⁵ Homans, 261

⁶ Judith Chazin-Bennahum, Dance in the Shadow of the Guillotine (Southern Illinois University, 1988): 69

However, it was important for the people to have a dance form that belonged to them, that could be done in the streets, and that quickly escalated revolutionary fervor. Because of the ease of participation that increased mob mentality, it is easy to consider why Dickens was so taken aback.

The Enlightenment set the stage for three important freedoms that propelled ballet's change: one, a need to establish formal guidelines for ballet in the *theater* (not courts); two, the ability to reinvent soloists and corps de ballet; and three, an escape from aristocratic commissions that put limitations on content. These specific, but not comprehensive gifts to ballet made it possible for the ballet to survive the Revolution. The new opportunities placed just enough space between the art form and its connections to the *ancien regime*.

Revolutionary Reigns and Classical Fanaticism

Yet even with these new liberties, ballet was not completely free. The Revolution just introduced different limits on content. The end of the 1700s was full of turmoil, and the arts, like the citizens, had to stay on the good side of changing authorities. Ballets had to promote pro-Revolutionary ideals. Many of the royalist dancers fled the country, and ballet masters, librettists, and musicians had to conform to vacillating controls.

Because the nation was facing such an uncertain future, many French decided to look backward. Fascination with antiquity had sparked during the Enlightenment, and now not just classical school of thought was appealing but classical art as well. Imbuing admiration of Plato and Aristotle with heroic military stories, intriguing myths, and Hellenistic emotion, the French created a vision for their future, taken from history. For decades, the content of ballets was classical myths and stories, which Napoleon strongly sanctioned.

Classical myths provided recognizable content for operas, offering escapist entertainment during the bloody years of the Revolution. Napoleon strengthened the revival of classical adulation in France, most notably through his Italian campaign. As the revolution finally hit its climax with the decrescendo of the Terror and creation of the Directory, Napoleon climbed the social and military ranks. His success during the Directory, from 1795 to 1799, prepared him for a successful military coup that set him up as Consul of France.

Before the Consulate, the Italian campaign had to transpire, with all its systematic looting. Napoleon's looting of fine art had precedence

pre-Revolution; in 1793, art looting was practiced in the French campaign in Belgium.⁷ It was Napoleon however that instituted the "contract law," which put a slightly more legal stamp on the stealing of art; the contract law forced the defeated to agree to give up treasures through contract-treaties. The contract law successfully evaded the residual logical thinking of the Enlightenment, which "no longer considered [looting] a natural right of warfare."8 Napoleon, with the aid of scholars, brought back thousands of invaluable pieces, putting them on display first through the streets of Paris in lavish parades, then in the Louvre museum. Public festivals put the bounty on display and aimed at replacing the moribund Revolutionary zeal of the 1790s. Festivals were held often and were publicized by way of France's new calendar-the French Republican calendar. This calendar replaced the Gregorian one from 1793 until 1806, when Napoleon ended usage. Festivals promoted nationalism and public unity. The 1798 Fête de la Liberté occurred under the Directory and had three main purposes: the first, to celebrate the end of The Terror and glory of the Directory; the second, to elevate Napoleon in the public eye as an able and intelligent military leader; and lastly, to mark the nation's adoption of antique art as the official state art.9

In Mainardi's article on the 1798 Fête de la Liberté, she focuses on the political and cultural supremacy derived from military conquests that echoed Republican Rome, so only briefly mentions dance, but Olivia Sabee, in "Dancing the Social Contract," reveals just how important dancing was to these national festivals. Festivals were extremely elaborate, with specific events that made a spectacle of rejecting the *ancien regime*, such as shedding royal dress publicly. Many citizens participated in these festivals, including groups of dancing women who wore all white. They represented the general will of the state, fusing individuals into a single power. The public compliance signaled the acceptance of liberty, equality, and fraternity as national values.¹⁰ These women in white acted as the precursor to the corps de ballet and in the Romantic era gave rise to ballet blancs, literally translated to "white ballets." These ballets were characterized by the second or third acts, which were entirely composed of ballerinas in white, delicate costumes. These white acts transported the audience to an ethereal realm mid-ballet and also identified the role

⁷Patricia Mainardi, "Assuring the Empire of the Future: The 1798 Fete de La Liberte." Art Journal, 48, no. 2: 155. (1989): 155

⁸ Ibid., 156

⁹ Ibid., 159

¹⁰Olivia Sabee "Dancing the Social Contract: The White Divertissement and and the French Revolution," Dance Chronicle 38, no. 1 (2015): 11

of the *corps*, solely through their unison choreography and identical costuming. For example, the Romantic ballet Giselle depends on the identical semblance of the corps (swan maidens) to tell the story. Only a few years after the Revolution and Napoleon's fall, the audience would have recognized the revolutionary origins of *ballet blancs*. The famous artist Jacques-Louis David was one of Napoleon's preeminent painters, reciprocating commissions with neoclassical masterpieces. Napoleon relied on David's artistic prowess to bestow immortality upon Napoleon's memory. The artist David and ballet-master Pierre-Gabriel Gardel helped stage national festivals.

David encountered some trouble during the Directory, escaping prison because of the indispensable nature of his artistic genius. He won the prestigious *Prix de Rome* scholarship, sharing with Napoleon a love of Roman art. Author-historian Henrik Bering calls David a "master propagandist" on account of his large, dramatic pieces that overtly flatter Napoleon. Of his 1800 piece *Napoleon Crossing the Alps*, David stated, "The cloak of Bonaparte is thrown to make one imagine the wings of a demigod gliding in the air."¹¹ David was instrumental in publicizing Napoleon's image, which Napoleon was careful in constructing. It follows therefore that in his involvement with the festivals and in the design of Opéra productions, David would have been eager to please Napoleon, whom he also stated was "a man to whom altars would have been erected in ancient times. Yes...Napoleon is my hero."¹²

David was also uniquely qualified to participate in the production end of performances; his precise rendering of human anatomy gave him a thorough understanding of the artistic instrument of ballet—the body. David's neoclassical approach, characterized by minute execution of musculature and classical draping, is very similar to the physique and costuming of dancers. Consider the physical similarity of the man in David's *Oath of the Horatii* and the illustration of the dancer's costume (Figure 1).

Napoleon surrounded himself with individuals eager to please him. During the Italian campaign, which aimed at "freeing" Italy of Austrian occupation, Napoleon won over another admirer. After leading his outnumbered troops to victory, he gained the highest respect of General Henri Jacques Guillaume Clarke, from the Ministry of War. In December 1796, Clarke wrote a report to the Directoire that paints a vivid picture of Napoleon's illustrious reputation. He states, "There is nobody here who does not look upon him as a man of genius, and he is effectively

 ¹¹Bering, Henrik. "The Master Propagandist." New Criterion 34, no. 10 (June 2016): 30
¹² Ibid., 30

that. He is feared, loved, and respected in Italy." He also stated that "Bonaparte can bear himself with success in more than one career. His superior talents and his knowledge give him the means."¹³ This glowing report is one of the many successes that set Napoleon's course in obtaining sovereignty. It also supports the reality of Napoleon's indirect influence: admirers behaving and producing in ways that were in line with Napoleon's preferences and personal interest.



Figure 1. (Left) Detail of Jacque-Louis David, *Oath of the Horatii*, 1784 Louvre; (right) Auguste Vestris in "La Dansomanie" 1800.

Passion for Grandeur: How Napoleon's Meritocracy Modernized Ballet

Of Napoleon's many superior talents, playing music was not one of them. However, he had a love of music and said "Of all the fine arts, music is the one which has the most influence on the emotions."¹⁴ He understood music's capabilities for influencing behavior, and further stated that,

¹³ Jeremy Green "Napoleon's Masterful Italian Campaign." Military History 14, no. 1 (Apr 1997) p. 26.

¹⁴ Napoléon Bonaparte, Correspondance générale, vol. 1, Paris: Fayard, 2004, letter 1821. As quoted by Peter Hicks in "Air and Graces: Napoleon and Vocal Music" from napoleon.org. Accessed April 2019

A piece of "moral" music, one by the hand of a master, cannot fail to touch the heart and has much more influence than a good, "moral" piece of writing, which moves the mind but has no effect on our behaviour.¹⁵

Napoleon cared about moral behavior in society, to the extent that he created a civil code for France, often known as The Napoleonic Code. He accepted the arts as a way to enforce his ideals of morality. Napoleon's more specific musical tastes may be connected to the great admiration he had for Roman art. Any connections to Republican and Imperial Rome flattered Napoleon, as he aspired to their level of cultural and military sophistication and legacy. He disliked French music and felt that the Italians were the only nation capable of producing fine operas.¹⁶ Therefore, many of the scores are by foreign composers and are also often different pieces of music stitched together to form a ballet. Napoleon's personal lack in performing music did not stop him from learning and even critiquing it. He once wrote to Désirée Clary detailed advice on her piano lessons and would also criticize the Neapolitan composer Paisiello.¹⁷

There are no written accounts of Napoleon criticizing ballet exclusively, although he must have seen a significant amount of dancing. He watched 163 different operas and attended 319 performances, and ballet was always present in the operas.¹⁸ Frédéric Masson, the historian of Napoleon the man said,

> [Music] was of all the arts the only one for which he had a specific and personal penchant. As for the others, he encouraged them for political reasons, or because he had a passion for grandeur and enjoyed the idea of immortality.¹⁹

As with commissioned paintings or architectural monuments, Napoleon's quest for immortality inspired him to make a mark on theatrical arts. Even if Napoleon had no "personal penchant" for ballet and had ignored the art completely, he still had an impact. His rule was incredibly

¹⁵Peter Hicks "Air and Graces: Napoleon and Vocal Music." Napoleon.org. Accessed April 2019

¹⁶ Ibid., online

¹⁷ Ibid., online

¹⁸L. Henry Lecomte, Napoléon et le Monde dramatique (Paris: H. Daragon, 1912): 494-96

¹⁹ Peter Hicks, online

thorough, and by eliminating funding or paying no attention to the theater, ballet would have regressed. Yet as has already been outlined, ballet established important changes during the Napoleonic years. Napoleon gave much attention to the theater, seeing in it political power and the promise of lasting fame.

Napoleon's passion for grandeur manifested itself in material areas as well, which influenced costuming. Clothing was tied to identity during the Napoleonic years, perpetuating the effort to refashion an anti-aristocratic French style of dress. Wearing a cockade during the Revolution was an outward expression of potentially life-saving support of revolutionary ideals, as was publicly discarding metal shoe buckles. Because Napoleon replaced an overthrown aristocracy with a new meritocracy, dress was a straightforward way of communicating rank, whether it be political, militant, or social.

Napoleon had strong opinions regarding certain fashions, and said in a letter to his friend Corvisart,

The corset is the assassin of the human race. This piece of coquettish clothing and bad taste tortures and murders women and destroys their future offspring. The corset is a product of frivolity and terrible decadence.²⁰

In line with Napoleon's personal tastes, corsets became less trendy, and the daily unrestrained ease of street clothes was reflected in ballet costuming. Costumes would be done in thinner, rippling fabrics, therefore increasingly accommodating to a more virtuosic dancing.

Although certain individuals, generally royalist sympathizers, valued the delicate, controlled manner of the *noble danse*, public taste and the new Grecian-inspired costumes offered themselves to more athletic and impressive manners of dance.²¹ The *demi-caractere* and *comedie* became more popular, and the ballet d'action was reimagined.

The Grecian-inspired tunics could be seen on the boulevards and salons of Paris. The women's dresses were also fluid, light, and thin. A new sense of virtue ensued, one that allowed women to expose their bosoms and wear transparent textiles. The neoclassical fashion was evocative of classical ideals that often symbolized virtue, transcending their physically evocative nature. Empress Josephine was a fashion icon and regular figure of the salon culture. One specific style she adopted was

²⁰ Chazin-Bennahum, Judith. Cahusac, Diderot, and Noverre: Three Revolutionary French Writers on Eighteenth Century Dance: 126

²¹ Ivor Guest. Ballet under Napoleon (University of California: Dance Books, 2002): 102

the empire waist, seen in Prud'hon's *Portrait of the Empress Josephine*. Her dress in this portrait is very similar to Marie Miller's costume from the 1790 production *Psyche* (Figure 2).



Figure 2. (Left) Pierre-Paul Prud'hon *The Empress Josephine*, 1805 Louvre. (right) Marie Miller in Gardel's "Psyche."

The fashion of French women was known far and wide, overstepping any political grievances caused by the Napoleonic Wars. The English magazine journal, *The Mirror of Graces* stated:

French dances, which include minuets, cotillions, and all the round of ballet figures, admit of every new refinement and dexterity in the agile art; and while exhibiting in them, there is no step, no turn, no attitude within the verge of maiden delicacy that the dancer may not adopt and practise.²²

Change in consumer demand for specialized fabrics gave way to a sartorial war. Napoleon wanted to reinvigorate France's economy, so he limited foreign imports. This stimulated French production but temporarily limited the use of muslin and cotton, which were in high demand. It seems the bans were worthwhile: by the time Napoleon was exiled, France had caught up to England in mechanization and industrialization.

²² Chazin-Bennahum, The Lure of Perfection

Furthermore, the ballet and opera costumes were less affected by the sartorial war than they were by financial burdens felt more keenly at the start of and during the Revolution.

Napoleon wanted to streamline every aspect of his Empire and elevate the careers to a new level of professionalism. Beyond improving the infrastructure of Paris, he directed his attention also to the theaters, which he felt could be improved. Just as the kings and the revolutionary citizens had done, Napoleon censored the art displayed at the Opera and organized the Empire into 25 artistic units.²³ Napoleon also limited the number of theaters, which had flourished in number during the Revolution. In 1806, he took the number down to 12, then to four in 1807.²⁴ Within these theaters, ballet was allowed to maintain its aesthetic and technical traditions.

Napoleon's rule was much different than that of the French royalty, mostly in that his was a meritocracy rather than an aristocracy, but similarities between the two were overtly existent. A major reason for the resentment of French aristocracy was their over-the-top opulence and luxury. Although Napoleon did not indulge quite so much at the expense of the peasants and did revitalize the economy, his Empire was no doubt extravagant. David's The Coronation of Napoleon from 1807 demonstrates how lavish Napoleon's rule truly was. Napoleon's Empress, Josephine Bonaparte, was especially ostentatious-she once wore a gown of stitched authentic rose petals to the opera!²⁵ Napoleon, by preserving the pomp and grandeur of previous reigns, avoided severing ballet's ties to nobility and grandeur. Without these ties, ballet would not be ballet. Hundreds of dance halls now inhabited Paris, and citizens loved dancing publicly. Ballet differentiated itself as a dance form by way of its regal grace, beautiful costume and set design, historic theaters, and wealthy audience. Napoleon allowed for these indulgences, ensuring that French ballet did not fade into obscurity or deviation.

Napoleon also put an end to the master-protégé predicament that was wreaking havoc within the Opera. There was no diplomatic hierarchy to the way students might attain higher positions. Instead, teachers would select a young dancer, usually one with personal connection, and teach them privately, outside the theater. If the dancer turned out to be promising, they would then enter the Opéra for a special debut. Napoleon put an end to that practice, most likely because of his expertise in the

²³ Chazin-Bennahum, 1

²⁴ Peter Hicks, "Napoleon and Theater" Napoleon.org

²⁵Homans, 115

military, plus a perceptive awareness of the Opera's lack of unity. Napoleon was not an expert on the mechanics or teaching of ballet. But his desire to organize every public institution led to an overhaul of Opéra training. Students formed actual classes in studios at the Paris Opéra. In these spaces, collective formal training was given, and talent was the only consideration for advancement, rather than personal connection. Ballet thus turned more meritocratic, and not aristocratic. Napoleon instituted a dress code for boys: tight pants, vests, and white stockings.²⁶ Today, this dress code is the most common mandate of dress for ballet academies, with a few modern moderations. The ballet became more militant and extremely disciplined. These principles turned ballet into the contemporary curriculum known today. Ballet companies in the 21st-century use hierarchies as organization for their dancers. The best dancers claim the highest title-usually called principal, then descending down to soloist, corps member, and character artists. The titles held at the company affect what roles they dance and even their salary. The competitiveness and rigidity of the academy that feeds into companies was instituted by Napoleon. It was not until his direction that the Opéra academie had such strict training and specific protocol.

Conclusion

A figurative and literal book of the history of French ballet must not leap over the Napoleonic chapter, for it would tragically lose insight and context into the Revolutionary and Romantic eras, as well as France's cultural history at large.

Without Napoleon Bonaparte and his Consulate and Empire, ballet would have been underfunded and demoted to a lower art form, in both traditional purity and popularity in the public eye. Napoleon had the ability to see potential power in every aspect of French life and manipulated them all into subservience.

The fascination with all things classical peaked during the Enlightenment and Revolution, shaping the repertoire of historic ballets. The survival of ballet depended on its separation from the *ancien regime*, yet classical ballet was also contingent on the continuation of its original aesthetics. The dancers themselves kept the noble and gracious quality of ballet, which they combined with unifying revolutionary ideals. Public awareness and acceptance of a reborn France resulted, as well as the corps de ballet and Romantic *ballet blancs*. Napoleon's military victories abroad, including the looting of precious Roman works from antiquity,

²⁶ Holmans, 200

furthered neoclassicism in France, changing balletic costuming, choreography, and optics.

Napoleon's exactness as Consul and Emperor resulted in lightly censored ballets but also structured the theaters of France and the training that happened within them. The militaristic approach to training modernized ballet. The set framework for ballet institutions allowed for the major changes that the Romantic era introduced to the ballet world. It is interesting to bear in mind, and perhaps ironic, that Napoleon's defeat in the Russian invasion immediately preceded the glorious years of Russian ballet. Some of the world's most famous ballets—*The Sleeping Beauty, The Nutcracker, La Bayadere, Swan Lake*—are all Russian. But the roots of ballet endure, reaching back through history all the way to King Henry II. Thanks to Napoleon Bonaparte, the dance of our theater survives, with its stage lights and resiliency still lit.

Bibliography

Anderson, Zoë. The Ballet Lover's Companion. New Haven: Yale University Press, 2015.

Bering, Henrik. "The Master Propagandist." New Criterion 34, no. 10 (June 2016): 30.

Chapman, John V. "Forgotten Giant: Pierre Gardel." Dance Research: The Journal of the Society for Dance Research 5, no. 1 (1987): 3-20. http://www.jstor.org/stable/1290661.

Chazin-Bennahum, Judith. "Cahusac, Diderot, and Noverre: Three Revolutionary French Writers on the Eighteenth Century Dance." Theatre Journal 35, no. 2 (1983): 126, 169–178. http://www.jstor.org/stable/3207147.

Chazin-Bennahum, Judith. The Lure of Perfection: Fashion and Ballet, 1780-1830. New York: Routledge, 2005.

Green, Jeremy. "Napoleon's Masterful Italian Campaign." Military History 14, no. 1 (April 1997): 26.

Guest, Ivor Forbes. Ballet under Napoleon. Binsted, UK: Dance Books, 2002.

Hicks, Peter. "Air and Graces: Napoleon and Vocal Music." napoleon.org. foundation NAPOLEON, April 2004. https://www.napoleon.org/en/history-of-the-two-empires/articles/air-and-graces-napoleon-and-vocal-music/.

Homans, Jennifer. Apollo's Angels: A History of Ballet. New York: Random House, 2010.

Judith Chazin-Bennahum, Dance in the Shadow of the Guillotine (Southern Illinois University, 1988): 69

L. Henry Lecomte, Napoléon et le Monde dramatique (Paris: H. Daragon, 1912): 494-96

Mainardi, Patricia. "Assuring the Empire of the Future: The 1798 Fête de la Liberté." Art Journal 48, no. 2 (1989): 155-163.

Sabee, Olivia. "Dancing the Social Contract: The White Divertissement and the French Revolution." Dance Chronicle, 38, no. 1 (2015): 3-26, https://doi.org/10.1080/01472526.2015.1001201.

A Determination of Evolutionary Relationships among Specimens of the Genus *Equisetum* Using ITS1 Sequences and Sequence Motif Secondary Structures

William D. Speer

Salt Lake Community College

Abstract

ITS1 rRNA sequences from 19 Equisetum specimens representing 9 recognized species and 3 hybrid taxa were compared in this study. Most sequences had comparable lengths of 231 to 232 bases However, the sequence for E. sylvaticum had a 62-base deletion, making it only 170 bases in length. RNA secondary structures for internal transcribed spacer 1 (ITS1) were predicted and evaluated. For each sequence, 4 sequence motif regions were identified, folded individually, and concatenated for the final overall secondary structural prediction. One sequence motif region (designated as Motif 3) displayed statistically significant (p=0.003) secondary structural variation that distinguished specimens of subg. Hippochaete and subg. Equisetum. However, structural variation did not tend to unite conspecific specimens, nor did it consistently distinguish among different species. Phylogenetic analyses of complete ITS1 sequences were also performed, which clearly grouped specimens according to subgenus. However, different specimens representing the same species were not always joined in the same clade. Possible causes for this observation may include geographically based variation or possible hybridization between species of the same subgenus. ITS1 nucleotide sequence data as well the secondary structure obtained for the sequence Motif 3 appear to be useful for delineating Equisetum specimens on a subgeneric basis but may not be as suitable for resolving relationships within and between species.

Introduction

Eukaryotic genomes have several hundreds to many thousands of rRNA genes that are tandemly arranged in huge clusters that form nucleolus organizer regions (Wallace and Birnstiel 1966, Long and Dawid 1980, Rabanal et al. 2017). These genes are usually described in most eukaryotes as two separate transcriptional units: 45S and 5S, which are transcribed by RNA polymerase I and RNA polymerase III, respectively (Goffová and Fajkus 2021). Typically, the 45S, or 35S in plants (and henceforth), and 5S units are each organized in distinct, separated clusters (S-type arrangement), although, somewhat less frequently, 5S units are sometimes inserted between 35S units (L-type arrangement) (Wicke et al. 2011, Goffová and Fajkus 2021). The 35S region of plants consists of the 18S, 5.8S, and 25S genes, with 18S at its 5' end and 25S on its 3' end. (Rodionov et al. 2017, Goffová and Fajkus 2021). As shown in Figure 1, the 18S and 5.8S genes are separated by an internal transcribed spacer (ITS1), whereas the 5.8S and 25S genes are separated by a second internal transcribed spacer (ITS2), with the entire region flanked by external transcribed spacer (ETS) regions (Layat et al. 2012; Zhu et al. 2016). Given that these rRNA genes are organized and transcribed in what is essentially an operon, it seems that 35S is an ancient genetic feature that has been passed from prokaryotes to eukaryotes (Rodionov et al. 2017). Within plant genomes, nuclear rDNA can show little or no variation because of concerted evolution, or, in the other cases, can be very heterogeneous as a result of hybridization or recombination (Suh et al. 1993, Wendel et al. 1995, Muir et al. 2001, Álvarez and Wendel 2003, Bailey et al. 2003, Won and Renner 2005, Xu et al. 2017).


Figure 1. Map of plant 35S rRNA genes. Identification of this set of genes as 35S rRNA (and not 45S) and the designation of the 25S gene (and not 26S) follows Rodionov *et al.* (2017). Shown also are the approximate PCR annealing (binding) positions for the ITS1 primers used. ITS = internal transcribed spacer, ETS = external transcribed spacer

The ITS1 and ITS2 spacer regions are very different structures evolutionarily speaking, as ITS1 is thought to have developed from an intergenic spacer and ITS2 from an expansion segment of the rDNA large subunit (Hershkovitz et al. 1999). Although the ITSs are noncoding and post-transcriptionally removed, they (and their secondary structure) are thought to play a role in pre-rRNA processing (van Nues et al. 1994, Bakker et al. 1995). ITS2 is remarkably consistent among all plant groups examined to date, with a range of 182 to 370 bp (Baldwin et al. 1995, Maggini et al. 1998, Gernandt et al. 2001, Shaw et al. 2003, van den Heede et al. 2003, Won and Renner 2005). Similarly, the length of reported ITS1 sequences for most angiosperms tends to fall in a narrow range of 187 to 298 bp (Baldwin et al. 1995). Correspondingly, Maggini et al. (1998) reported that the range of lengths of ITS1 of several ferns (Equisetum arvense, Psilotum nudum, and Pteridium aquilinum) and lycophyte species (Isoetes histrix and Selaginella denticulata) turned out to be similar in length to those found in angiosperms. Likewise, van den Heede et al. (2003) reported a length of 237 to 279 bp within the fern genus Asplenium. Similarly, Shaw et al. (2003) reported a range of 236 to 292 bp for three different moss species. Nevertheless, ITS1 can be considerably more variable in size for other plant groups. For example, the ITS1 region in many gymnosperms has been found to vary from 630 to 3263 bp (Gernandt and Liston 1999, Gernandt et al. 2001, Campbell et al. 2005, Won and Renner 2005).

This study focuses on the ITS1 region of the genus *Equisetum*. More recent systematic treatments of the genus indicate 15–18 species (Hauke 1963, 1978, Christenhusz *et al.* 2019). Depending on the taxonomic assessment, taxa are placed in 2 or 3 subgenera: subg. *Equisetum* (Hauke 1978), subg. *Hippochaete* (Hauke 1963), and, more recently, subg. *Paramochaete* (Christenhusz *et al.* 2019). Subg.

Paramochaete is monotypic and is represented solely by the South American species *E. bogotense* (Christenhusz *et al.* 2019), which was formerly placed in subg. *Equisetum* (Hauke 1978). There are also numerous recognized hybrids within, but, to date, not between subgenera (Duckett 1979; Des Marais *et al.* 2003). Most of these hybrids are sterile, with misshapen, abortive spores and, therefore, reproduce vegetatively (clonally) and in some cases can look very similar to one or the other parental species (Des Marais *et al.* 2003). It should be noted, however, that allotriploidy has been documented in subg. *Hippochaete*, which appears to have resulted from the backcrossing of a hybrid with a parental species (Bennert *et al.* 2005), indicating that some *Equisetum* hybrids can, although rarely, produce fertile spores.

This study compares ITS1 sequences representing both subg. *Equisetum* and subg. *Hippochaete* to evaluate secondary structure. Additionally, G+C content and length variation are also compared. Finally, phylogenetic analyses are conducted.

Materials and methods

Specimens studied

Sequences representing both subg. Equisetum and subg. *Hippochaete* were selected. Sequences used include those sequenced by the author as described below, as well as ITS1 sequences from other researchers downloaded from GenBank (https://www.ncbi.nlm.nih.gov/ genbank/) and shown in Table 1. Nine species were represented: 6 for subg. Hippochaete (E. hyemale, E. laevigatum, E. myriochaetum, E. ramosissimum, E. scirpoides, and E. variegatum) and 3 representing subg. Equisetum (E. pratense, E. sylvaticum, and E. telmateia). Two or more specimens of E. hyemale, E. ramosissimum, and E. variegatum are included for examination of possible infraspecific or geographical variation. Also included were specimens of 3 hybrid taxa: E. × ferrissii (E. laevigatum \times E. hyemale), E. \times meridionale (E. ramosissimum \times E. variegatum), and E. \times moorei (E. hyemale \times E. ramosissimum), all of which are subg. Hippochaete hybrids. Altogether, 19 Equisetum ITS1 sequences were examined in this study. It should be noted, however, that not all recognized Equisetum species are represented because some taxa were not available to or could not be collected by the author.

DNA extraction, PCR, sequencing, and alignment

For those sequences generated by the author, total genomic DNA was extracted from either fresh or silica gel–dried plant material using

Table 1. Specimens/sequences used in this study						
Taxon-specimen	GenBank ac-	Collection/location information				
	cession no.					
Subgenus Equisetum						
E. pratense	DQ377152	downloaded from GenBank				
E. sylvaticum	EU328342	France: Approx. 30 km from				
		Grenoble; PG Wolf 908				
E. telmateia	DQ377154	downloaded from GenBank				
Subgenus Hippocha	iete					
E. hyemale1	EU328339	US: California: Alameda County:				
		Clarement; A Smith s.n. (UC				
		1733472)				
E. hyemale2	EU328336	US: Utah: Cache County: Logan				
		Canyon; along Logan R.; WD				
		Speer282				
E. hyemale3	AB817880	downloaded from GenBank				
E. hyemale4	DQ377151	downloaded from GenBank				
E. laevigatum	EU328341	US: Utah: Cache County: Logan;				
		WD Speer s.n. (UC 1748060)				
E. myriochaetum	EU328337	US: California: Berkeley:				
		Strawberry Creek, likely an				
		escape from UC. Bot. Gard.; A				
		Smith s.n. (UC 1733469)				
E. ramosissimum1	DQ377153	downloaded from GenBank				
E. ramosissimum2	AF448794	downloaded from GenBank				
E. ramosissimum3	EU328343	France: Grenoble: Domaine Univ;				
		PG Wolf 916 (UC 1740884)				
E. scirpoides	EU372663	US: California: San Francisco				
		(Strybing Arboretum–cultivated);				
		P. Hammond s.n. (UC 1733473)				
E. variegatum1	DQ377155	downloaded from GenBank				
E. variegatum2		B. Hoshizaki203 (location info				
		unavailable-grown plant) (UC				
		1733468)				
E. variegatum3	EU372664	US: Alaska: Prince of Wales Is.;				
		B. Hoshizaki 592 (UC 1733475)				
Hybrids						
E. x ferrissii	EU328338	US: California: San Francisco,				
		Golden Gate Park; P. Hammond				
		s.n. (UC 1733476)				
E. x meridionale	DQ377156	downloaded from GenBank				
E. x moorei	DQ377157	downloaded from GenBank				

the Doyle and Doyle (1987) cetyltrimethylammonium bromide method. One hundred nanograms of DNA was used in each 100-µl PCR reaction mixture. Individual reaction mixtures were amplified using the forward ITS-5 (5'-GGAAGTAAAAGTCGTAACAAGG-3') and reverse ITS-2 (5'-GCTGCGTTCTTCATCGATGC-3') primers described in White et al. (1990). It should be noted that annealing sites for each primer are just inside the flanking 18S gene and the flanking 5.8S gene, respectively (Figure 1). Thermocycling involved heating the PCR reaction mixtures to 95°C for 5 min, which was then followed by 30 cycles of 95°C (1 min), 42°C (1.5 min), and 72°C (1 min), concluded by a final extension of 72°C for 10 min., and stored at 4°C in a GeneAmp PCR System 2400 (Perkin-Elmer, Norwalk, CT). A Wizard PCR Prep Purification System (Promega, Madison, WI) was used to clean up and purify the PCR products prior to sequencing. All sequencing reactions used BigDye Terminator Cycle Sequencing Ready Reaction (PE Applied Biosystems, Foster City, CA). Using a GeneAmp PCR System 2400, sequencing reactions were heated to 96°C for 1 s, then followed by 30 cycles of 96°C (1 s), 47°C (5 s), and 60°C (4 min), and then stored at 4°C. Reactions were then cleaned up using Sephadex columns (Sigma-Aldrich, St. Louis, MO). Afterwards, they were loaded onto an acrylamide gel and electrophoresed on an ABI Prism 377 DNA Sequencer (PE Applied Biosystems). Sequences were aligned initially with Sequencher 3.1.RC4 (Gene Codes Corporation, Ann Arbor, MI) using the "dirty data" algorithm with default alignment settings (80% minimum match, 20-bp minimum overlap). Sequence editing was done by manual sight inspection. Because the primers used in this study were originally designed for fungi (White et al. 1990), all sequences were compared carefully with GenBank databases using a BLAST search to ensure against the possibility of fungal contamination (Saar et al. 2001). All sequences obtained as described above were deposited in GenBank and assigned accession numbers. Table 1 provides full collection information and GenBank accession numbers for all sequences obtained by the author. Collection information for sequences of other researchers is not given and is only designated as "downloaded from GenBank."

Secondary structure analyses

Because the generated ITS1 sequences also included small flanking portions of the 18S (at the 5' end) and 5.8S (at the 3' end), the 18S/ITS1 and the ITS1/5.8S boundaries were identified by comparing previously published sequences deposited in GenBank. Similar to the methodology of Koetschan *et al.* (2014), putative sequence motifs were identified using the MEME Suite server (https://meme-suite.org/meme/tools/

meme, Bailey et al. 2009) and compared for all sequences. Once individual sequence motifs were identified, secondary structures were predicted using the mFold server (http://www.unafold.org/mfold/ applications/rna-folding-form-v2.php, Zuker 2003) using RNA Folding Form V2.3. Folding constraints were used minimally and then mostly with base positions located near nucleotide ambiguities and only after examination of other sequences. Otherwise, default settings were employed, including a folding temperature of 37°C, 5% suboptimality, an upper bound of 50 for computed foldings, and the maximum distance between paired bases set to "no limit." Complete ITS1 secondary structures were generated by concatenating the predicted individual sequence motif secondary structures for each sequence that spanned the entire ITS1 region. Incomplete sequences were also assessed to evaluate secondary structures where appropriate. It has been suggested that it may be useful to analyze complete RNA secondary structures by using more than one folding program (Leamy et al. 2016). To this end, secondary structure of individual motifs were evaluated as well using the TURBOFold server (https://rna.urmc.rochester.edu/RNAstructureWeb/ Servers/TurboFold/TurboFold.html, Harmanci et al. 2011, Mathews 2014). Where secondary structural variants for individual sequence motifs appeared between specimens, a binomial proportions test was performed using the program PAST (ver. 3.35, Hammer et al. 2001) to test the null hypothesis that two categories (secondary structural variants) are equally likely to occur.

Phylogenetic analysis

MEGA X (ver. 10.2.2, Kumar et al., 2018) was used to evaluate phylogenetic relationships of nucleotide data from the 19 *Equisetum* ITS1 sequences. This was performed in using both maximum parsimony (MP) and maximum likelihood (ML) optimality criteria. To determine appropriate nucleotide substitution model(s) for ML, the "Find Best DNA/Protein Models (ML)" option was selected under the "Model" tab in MEGA X. The suggested best model is based on the lowest Bayesian Information Criterion (BIC) score (Schwarz 1978). Based on these results, the Tamura 3-parameter (T92) model (Tamura 1992) with gamma distribution (*G* parameter = 0.6485, using 5 discrete gamma categories), or a T92+G model was selected.

For both ML and MP analyses, the "Use all sites" option was selected as the treatment in MEGA X for gaps and missing data. The MP analysis utilized the subtree–pruning–regrafting search method and the number of trees, tree length, and goodness of fit statistics (consistency index (CI), retention index (RI), informative site CI (iCI), and informative site RI (iRI)) were obtained and recorded. The number of variable and parsimony informative sites was also recorded. ML analyses were performed using the nearest–neighbor–interchange heuristic approach (using default settings for initial tree-NJ/BioNJ) and the log likelihood for trees was obtained and reported. Bootstrapping (500 replicates) was performed for both ML and MP to determine branch support and branches with less than 50% bootstrap support (BS) were collapsed.

G+C content

MEGA X was also used to determine G+C content. Only complete ITS1 sequences were used for determination of G+C content. Standard deviations (s.d.) for G+C content were calculated using Microsoft Excel for Microsoft 365 MSO.

Results

Nucleotide sequences and comparative lengths

The attachment sites for the forward and reverse primers were in the flanking 18S and 5.8S regions, respectively. Most complete ITS1 sequences were 231 to 232 bases in length. However, E. sylvaticum had a 62-base deletion and was only 170 bases long. The deletion was flanked by two nearly identical sequences: GTCCCCCC and GTCCCCC. Resequencing confirmed the comparative shortness of the E. sylvaticum sequence. Aside from these results, there were otherwise not any discernible differences in sequence lengths observed between subgenera Hippochaete and Equisetum. Several of the downloaded sequences were incomplete and did not cover the entire ITS1 region, preventing any evaluation of Motif 4 for those sequences. These were E. hyemale4 E. (DQ377151), ramosissimum1 (DQ377153), E. telmateia (DQ377154), E. \times meridionale (DQ377156), and E. \times moorei (DQ377157). Including indel positions, there were 237 positions in the sequence alignment with MEGA. No intra-individual ITS1 nucleotide variation was observed for any specimen, although this was not specifically examined. There were 94 (39.66%) nucleotide positions that were variable, but only 46 (19.41%) were parsimony informative. Nucleotide variation appeared to be evenly distributed throughout without any noticeably large variable regions or mutational hot spots being observed (data not shown).

Secondary structure comparison

Evaluation of the MEME Suite was interpreted as indicating 4 sequence motif regions. Motif designation follows the $5' \rightarrow 3'$ nucleotide order (i.e., Motif 1 precedes Motif 2, Motif 2 precedes Motif 3, etc.). The TURBOFold and the concatenated mFold results tended to agree as to which individual stem-loops were present and usually as to the basic overall ITS1 secondary structure. However, there were some differences, mostly with respect to nucleotide-pairing relationships at the base of certain stems. The locations of the motifs on the ITS1 secondary structure using the sequence for the *E. hyemale*1 specimen are shown in Figure 2. Depending on subgenus, secondary structures for most sequences had either 5 (subg, Equisetum) or 6 (subg. Hippochaete) stemloops, a difference that appeared to be primarily due to subgeneric variation for Motif 3 (see below). Additionally, the E. variegatum2 sequence differed from other subg. *Hippochaete* specimens (including the other 2 *E variegatum* sequences) by having only 5 stem structures because of an anomalous secondary structure obtained for sequence Motif 3 (Figure 3). On the other hand, the 62-base deletion in Motif 2 of E. sylvaticum (subg, Equisetum) resulted in a secondary structure with only 4 stems (Figure 4).



Figure 2. The positions of identified motifs on the ITS1 secondary structure using the *E. hyemale*1 specimen as a representative. In general, the obtained secondary structures for all *Equisetum* species were similar, though not always identical. *E. hyemale* is a subg. *Hippochaete* taxon. See text about the secondary structural differences between subg. *Hippochaete* and subg. *Equisetum* for sequence Motif 3.



Figure 3. The secondary structure for the *E. variegatum*2 sequence with the position of the sequence Motif 3 anomaly indicated.



Figure 4. The obtained secondary structure for *E. sylvaticum*. Note the anomalous secondary structure for sequence Motif 2 resulting from the 62-base deletion. *E. sylvaticum* is a subg. *Equisetum* taxon. See text about the secondary structural differences between subg. *Hippochaete* and subg. *Equisetum* for sequence Motif 3.

The secondary structure for Motif 1 was similar for all complete *Equisetum* sequences evaluated, although there was some nucleotide variation that sometimes resulted in minor secondary structural variation between sequences. Similar patterns of similarity of motif secondary structure among sequences were also seen for Motif 2 (except for *E. sylvaticum* because of the 62-base deletion) and Motif 4. Representative secondary structures for Motifs 1 and 4 are shown in Figure 5, while the larger Motif 2 is shown Figure 6.



Figure 5. Representative secondary structures for sequence Motifs 1 and 4: (a) Motif 1 secondary structure for *E. laevigatum*. (b) Motif 4 secondary structure for *E. ramosissimum*2.

Examination of base-pairing variation within stems revealed that secondary structure tended to be maintained, as many substitutions affected only one nucleotide of a base-pairing position and caused a change from a strict Watson–Crick pairing to a wobble relationship or vice versa. In one case, an example of a compensatory base change was observed for Motif 2 in *E. laevigatum*, where both nucleotides were changed. Despite some degree of nucleotide variation, secondary structure appeared to be conserved among sequences in general for Motifs 1, 2, and 4. In contrast, Motif 3 appeared in this study to show consistent secondary structural variation between subg. *Hippochaete* and subg. *Equisetum* (Figure 7). The difference between the occurrences of the two structural variants was statistically significant (Z = -2.98, p = 0.003). Except the aforementioned *E. variegatum*2 specimen, all subg. *Hippochaete* specimens had the Motif 3 variant shown in Figure 7a, while all subg. *Equisetum* specimens had the variant shown in Figure 7b.



Figure 6. Representative secondary structure for sequence Motif 2. Shown is Motif 2 for *E. variegatum*2.



Figure 7. Subspecific secondary structural variation for the sequence Motif 3: (a) subg. *Hippochaete*, (b) subg. *Equisetum*.

Phylogenetic analysis

MP generated 4 equally parsimonious trees of length 137 with CI = 0.773, RI = 0.723, iCI = 0.639, and iRI = 0.723. The MP bootstrap tree is shown in Figure 8a. The two subgenera were robustly resolved into two clades (BS = 99%). However, the subg. Hippochaete clade was mostly polytomous, with most taxonomic relationships not resolved. Of the 3 species represented by more than one sequence (*E. hyemale, E. ramosissimum*, and *E. variegatum*), none formed a united clade. However, one E. ramosissimum specimen grouped together with the *E. ramosissimum* hybrids *E.* × *meridionale* and *E.* × *moorei* in a moderately well-supported clade (BS = 86%). Also, *E. scirpoides* and one of the *E. variegatum* sequences were joined in a well-supported clade (BS = 95%).

ML generated a tree of log likelihood = -1008.51 using the T92+G model. The ML bootstrap tree is shown in Figure 8b. Like the MP tree, both subgenera were vigorously separated into two clades. Systematic relationships in subg. *Hippochaete* were mostly poorly resolved, like MP. As with MP, an *E. ramosissimum* specimen and the hybrids *E.* × *meridionale* and *E.* × *moorei* did group together, although with much lower bootstrap support (BS = 73%). Like MP, *E. scirpoides* and one of the *E. variegatum* sequences were joined, although with much lower support clade (BS = 63%). *E. scirpoides* and an *E. variegatum* sequences grouped together as they did in MP, although with considerably weaker support (BS = 63%). In distinct contrast with MP, both ML results united two *E. hyemale* sequences (but none of the other two), although with very low support (both with BS = 60%).

G+C content comparisons

For complete sequences, G+C values ranged from 65.64% (*E. myriochaetum*) to 71.43% (*E. variegatum*1), with an average G+C content of 69.39% (s.d. 2.59). There was some small variability observed among conspecific sequences. For example, *E. variegatum* sequences varied as much as 4.47% and G+C content among *E. hyemale* sequences differed by as much as 2.97%. There was not any distinguishing subgeneric variation, and there was considerable G+C content overlap between specimens of both subgenera.



Figure 8. Phylogenetic trees obtained in this study. The numbers indicate the bootstrap support (BS) for that branch. (a) Maximum parsimony tree. (b) Maximum likelihood tree using the Tamura 3-parameter model with gamma distribution.

Discussion

ITS1 length

Except for the much shorter *E. sylvaticum* sequence, all other complete *Equisetum* ITS1 sequences evaluated had lengths of 231 to 232 bases. This is well within the range of 187 to 298 bases reported for most angiosperms (Baldwin *et al.* 1995). Maggini *et al.* (1998) observed similar lengths for several ferns and lycophytes. Likewise, van den Heede *et al.* (2003) reported that taxa in the fern genus *Asplenium* had ITS1 lengths of 237 to 279 bases. A comparable range of values also has been observed for several moss species (Shaw *et al.* 2003). In stark contrast to these values, the ITS1 region for many gymnosperms has been observed to be two or more times greater in length, with some being as long as 3263 bases (Campbell *et al.* 2005, Won and Renner2005). With the exception of *E. sylvaticum* noted previously, the similarity in ITS1 lengths observed among specimens of the two subgenera, or phylogenetic clades, further tends to confirm their close relationship within the genus *Equisetum*.

Secondary structure

Despite its widespread use, in silico modelling of RNA secondary structure, such as was used here, is not without limitations, which have been discussed elsewhere (e.g., Mathews et al. 2004, Andronescu et al. 2014, Leamy et al. 2016). RNA secondary structure is determined by several different (and, perhaps, sometimes unknown) interacting factors. Therefore, computer-generated optimal secondary structures may not necessarily represent an actual in vivo structure (Gottschling and Plötner 2004). Furthermore, it is known that some RNAs may occur in at least two alternative secondary structures to function properly (Ritz et al. 2013). Nevertheless, in silico approaches offer testable hypotheses about RNA secondary structure, while providing a context for interpreting experimental results (Gottschling and Plötner 2004, Leamy et al. 2016). Additionally, it is often the case that predicted RNA secondary structures are thought to provide information potentially useful for phylogenetic inference (Schöniger and Von Haeseler 1994, Telford et al. 2005, Keller et al. 2010, Zhuang and Liu 2012).

As ITS1 is not conserved within the domain Eukarya (Koetschan *et al.* 2014), the predicted secondary structures shown here are dissimilar to those that have been proposed for other eukaryotic taxa, just as those are different from each other (e.g., Gottschling and Plötner 2004, Tippery and Les 2008, Hřibová *et al.* 2011, Lim *et al.* 2012, Coleman

2013, Rodionov et al. 2017, Kapoor et al. 2018). Nevertheless, the general ITS1 secondary structural similarity for the Equisetum species examined here is consistent with the observation of core structural similarities at the genus and other taxonomic levels for certain eukaryotic taxa (Coleman et al. 1998, Gottschling et al. 2001, Hoshina 2010, Thornhill and Lord 2010). Based on the results obtained in this study, this idea of core structural similarities may possibly be extended to subgenus regarding Motif 3. It was here observed that subg. *Hippochaete* taxa had similar Motif 3 secondary structures that differed from the secondary structure for this same motif area found for all specimens of subg. Equisetum. The secondary structure for the E. variegatum2 sequence was anomalous for Motif 3. Unlike all other subg. *Hippochaete* sequences, including the other sequences for *E. variegatum*, it lacked the smaller, second stem-loop structure. This appears to be an ITS1 secondary structural mutation unique to this specimen in this study. Otherwise, it was similar to the rest of the subg. *Hippochaete* specimens and its Motif 3 secondary structure was clearly distinct from subg. Equisetum specimens. The Motif 3 distinction between the two subgenera observed here is made cautiously, however, as only a small number of specimens were examined, nor were all recognized Equisetum species included.

The 62-base deletion in the Motif 2 region of *E. sylvaticum* resulted in a somewhat aberrant secondary structure as compared with the secondary structures of the other *Equisetum* sequences. However, *E. sylvaticum* was similar with respect to Motifs 1 and 4 for the rest of the genus and to Motif 3 for other subg. *Equisetum* taxa. One possible explanation for the deletion, particularly because it appears to be flanked at both ends by nearly identical sequences, is a DNA replication error known as slippage, which has been reported previously (e.g., Oron-Karni *et al.* 1997). However, because only a single specimen of this species was sequenced, it is not clear whether the 62-base deletion is a common ITS1 feature for *E. sylvaticum* in general or whether what is seen here is a unique ITS1 mutation in one plant (as was seen for Motif 3 of *E. variegatum*2). Further specimens will need to be sequenced for clarification.

Systematic/phylogenetic relationships

The chloroplast DNA (cpDNA) phylogenies of Des Marais *et al.* (2003), Guillon (2004), and Guillon (2007), in general, reliably separated taxa belonging to subg. *Equisetum* and subg. *Hippochaete*, with the sole exception to this being *E. bogotense*. As noted previously, this taxon was formerly placed in subg. *Equisetum* but has been more recently been put

in the monotypic subg. *Paramochaete* by Christenhusz *et al.* (2019). Although these chloroplast studies do differ as to certain specific phylogenetic relationships within subgenera, the ITS1 results presented here are consistent with them regarding resolution of relationships between subgenera. Interspecific relationships within subgenera, particularly subg. *Hippochaete*, were largely unresolved using ITS1 sequences, unlike those for cpDNA. When the same taxon was represented by two or more specimens, ITS1 did not consistently group these conspecific sequences. For the most part, none of the interspecific relationships found in any of the cpDNA phylogenies were recovered using ITS1.

The observed lack of phylogenetic resolution may be due, at least in part, to geographical and subspecific variation. For example, based on the author's collection data and information provided in GenBank, the four *E. hyemale* sequences used here represent specimens from North America, Europe, and Asia. Furthermore, the GenBank information indicates the presence of two *E. hyemale* subspecies in this study: subsp. *affine* and subsp. *hyemale*. Intraspecific ITS1 variation has been observed for other organisms (e.g., Saini *et al.* 2008, Zhang *et al.* 2017), as well as intra-individual ITS1 variation (e.g., Fama *et al.* 2000), and cannot be ruled out for *Equisetum*. However, the question of intraspecific ITS1 variation in this genus remains to be examined more extensively.

Another possible cause for the lack of resolution is hybridization, which is well documented within the Equisetum subgenera evaluated here (Duckett 1979), particularly in subg. Hippochaete (Husby 2013). Des Marais et al. (2003) point out that hybrids can often look very similar to one of the parental species and, therefore, can be misidentified for them. Husby (2013) notes that hybrids are usually sterile. Examinations of most hybrids reveal that they generate abortive spores that are noticeably misshapen and achlorophyllous when compared with spores produced by fertile plants (e.g., Jepson et al. 2013, Page and Gureyeva 2013, Lubienski and Dörken 2017). However, this may not always be the case. For example, Page (1973) observed some hybrid plants that produced both obviously abortive spores, as well as properly shaped, chlorophyllous, and, therefore, possibly viable spores. Furthermore, Bennert et al. (2005) reported several cases of allotriploidy in subg. Hippochaete, which also suggests that some Equisetum hybrids can produce fertile spores, although infrequently. However, Bennert et al. (2005) also consider the possible involvement of unreduced diplospores, which have been examined in other fern hybrids, for some of these triploids. If hybridization followed by introgression has occurred in the past, this may have blurred, in some cases, the genetic distinctions between some of these species.

G+C content

The range of ITS1 G+C values observed here fall within the upper end of the range of 42% to 73% reported for most angiosperms (Baldwin *et al.* 1995). The G+C values observed here for *Equisetum* tend to be higher than the 47.7% to 61.0% reported for members of the fern genus *Asplenium* (van den Heede *et al.* 2003), as well as the 51.9% to 60.6% noted for members of the Pinaceae (Campbell *et al.* 2005), although these taxa also fall within the distribution seen for angiosperms. The two *Equisetum* subgenera evaluated here were not distinguishable on the basis of G+C content.

Conclusions

A more extensive evaluation of ITS1 in this genus is needed because this study examined only a small number of specimens and a portion of the recognized species. Nevertheless, the results obtained in this study strongly suggest that ITS1 may not be reliable for elucidating interspecific relationships or for grouping conspecific specimens, at least not for subg. *Hippochaete*. At the same, ITS1 does certainly appear to be useful for identifying subgeneric relationships within the genus *Equisetum*. This was clearly indicated by both the predicted secondary structures obtained in this study and the phylogenetic analysis of the sequence data.

Literature Cited

Álvarez I, Wendel JF. 2003. Ribosomal ITS sequences and plant phylogenetic inference. *Mol Phylogenet Evol* 29:417-434.

Andronescu M, Condon A, Turner DH, Matthews DH. 2014. The determination of RNA folding nearest neighbor parameters. *Methods Mol Biol* 1097:45-70.

Bailey CD, Carr TG, Harris SA, Hughes CE. 2003. Characterization of angiosperm nrDNA polymorphism, paralogy, and pseudogenes. *Mol Phylogenet Evol* 29:435-455.

Bailey TL, Bodén M, Buske FA, et al. MEME SUITE: tools for motif discovery and searching. *Nucleic Acids Res* 37:W202-W208.

Baldwin BG, Sanderson MJ, Porter JM, et al. 1995. The ITS region of nuclear ribosomal DNA: A valuable source of evidence on angiosperm

phylogeny. Ann Mo Bot Gard 82:247-277.

Bakker FT, Olsen JL, Stam WT. 1995. Global phylogeography in the cosmopolitan species *Cladophora vagabunda* (Chlorophyta) based on nuclear rDNA internal transcribed spacer sequences. *Eur J Phycol* 30:197-208.

Bennert W, Lubienski M, Körner S, Steinberg M. 2005. Triploidy in *Equisetum* subgenus *Hippochaete* (Equisetaceae, Pteridophyta). *Ann Bot* 95:807-815.

Campbell CS, Wright WA, Cox M, et al. 2005. Nuclear ribosomal DNA internal transcribed spacer 1 (ITS1) in *Picea* (Pinaceae): sequence divergence and structure. *Mol Phylogenet Evol* 35:165-185

Christenhusz MJM, Bangiolo L, Chase MW, et al. 2019. Phylogenetics, classification and typification of extant horsetails (*Equisetum*, Equisetaceae). *Bot J Linn Soc* 189:311-352.

Coleman AW. 2013. Analysis of mammalian rDNA internal transcribed spacers. *PLoS ONE* 8:e79122.

Coleman AW, Maria Preparata R, Mehrotra B, Mai JC. 1998. Derivation of the secondary structure of the ITS-1 transcript in Volvocales and its taxonomic correlations. *Protist* 149:135-146.

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

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

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

Fama P, Olsen JL, Stam WT, Procaccini G. 2000. High levels of intraand inter-individual polymorphism in the rDNA ITS1 of *Caulerpa racemosa* (Chlorophyta). *Eur J Phycol* 35:349-356. Gernandt DS, Liston A. 1999. Internal transcribed spacer region evolution in *Larix* and *Pseudotsuga* (Pinaceae). *Am J Bot* 86:711-723.

Gernandt DS, Liston A, Piñero D. 2001. Variation in the nrDNA ITS of *Pinus* subsection *Cembroides*: Implications for molecular systematic studies of Pine species complexes. *Mol Phylogenet Evol* 21:449-467.

Goffová I, Fajkus J. 2021. The rDNA Loci—Intersections of replication, transcription, and repair pathways. *Int J Mol Sci* 22:1302.

Gottschling M, Hilger HH, Wolf M, Diane N. 2001. Secondary structure of the ITS1 transcript and its application in a reconstruction of the phylogeny of Boraginales. *Plant Biol* 3:629-636.

Gottschling M, Plötner J. 2004. Secondary structure models of the nuclear internal transcribed spacer regions and 5.8S rRNA in Calciodinelloideae (Peridiniaceae) and other dinoflagellates. *Nucleic Acids Res* 32:307-315.

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

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

Hammer Ø, Harper DAT, Ryan PD. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontol Electron* 4(1): 9pp.

Harmanci AO, Sharma G, Mathews DH. 2011. TurboFold: Iterative probabilistic estimation of secondary structures for multiple RNA sequences. *BMC Bioinformatics*. 12:108.

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

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

Hershkovitz MA, Zimmer EA, Hahn WJ. 1999. Ribosomal DNA sequences and angiosperm systematics. In: Hollingsworth PM, Bateman RM, Gornall RJ (eds), *Molecular systematics and plant evolution*, Taylor & Francis: London, pp 268-326.

Hoshina R. 2010. Secondary structural analyses of ITS1 in *Paramecium*. *Microbes Environ* 25:313-316.

Hřibová E, Čížková J, Christelová P, et al. 2011. The ITS1-5.8S-ITS2 sequence region in the Musaceae: structure, diversity and use in molecular phylogeny. *PLoS ONE* 6:e17863.

Husby C. 2013. Biology and functional ecology of *Equisetum* with emphasis on the giant horsetails. *Bot Rev* 79:147-177.

Jepson P, Lubienski M, Llewellyn P, Viane R. 2013. Hybrids within *Equisetum* subgenus *Hippochaete* in England and Wales. *New J Bot* 3:47-58.

Kapoor N, Gambhir L, Saxena S. 2018. Secondary structure prediction of ITS rRNA region and molecular phylogeny: an integrated approach for the precise speciation of *Muscodor* species. *Ann Microbiol* 68:763-772.

Keller A, Förster F, Müller T, et al. 2010. Including RNA secondary structures improves accuracy and robustness in reconstruction of phylogenetic trees. *Biol Direct* 5:4.

Koetschan C, Kittelmann S, Lu J, et al. 2014. Internal transcribed spacer 1 secondary structure analysis reveals a common core throughout the anaerobic fungi (Neocallimastigomycota). *PLoS ONE* 9:e91928.

Kumar S, Stecher G, Li M, Knyaz C, Tamura K. 2018. MEGA X: Molecular Evolutionary Genetics Analysis across computing platforms. *Mol Biol Evol* 35:1547-1549

Layat E, Sáez-Vásquez J, Tourmente S. 2012. Regulation of Pol Itranscribed 45S rDNA and Pol III-transcribed 5S rDNA in *Arabidopsis*. *Plant Cell Physiol* 53:267-276.

Leamy KA, Assmann SM, Mathews DH, Bevilacqua PC. 2016. Bridging the gap between in vitro and in vivo RNA folding. *Q Rev Biophys.* 49:e10.

56 Biology

Lim HC, Lim P-T, Pau Su SNP, Teng ST, Leaw C-P. 2012. Genetic diversity of *Pseudo-nitzschia pungens* (Bacillariophyceae) in Borneo, Malaysia. *Coast Mar Sci* 35:58-63

Long EO, Dawid IB. 1980. Repeated genes in eukaryotes. *Annu Rev Biochem* 49:727-764.

Lubienski M, Dörken VM. 2017. Two hybrids of *Equisetum sylvaticum* (Equisetaceae) on the island of Senja, Troms, Norway. *Fern Gaz* 20:181-196.

Maggini F, Marrocco R, Gelati MT, Ilio De Dominicis R. 1998. Lengths and nucleotide sequences of the internal spacers of nuclear ribosomal DNA in gymnosperms and pteridophytes. *Plant Syst Evol* 213:199-205.

Mathews DH. 2014. Using the RNAstructure Software Package to Predict Conserved RNA Structures. *Curr Protoc Bioinformatics*. 46:12.4.1-12.4.22

Mathews DH, Disney MD, Childs JL, et al. 2004. Incorporating chemical modification constraints into a dynamic programming algorithm for prediction of RNA secondary structure. *Proc Natl Acad Sci U S A* 101:7287-7292.

Muir G, Fleming CC, Schlötterer C. 2001. Three divergent rDNA clusters predate the species divergence in *Quercus petraea* (Matt.) Liebl. and *Quercus robur* L. *Mol Biol Evol* 18:112-119.

Oron-Karni V, Filon D, Rund D, Oppenheim A. 1997. A novel mechanism generating short deletion/insertions following slippage is suggested by a mutation in the human α 2-globin gene. *Hum Mol Genet* 6:881-885.

Page CN. 1973. Two hybrids in Equisetum new to the British flora. *Watsonia* 9:229-237.

Page CN, Gureyeva II. 2013. *Equisetum* x sergijevskianum, a hybrid horsetail from Siberia. *Fern Gaz* 19:181-190.

Rabanal FA, Mandáková T, Soto-Jiménez LM, et al. 2017. Epistatic and allelic interactions control expression of ribosomal RNA gene clusters in *Arabidopsis thaliana*. *Genome Biol* 18:75.

Ritz J, Martin JS, Laederach A. 2013. Evolutionary evidence for alternative structure in RNA sequence covariation. *PLoS Comput Biol* 9:e1003152.

Rodionov AV, Gnutikov AA, Kotsinyan AR, et al. 2017. ITS1-5.8S rDNA-ITS2 sequence in 35S rRNA genes as marker for reconstruction of phylogeny of grasses (Poaceae family). *Biol Bull Rev* 7:85-102.

Saar DE, Polans NO, Sørensen PD, Duvall MR. 2001. Angiosperm DNA contamination by endophytic fungi: Detection and methods of avoidance. *Plant Mol Biol Rep* 19:249-260.

Saini A, Reddy SK, Jawali N. 2008. Intra-individual and intra-species heterogeneity in nuclear rDNA ITS region of *Vigna* species from subgenus *Ceratotropis*. *Genet Res (Camb)* 90:299-316.

Schöniger M, Von Haeseler A. 1994. A stochastic model for the evolution of autocorrelated DNA Sequences. *Mol Phylogenet Evol* 3:240-247.

Schwarz G. 1978. Estimating the dimension of a model. Ann Statist 6:461-464.

Shaw AJ, Werner O, Ros RM. 2003. Intercontinental Mediterranean disjunct mosses: Morphological and molecular patterns. *Am J Bot* 90:540-550.

Suh Y, Thien LB, Reeve HE, Zimmer EA. 1993. Molecular evolution and phylogenetic implications of internal transcribed spacer sequences of ribosomal DNA in Winteraceae. *Am J Bot* 80:1042-1055.

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

Telford MJ, Wise MJ, Gowri-Shankar V. 2005. Consideration of RNA secondary structure significantly improves likelihood-based estimates of phylogeny: Examples from the Bilateria. *Mol Biol Evol* 22:1129-1136,

Thornhill DJ, Lord JB. 2010. Secondary structure models for the internal transcribed spacer (ITS) region 1 from symbiotic dinoflagellates. *Protist* 161:434-451.

Tippery NP, Les DH. 2008. Phylogenetic analysis of the internal transcribed spacer (ITS) region in Menyanthaceae using predicted secondary structure. *Mol Phylogenet Evol* 49:526-537.

van den Heede CJ, Viane RLL, Chase MW. 2003. Phylogenetic analysis of *Asplenium* subgenus *Ceterach* (Pteridophyta: Aspleniaceae) based on plastid and nuclear ribosomal ITS DNA sequences. *Am J Bot* 90:481-495.

van Nues RW, Rientjes JM, van der Sande CA, et al. 1994. Separate structural elements within internal transcribed spacer 1 of *Saccharomyces cerevisiae* precursor ribosomal RNA direct the formation of 17S and 26S rRNA. *Nucleic Acids Res*, 22:912-919.

Wallace H, Birnstiel ML. 1966. Ribosomal cistrons and the nucleolar organizer. *Biochim Biophys Acta* 114:296-310.

Wendel JF, Schnabel A, Seelanan T. 1995. Bidirectional interlocus concerted evolution following allopolyploid speciation in cotton (*Gossypium*). *Proc Natl Acad Sci U S A* 92:280-284.

White TJ, Bruns T, Lee S, Taylor J. 1990. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innes M, Gelfand D, Sninsky J, and White T (eds.), *PCR Protocols: A Guide to Methods and Applications*, Academic Press: San Diego, pp 315-322.

Wicke S, Costa A, Muñoz J, Quandt D. 2011. Restless 5S: the rearrangement(s) and evolution of the nuclear ribosomal DNA in land plants. *Mol Phylogenet Evol*. 61:321-32.

Won H, Renner SS. 2005. The internal transcribed spacer of nuclear ribosomal DNA in the gymnosperm *Gnetum*. *Mol Phylogenet Evol* 36:581-597.

Xu B, Zeng X-M, Gao X-F, Jin D-P, Zhang L-B. 2017. ITS nonconcerted evolution and rampant hybridization in the legume genus *Lespedeza* (Fabaceae). *Sci Rep* 7:40057.

Zhang X, Xu Z, Pei H, et al. 2017. Intraspecific variation and phylogenetic relationships are revealed by ITS1 secondary structure analysis and single-nucleotide polymorphism in *Ganoderma lucidum*. *PLoS ONE* 12:e0169042.

Zhu P, Wang Y, Qin N, et al. 2016. *Arabidopsis* small nucleolar RNA monitors the efficient pre-rRNA processing during ribosome biogenesis. *Proc Natl Acad Sci U S A* 113:11967-11972.

Zhuang WY, Liu CY. 2012. What an rRNA Secondary Structure Tells about Phylogeny of Fungi in Ascomycota with Emphasis on Evolution of Major Types of Ascus. *PLoS ONE* 7:e47546

Zuker M. 2003. Mfold web server for nucleic acid folding and hybridization prediction. *Nucleic Acids Res* 31:3406-3415.

Self-Efficacy, Emotional Intelligence, Self-Determination, and Self-Regulated Learning: Student Survey Results and Relationship to Practice CPA Exam Scores in an Auditing Course

Jefferson T. Davis Weber State University

Abstract

A long and rich research history in self efficacy, emotional intelligence, self-determination, and self-regulated learning ties these cognitive constructs to academic performance. This study reports survey results of a self-reported questionnaire related to these constructs obtained from the literature. The paper makes a simple relationship to academic performance of these students in the form of two practice exams for the auditing section of the CPA exam. Students took the first practice exam before taking the survey and the second practice exam after taking the survey. Preliminary analysis suggests that the test scores improved based on t-test descriptive analysis after the students were introduced to the cognitive principles incorporated in the survey questions. However, predictive analysis showed little if any statistical significance toward improved test scores. More research needs to be done to isolate any confounding variables for the improvement on the second test.

Introduction

With the advent of testing centers, online tests, etc., students taking the same tests over multiple days may have opportunity to benefit from information leakage. Mouritsen and Davis (2012) and Mouritsen et al. (2016) studied whether information leakage was a benefit to students who took the test later in the testing period. They found that the average test score for students who took the test later in the test period was lower than that of students who took the test earlier in the testing period. This result applied to testing days and even time during the last day of the test. There was also more variability in the testing scores for students who took the test closer and closer to the deadline. They also found that students with lower grade point average (GPA) tended to take the test later in the testing period. In their discussion, they wondered how an instructor could provide help and intervention to students who waited to the last day and, in some cases, last hours to take the test. They wondered about student procrastination in relation to the students' preparation and confidence in their ability to perform well on a test.

Bandura (1977) provided a seminal article related to self-efficacy (see also Schwarzer 1992). Mayer et al. (2004) discussed their theory and findings related to emotional intelligence. Gagne and Deci (2005) present self-determination theory that includes the concepts of intrinsic and extrinsic motivation. Pintrich and DeGroot (1990a,b), and Pintrich and Schrauben (1992) provide important theories on self-regulated learning and learning strategies. Using these psychology research articles as a foundation, subsequent researchers have studied academic performance and procrastination as it relates to these important psychological constructs in students (see, e.g., Haycock et al. (1998); Deniz et al. (2009); Barrows et al. (2013); Hen and Goroshit (2014a,b).

Specifically, Hen and Goroshit (2014b, p. 5) find statistically significant results that self-efficacy as a mediating variable of emotional intelligence showed a positive *indirect* relationship with improved GPA and an inverse *indirect* relationship with procrastination. However, they also found that a *direct* relationship between self-efficacy and GPA and with procrastination was *not* statistically significant. Their study used structural equation modeling (SEM).

The basic research model for our study is presented in Figure 1. Self-efficacy, emotional intelligence, self-determination, and self-regulated learning all combine to affect procrastination and performance. Thus, higher self-efficacy, higher emotional intelligence, higher selfdetermination, and better self-regulated learning applied by an individual lead to less procrastination and better performance. Unlike Hen and Goroshit (2014b), the current study attempts to use simpler statistical descriptive and predictive models than SEM and does not try to separate out mediating or moderating variables. The current study looks at selfefficacy, emotional intelligence, self-determination, and self-regulated learning as variables to provide explanation as to the relationship of these variables to procrastination and test scores. In the current study, the expectation or hypothesis is that if a student has higher measures of cognitive constructs, overall, then procrastination, that is, taking the test at the last minute will decrease, and the test score will be higher.



Figure 1: Cognitive constructs, procrastination, and performance

There are several accounting practice and educational articles referring to emotional intelligence and its role in education and work experience. These papers are based on the premise that accounting students can perform better in areas such as leadership roles, client relations, and perhaps even decision-making if the accounting educators can help students improve their emotional intelligence in addition to accounting and business technical knowledge and skills (Bay and McKeage, 2006). The authors concluded that attempts to increase emotional intelligence of the students may require targeted education interventions. Cook et al. (2011) studied the role of emotional

intelligence in accounting education and work experience. They concluded that work experience in addition to emotional intelligence classroom exercises was important for improving emotional intelligence skills. Several more recent articles have studied or opined about the importance and role of emotional intelligence in public sector accounting (Puspitasari et al., 2020), auditor performance (Brody et al., 2020), emotional agility during the coronavirus pandemic (Padar 2020), and using improved emotional intelligence to shine in the workplace (Wotapka 2018).

The current research study seeks to add to this literature by studying the performance of auditing students on certified public account (CPA) exam audit practice tests. Two types of intervention for helping students perform well on the practice CPA audit exam are applied. First, students were given an opportunity to take a self-assessment survey that asked questions to measure their own self-efficacy, emotional intelligence, self-determination, and self-regulated learning components. This survey was intended to educate and help students be aware and begin to understand these psychological constructs in relation their test preparation. The hypothesis is whether taking this survey leads to an improved multiple choice test score as represented by the CPA exam audit practice test taken in a university audit course. The null hypothesis (H_0) is that the test score is not increased, whereas the alternate hypothesis (H_a) is that an increased test score does occur after taking the survey. Second, students were provided access to multiple practice tests in preparation for the practice CPA exam that was counted as part of the final audit course grade.

Definitions of Cognitive Constructs and Sources for the Survey Questions

Self-efficacy is described as an individual's judgments of his or her capabilities to perform given actions (Schwarzer and Jerusalem, 1995). This can also be thought of as the confidence a person has in themselves and their abilities to perform any given action. For example, a student with high self-efficacy is confident in his or her ability to perform well on tests. If a student does not believe they have a strong ability to perform well on tests, this would be an indication of low self-efficacy on test taking. The survey questions for self-efficacy included 10 questions. A Likert scale of 1 to 5 (Low to High) was used.

Emotional intelligence is broken up into four different parts: selfawareness, self-management, social-awareness, and social skills. Selfawareness is an individual's judgments of his or her ability to recognize and understand his/her own emotions. Self-management is an individual's judgments of his or her ability to manage or control their own emotions. Social awareness can be described as an individual's judgments of their own ability to recognize the emotions of others. Social skill is an individual's judgments of his or her ability to appropriately interact with others (Mayer et al., 2004). Proper recognition, understanding, and application of these emotional intelligence components should lead to improved performance on tasks, assignments, and tests. Each of these four emotional intelligence areas include 10 survey questions. Again, a Likert scale of 1 to 5 (Low to High) was used.

Self-determination is an individual's judgments of his or her motivations and ability to set and achieve goals (Gagne & Deci, 2005). Self-determination includes understanding intrinsic and extrinsic motivations and their power to help the individual reach a goal or objective. High self-determination should help a student improve performance based on proper motivations to succeed in a given task, assignment, or test. Self-determination has 6 questions using a Likert scale of 1 to 5 (Low to High).

Self-regulated learning relates to an individual's judgments of his or her ability to learn appropriately using their own learning talent, strengths, and weaknesses. During self-regulated learning, the student monitors and assesses his/her learning process (Pintrich and DeGroot, 1990a,b). The self-regulated learning survey section includes 44 questions, each using a Likert scale of 1 to 5 (Low to High).

The survey questions from each of these sources were adjusted to a Likert scale of 1 to 5 to provide for internal consistency and validity as opposed to stronger external validity if the survey questions had used original survey scales to the questions. The tradeoff of more internal validity, rather than measuring external values from prior research, provided an ability to relate averages and variations to all the question areas for the respondents in the current study. The survey instrument including the various sections and individual questions are shown in the Appendix.

Audit Class and CPA Exam Practice Tests, Survey Administration

The audit class consisted of 61 seniors in the accounting program at an AACSB-accredited institution. Included in the course assignments and testing were two practice audit CPA exams using Gleim online testing software. The first test was the first half of the audit topics that correlated to about 500 randomized questions in Gleim and the auditing textbook. The second test was a different set of audit topics that correlated to a different set of about 500 randomized questions in Gleim and to the last half of audit topics covered in the auditing textbook. Each of the practice CPA audit tests included 60 questions from Gleim practice software. In addition to chapter reading, chapter assignments, and audit assignments using ACL computerized audit software, the students were given access to the randomized questions from the Gleim test bank. Each student could take up to 10 "noncounting" exams before taking the exam that would count toward the course grade. These practice sessions are consistent with typical preparation for taking the actual CPA exam. Each student also had two tries at the exam. The highest score of the two tries was recorded toward the class grade.

The students were offered the self-efficacy, emotional intelligence, self-determination, and self-regulated learning survey as an extra credit option to the course. Because the survey is a self-assessment survey, there is no grade and no right or wrong answers for the survey. The survey instructions made this clear to the students. The results of the survey were not reviewed nor summarized until after the semester grades were posted. Only the extra credit points relating to 2% of the total course grade were recorded for students who chose to take the survey.

The survey was only available to students after all students had already taken practice audit test 1. Forty-seven of the students chose to take the survey before taking test 2. This group comprises the "survey" group (n=47). Fourteen students either took the survey after test 2 or not at all, so this comprises the "non-survey" group (n=14). The survey was administered online through the learning management system.

CPA Practice Test Results

Descriptive statistics using a one-tailed t-test was used to compare whether the survey may have an impact on improving audit CPA practice test scores on test 2 in comparison to test 1. The H_o hypothesis is that test scores for test 2 did not improve from test 1. The H_a hypothesis is that test scores for test 2 did increase in relation to test 1 after taking the survey.

The survey group average test result for CPA audit test 1 was 85.87% with a standard deviation of 14.97%. The average score for CPA audit test 2 was 89.13% with a standard deviation of 11.52%. The survey group increased their test score from test 1 to test 2 by 3.24% after taking the survey. A one-tailed paired t-test for test 1 and test 2 scores for the survey group yielded a p-value of .0274, which indicates a statistically significant increase after taking the survey.

The non-survey group average test result for CPA audit test 1 was 85.60% with a standard deviation of 14.99%. The average and standard deviation for the non-survey group is very close to that of the survey

group. The non-survey group average for test 2 was 88.10% with a standard deviation of 13.49%. The non-survey group increased their test score from test 1 to test 2 by 2.50%. A one-tailed t-test for test 1 and test 2 scores for the non-survey group yielded a p-value of .2124, which is not statistically significant.

So, the one-tailed t-test comparison suggests that taking the survey may have helped students increase their test score. Of course, only correlation, not causation, can be concluded. Also, the smaller number of respondents for the non-survey group (n=14) versus the larger number of respondents for the survey group (n=47) may contribute to the difference in the one-tailed p-values between the non-survey and survey groups' test score increases. Further analysis using predictive statistics of an ANOVA on test scores for survey and non-survey group was also completed. The p-value is the probability that the students' test scores did not increase after taking the survey (H_o). This p-value for the ANOVA was .8294, that is, the probability that there is no difference between the groups is high. Thus, predictive ability of the ANOVA model that taking the survey increases test scores is low.

Survey Results

The survey results are summarized in Table 1. A correlation matrix was also performed for correlation between the cognitive constructs and the difference between tests 1 and 2. This is found in Table 2.

Table 1: Average Response Scores for Self-Efficacy, Emotional
Intelligence, Self-Determination, and Self-Regulated Learning
(Likert Scale 1-5)

	Average Self Efficacy Q 1-10	Emotional Intelligence: Average Self- Awareness Q 11-20	Emotional Intelligence: Average Self- Management Q 21-30	Emotional Intelligence: Average Social Awareness Q 31-40	Emotional Intelligence: Average Social Skills Q 41-50	Average Self- Determination Q 51-56	Average Self- Regulated Learning Q 57 - 100
	0.0057	0 5005	0.5540	0.01.10	0.0000	0.0000	0.5757
Mean	3.9357	3.5925	3.5518	3.8143	3.6929	3.8869	3.5757
Standard Error	0.0505	0.0600	0.0674	0.0666	0.0647	0.0715	0.0639
Median	3.90	3.60	3.60	3.80	3.70	4.00	3.52
Mode	3.80	3.90	4.20	3.60	3.70	4.00	4.20
Standard Deviation	0.3782	0.4490	0.5042	0.4985	0.4839	0.5348	0.4785
Sample Variance	0.1431	0.2016	0.2542	0.2485	0.2341	0.2860	0.2290
Kurtosis	-0.4807	0.2379	-0.8427	-0.4817	-0.3903	0.8926	-0.3850
Skewness	0.2726	-0.1003	-0.3659	0.0983	0.0812	-0.6415	0.4274
Range	1.50	2.20	1.90	2.20	2.20	2.67	2.15
Minimum	3.30	2.50	2.50	2.60	2.70	2.33	2.66
Maximum	4.80	4.70	4.40	4.80	4.90	5.00	4.81
Sum	220.40	201.18	198.90	213.60	206.80	217.67	200.24
Count	56	56	56	56	56	56	56

Table 2: Correlations between Survey Response Scores and Test									
Improvement									
	Average Self Efficacy q 1-10	Emotional Intelligence: Average Self Awareness Q 11-20	Emotional Intelligence: Average Self Management Q 21-30	Emotional Intelligence: Average Social Awareness Q 31-40	Emotional Intelligence: Average Social Skills Q 41-50	Average Self Determination Q 51-56	Average Learning Strategies Q 57 - 100	overall individual avg	tst2 - tst1
Average Self Efficacy q 1-10	1								
Emotional Intelligence: Average Self Awareness Q 11-20	0.1504	1							
Emotional Intelligence: Average Self Management Q 21-30	0.5498	0.1810	1						
Emotional Intelligence: Average Self Awareness Q 31-40	0.3743	0.2778	0.5417	1					
Emotional Intelligence: Average Social Skills Q 41-50	0.5359	0.2394	0.5270	0.6788	1				
Average Self Determination Q 51-56	0.4713	0.4886	0.2548	0.3449	0.5227	1			
Average Learning Strategies Q 57 - 100	0.2848	0.3224	0.0621	0.3805	0.3861	0.3996	1		
overall individual avg	0.6819	0.5548	0.6500	0.7588	0.8155	0.7343	0.5923	1	
tst2 - tst1	-0.0394	-0.2091	0.0373	0.0600	0.0611	-0.0035	-0.0450	-0.0236	1

The means, medians, and modes of the student responses to the questions in each category show generally consistent values among each other. The measures of variance do as well. Also, the kurtosis (measures high or low tails in the frequency distribution) and skewness (measures length of the tails on each side of the distribution mean) are small, so the results generally follow a normal distribution, meaning there are no significant outliers in the results. In this data with n=56, the small number of n does make it more difficult to accurately identify outliers in the results. However, a normal distribution does indicate that performing predictive analysis such as regression should be a good option because regression models typically assume the data has a normal distribution. However, a small n does make prediction ability more difficult.

Before performing predictive analysis using a regression, it is also useful to look at the correlations. Correlations indicate whether there is independence between the potential independent variables which are the survey question results. The correlations are not strong among the question categories. So, this seems to indicate independence, among the question categories which will serve as the independent variables for predicting test score improvement. However, the correlation between each of the question categories to improvement from test 1 to test 2 (tst2tst1) also shows very low correlation, which is not a good indicator of prediction.

Regressions

The expectation of a regression predicting test score improvement based on the student' survey question responses is remote, especially given the ANOVA results showing no difference between the survey and non-survey group in test improvement. However, a more detailed look at specific question category results from each student to predict their test improvement might be fruitful.

A simple regression using overall average survey response values to predict test improvement (tst2-tst1) showed practically no explanatory ability (r-square = 0.0005; adj r-square = -0.0179). A multiple regression using the 7 question categories as independent variables also showed no explanatory ability (r-square = 0.080; adj r-square = -0.054). A negative adjusted r-square means insignificance of explanatory variables. The results may be improved with the increase in sample size. However, the variable for Emotional Intelligence: Self-awareness question results showed a variable p-value of 0.075. So, a regression was run using emotional intelligence: self-awareness as the independent variable to predict test score improvement (tst2-tst1). The regression provided some explanatory ability (r-square .044; adj r-square = .026).

Procrastination

Procrastination, taking the test later toward the test deadline, may also be an important instruction and learning characteristic, given that prior research literature reports procrastination is negatively related to higher test scores. Correlations between the date and time each student took the test and whether they improved on the test score showed very small negative correlation (-0.17). That is, the later the date and time, the lower the test score. A simple regression was also performed, using test time and date on the 2^{nd} test as to whether the students test score improved. The regression resulted in very low prediction of procrastination to test improvement, although the adjusted r-square was still positive, indicating a small explanatory ability of the regression model (r-square = .003; adj r-square = 0.013).

Summary, Discussion, Limitations, Future Research

The overall conclusion is that there is only small evidence from the descriptive and predictive statistical analysis that a student's awareness of their own cognitive learning abilities leads to improved test scores. Descriptive analysis showed that the survey group statistically improved performance on test 2 in comparison to test 1 after taking the cognitive constructs survey, while the non-survey group's test improvement was not statistically significant. Predictive analysis generally provided little, if any explanatory power that cognitive construct survey questions answered by students were useful in predicting test improvement. Emotional intelligence questions relating to self-awareness did provide small explanatory ability to predict test score improvement from test 1 to test 2. Also using procrastination as a variable to predict decrease in test scores from test 1 to test 2 showed very small explanatory ability.

However, just because there are only small or mixed results in statistical findings, does not mean that the contribution to the learning and education literature in business is not significant. For example, in

financial markets research, a small adjusted R-square means that the independent variables are only able to provide only small explanatory power for the dependent variable(s). Small explanatory power (small adjusted R-square) is somewhat frequent in financial markets research that has significant impact on the financial markets academic research literature. Explanatory power is difficult in financial markets research because the complexity, noise, and volatility of the markets make correlation, regression and other statistical modeling difficult for making conclusions for descriptive, predictive, prescriptive purposes. This research phenomenon is also true in the complex research area of learning, memory and cognition, which is a foundation area of education research. For example, in the learning and education literature included in the literature review earlier in this paper, Hen and Goroshit (2014, Eurasion Journal of Social Science) find statistically significant indirect results but not statistically significant direct results in their SEM modeling. Even to get the statistically significant results, they had to bootstrap their 207-sample size of student surveys (by resampling 1000 times and using the percentile method to create a 95% confidence interval they gleaned from a prior research article). The current research also has mixed results, yet provides useful information toward understanding whether, a student's exposure to the cognitive constructs of self-efficacy, emotional intelligence, self-determination and selfregulated learning can potentially impact student procrastination and test scores.

An important limitation in this study relates to the question, "Do students gain an understanding of their own self-efficacy, emotional intelligence, self-determination, self-regulated learning simply by taking a survey?" Taking the survey may not provide students with enough understanding of their own cognitive constructs to help them improve test scores. Since students were given extra credit for taking the survey, there may have also been a self-selection bias between survey and nonsurvey groups. However, it might be hard to predict which way the bias would be, since survey takers could either believe they need the extra points for a better grade, or they tend to be students with higher achievement goals than the non-survey group. Another question to still ask is whether students overestimate their own cognitive abilities. Also, cognitive learning is a very complicated process with many confounding variables, so further research and is needed to isolate and remove confounding learning variables to perhaps improve predictive ability.

In this study, auditing students had many opportunities to study and practice audit questions before taking the tests that provided the test scores used as the dependent variable of test improvement from test 1 to test 2. Having so many practice test opportunities may have decreased the difference between test 1 and test 2 scores. Also having many practice test opportunities may have decreased the impact of cognitive learning survey question differences among the students. The students were given the many practice study opportunities because that is the model used in the professional world to study for the real CPA exam. One of the minor goals of the audit course was to help students prepare for the audit section of the real CPA exam.

A broader study using more than just students from an audit class would increase the number of respondents and broaden the scope of students at different levels in their academic and learning progression. Also using practitioner respondents would be an important addition to future research regarding self-efficacy, emotional intelligence, selfdetermination, and self-regulated learning in tasks other than test taking. Finally, finding and using measures other than self-reported survey responses to the cognitive constructs would add value to the research stream.

References

Bandura, A. (1977). Self-Efficacy: Toward a Unifying Theory of Behavioural Change. *Psychological Review*, 84: 191-215.

Barrows, J., Dunn, S., & Lloyd, C. (2013) Anxiety, Self-Efficacy, and College Exam Grades. *Universal Journal of Educational Research*, 1(3): 204-208.

Bay, D., & McKeage, K. (2006). Emotional Intelligence in Undergraduate Accounting Students: Preliminary Assessment. *Accounting Education*, 15(4): 439-454.

Brody, R., Gupta, G., & Salter, S. (2020). The influence of emotional intelligence on auditor performance. *Journal of Accounting and Management Information Systems*, 19(3): 543-565.

Cook, G., Bay, D., Visser, B., Myburgh, J., & Njoroge, J. (2011). Emotional Intelligence: The Role of Accounting Education and Work Experience. *Issues in Accounting Education*, 26(2): 267-286.

Deniz, M., Tras, Z., & Adygan, D. (2009). An Investigation of Academic Procrastination, Locus of Control, and Emotional Intelligence. *Educational Sciences: Theory & Practice*, 9(2): 623-632.

Gagne, M., & Deci, E. (2005) Self-determination Theory and Work Motivation. *Journal of Organizational Behavior*, 26: 331-362.

Haycock, L., McCarthy, P., & Skay, C. (1998). Procrastination in College Students: The Role of Self-Efficacy and Anxiety. *Journal of Counseling & Development*, 76(3): 317-324.

Hen, M., & Goroshit, M. (2014a). Academic Self-Efficacy, Emotional Intelligence, GPA and Academic Procrastination in Higher Education. *Eurasian Journal of Social Science*, 2(1): 1-10.

Hen, M., & Goroshit, M. (2014b). Academic Procrastination, Emotional Intelligence, Academic Self-Efficacy, and GPA: A Comparison between Students With and Without Learning Disabilities. *Journal of Learning and Disability*, 47(2): 116-124.)

Mayer, J., Salovey, P., & Caruso, D. (2004). Emotional Intelligence: Theory, Findings, and Implications. *Psychological Inquiry*, 60: 197-2015.

Mouritsen M., & Davis, J. (2012). Declining Test Scores among Introductory Accounting Sutdents: A Comparison of Mean Test Scores in Multi-Day Examination Periods. *International Journal of Business and Social Sciences*, 3(15): 1-8.

Mouritsen, M., Davis, J., & Jones, S. (2016) ANOVA Analysis of Student Daily Test Scores in Multi-Day Test Periods. *Journal of Learning in Higher Education*, 12(2): 73-82.

Padar. J. (2020). Emotional Agility in the age of coronavirus: A Crash Course. *The Accounting Today*. April 21.

Pintrich, P., & DeGroot, E. (1990a). Motivational and Self-regulated Learning Components of Classroom Academic Performance. *Journal of Educational Psychology*, 82: 33-40.

Pintrich, P., & DeGroot, E. (1990b). Quantitative and Qualitative Perspectives on Student Motivational Beliefs and Self-regulated Learning. Paper presented at the Annual American Educational Research Association Convention, Boston, Massachusetts, April.
Pintrich, P., & Schrauben, B. (1992). Students' Motivational Beliefs and Their Cognitive Engagement in Classroom Academic Tasks, pp. 149-183. In D. Schunk & J. Meece (Eds.), *Student Perceptions in the Classroom: Causes and Consequences*. Hillsdale, NJ: Erlbaum.

Puspitasari, D., Widajantie, T., Yuhertiana, I., Ratnawati, D., & Thamrin, T. (2020). The Influence of Emotional Quotient and Learning Behavior to Accounting Student's Understanding on Public Sector Accounting. *Conference Proceedings, 2nd International Conference on Economics, Business and Government Challenges.* January.

Schwarzer, R., & Jerusalem, M. (1995). Generalized Self-Efficacy Scale. (pp. 35-37). In J. Weinman, S. Wright, & M. Johnston (Eds.), *Measures in Health Psychology: A User's Portfolio, Causal and Control Beliefs.* Windsor, UK: NFER-NELSON.

Schwarzer, R. (1992). *Self-Efficacy: Thought Control of Action.* Washington, DC: Hemisphere.

Wotapka, D. (2018). Increase your EQ and Shine in the Workplace. *Journal of Accountancy*. June 12. Retrieved October 7, 2021, from https://www.journalofaccountancy.com/news/2018/jun/emotional-intelligence-201818533.html

Appendix: Self-Efficacy, Emotional Intelligence, Self-Determination, Self-Regulated Learning Survey

Self-Efficacy is the individual's judgment about their own ability to perform an action. Studies have shown that self-efficacy is related to academic performance and procrastination.

Reference: Bandura, A. (1977). Self-Efficacy: Toward a Unifying Theory of Behavioural Change. Psychological Review, 84: 191-215.

This survey is a self-report measure of self-efficacy. There are no wrong or right answers. There are 10 items in this self-efficacy section.

Please Rate each item by typing in a number on a scale of 1 to

5:

- 1 = Never
- 2 =Almost Never
- 3 =Sometimes
- 4 = Almost Always
- 5 = Always
 - 1. I can always manage to solve difficult problems if I try hard enough.
 - 2. If someone opposes me, I can find the means and ways to get what I want.
 - 3. It is easy for me to stick to my aims and accomplish my goals.
 - 4. I am confident that I could deal efficiently with unexpected events.
 - 5. Thanks to my resourcefulness, I know how to handle unforeseen situations.
 - 6. I can solve most problems if I invest the necessary effort.
 - 7. I can remain calm when facing difficulties because I can rely on my coping abilities.
 - 8. When I am confronted with a problem, I can usually find several solutions.
 - 9. If I am in trouble, I can usually think of a solution.
 - 10. I can usually handle whatever comes my way.

Emotional Intelligence is the ability to assess, regulate, and utilize emotions. Emotional intelligence has been related to academic performance and procrastination. Emotional intelligence is a term used to describe the way in which a person handles their own emotions and those of others and the impact they have on both ourselves and others.

Reference: Mayer, J., Salovey, P., & Caruso, D. (2004). Emotional Intelligence: Theory, Findings, and Implications. Psychological Inquiry, 60: 197-2015.

Please rate each item by typing in a number on a scale of 1 to 5:

- 1 = Not good/often neglected
- 2 =Could be better/Inconsistent
- 3 = Acceptable/OK
- 4 = Good
- 5 = Very Good

Please rate yourself as honestly as possible. There are no wrong or right answers. There are 10 items in this section on Self-Awareness.

- 1. I act confidently when I have some relevant expertise or experience.
- 2. I make decisions without approval or support.
- 3. I evaluate when I am close to the limit of my capabilities.
- 4. I share with others when I am uneasy about taking on a task.
- 5. I manage how much pressure I put myself under.
- 6. I identify when I am starting to feel under pressure.
- 7. I am open about the emotional impact events may have had on me.
- 8. I recognize when my feelings may be impacting my judgment.
- 9. I anticipate accurately my reaction to events.
- 10. I admit when my behavior may have been unreasonable.

Please rate yourself as honestly as possible. There are no wrong or right answers. There are 10 items in this section on **Self-Management**.

- 1. I maintain a calm appearance when my situation becomes uncomfortable.
 - 2. I make my actions match my words.
 - 3. I control any potentially emotional outbursts.
 - 4. I stay openly committed on tasks I do not consider worthwhile.
 - 5. I hold back from expressing criticism of others.
 - 6. I adjust rapidly when the situation changes.
 - 7. I tackle obstacles and problem rather than simply complaining about them.
 - 8. I initiate action on tasks without needing to be asked.
 - 9. I take advantage of new opportunities in the workplace.
 - 10. I consider all criticism non-defensively.

Please rate yourself as honestly as possible. There are no wrong or right answers. There are 10 items in this section on **Social Awareness**.

- 1. I sense when others are feeling down or upset.
- 2. I address the needs and concerns of others.
- 3. I alert others when the harmony within the group is under strain.
- 4. I take account of others' agendas and priorities when making presentations.
- 5. I am sensitive to the political undertones in the organization.
- 6. I spot where personality clashes may impact on work performance.
- 7. I identify where alliances could be built with other areas.

- 8. I appreciate the pressures under which others are operating.
- 9. I anticipate customer/client needs.
- 10. I generate ideas that others find attractive.

Please rate yourself as honestly as possible. There are no wrong or right answers. There are 10 items in this section on **Social Skills**.

- 1. I take the lead whenever there is an opportunity to do so.
- 2. I work through informal networks to get things done.
- 3. I influence the thinking of others.
- 4. I present ideas in a way that engages others and inspires them to achieve more.
- 5. I provide feedback which others act on.
- 6. I support others in their learning and development.
- 7. I communicate clearly and effectively.
- 8. I listen attentively.
- 9. I cooperate fully with others to achieve goals.
- 10. I handle disagreements and confrontations positively.

Self-Determination has been linked to academic performance and procrastination.

Reference: Gagne, M., & Deci, E. (2005) Self-determination theory and work motivation. Journal of Organizational Behavior, 26: 331-362.

Rate each item by typing in a number on a scale of 1 to 5:

- 1 = Never
- 2 = Almost Never
- 3 =Sometimes
- 4 = Almost Always
- 5 = Always

Please rate yourself honestly as possible. There are no right or wrong answers. There are 6 items for **Self-Determination.**

- 1. I know what I need, what I like, and what I am good at.
- 2. I set goals to get what I want or need. I think about what I am good at when I do this.
- 3. I figure out how to meet my goals. I make plans and decide what I should do.
- 4. I begin working on my plans to meet my goals as soon as possible.
- 5. I check how I am doing when I am working on my plan. If I need to, I ask others what they think of how I am doing.
- 6. If my plan doesn't work, I try another one to meet my goals.

Motivation and self-regulation are linked to academic performance and procrastination. This is a self-reported test regarding motivational and self-regulated learning in an academic classroom.

Reference: Pintrich, P., & DeGroot, E. (1990). Motivational and self-regulated learning components of classroom academic performance. **Journal of Educational Psychology**, 82: 33-40.

Please rate yourself honestly as possible. There are no right or wrong answers. There are 44 items for **Self-Regulated Learning.**

Rate each item by typing in a number on a scale of 1 to 5:

- 1 =Not at All True
- 2 = Mostly Not True
- 3 = Somewhat True
- 4 = Mostly True
- 5 = Very True
- 1. I prefer class work that is challenging so I can learn new things.
- 2. Compared with other students in this class I expect to do well.
- 3. I am so nervous during a test that I cannot remember facts I have learned.
- 4. It is important for me to learn what is being taught in this class.
- 5. I like what I am learning in this class.
- 6. I am certain I can understand the ideas taught in this course.
- 7. I think I will be able to use what I learn in this class in other classes.
- 8. I expect to do very well in this class.
- 9. Compared with others in this class, I think I am a good student.
- 10. I often choose topics I will learn something from even if they require more work.
- 11. I am sure I can do an excellent job on the problems and tasks assigned for this class.
- 12. I have an uneasy, upset feeling when I take a test.
- 13. I think I will receive a good grade in this class.
- 14. Even when I do poorly on a test I try to learn from my mistakes.
- 15. I think that what I am learning in this class is useful for me to know.
- 16. My study skills are excellent compared with others in this class.
- 17. I think that what we are learning in this class is interesting.
- 18. Compared with other students in this class I think I know a great deal about the subject.
- 19. I know that I will be able to learn the material for this class.

- 20. I worry a great deal about tests.
- 21. Understanding this subject is important to me.
- 22. When I take a test, I think about how poorly I am doing.
- 23. When I study for a test, I try to try to put together the information from class, text, and other learning material.
- 24. When I do homework, I try to remember what the teacher said in class and from the text and other learning material.
- 25. I ask myself questions to make sure I know the material I have been studying.
- 26. It is hard for me to decide what the main ideas are in what I read.
- 27. When work is hard I either give up or study only the easy parts.
- 28. When I study I put important ideas into my own words.
- 29. I always try to understand what the teacher is saying even if it doesn't make sense to me at first.
- 30. When I study for a test I try to remember as many facts as I can.
- 31. When studying, I copy my notes over to help me remember material.
- 32. I work on practice exercises and answer end of chapter questions even when I don't have to.
- 33. Even when study materials are dull and uninteresting, I keep working until I finish.
- 34. When I study for a test, I practice saying the important facts over and over to myself.
- 35. Before I begin studying, I think about the things I will need to do to learn.
- 36. I use what I have learned from old homework assignments and the textbook to do new assignments.
- 37. I often find that even though I have been reading for class, I struggle to know what it is all about.
- 38. I find that when the teacher is talking, I think of other things and don't really listen to what is being said.
- 39. When I am studying a topic, I try to make everything fit together.
- 40. When I am reading I stop once in a while and go over what I have read.
- 41. When I read materials for class, I say the words over and over to myself to help me remember.
- 42. I outline the chapters in my book to help me study.
- 43. I work hard to get a good grade even when I don't like a class.
- 44. When reading I try to connect the things I am reading about with what I already know.

Greater Rudeness: Interruptive Behavior in the Graduate School Classroom

Thomas C. Terry Utah State University

Abstract

Professor Fiona Draper, Ph.D., 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." Dr. 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. Percentagewise, 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.

> "There cannot be greater rudeness than to interrupt another in the current of his discourse."

- John Locke

Professor Fiona Draper, Ph.D., surveyed the hands raised in the classroom in front of her. Ignoring the vocal outbursts by two of the male graduate students, she gestured to one female student. "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."

Dr. Draper's observation, she said, was not limited just to the elementary or secondary classroom but extended to the college classroom as well. The purpose of this study is to examine to what extent male graduate students dominated and interrupted female graduate students at a major research university in the South. Dr. Fiona Draper is not her real name, nor are any of the names in this article, including individuals and buildings, or universities/colleges. Gender and ethnic differences were retained.

Setting the Stage

Over the two classes, Dr. Draper allowed conversation and comments to ebb and flow, intervening to keep things moving along or to make a point. She did small things, such as checking the temperature and the clock to start the class, and clearly made decisions based on pedagogical purposes. She put one male student on the spot about an aside to another classmate and asked him to repeat it. She slid into the midst of the class physically as well as conversationally; this seemed to encourage more banter and interruptions, making the professor seem more approachable. Dr. Draper complained rather sharply when six people were late on the first day studied; nobody was late the next class period. She shushed one female student but did not do so to any of the male students. At one point, she set up a queue of students to talk, creating an order that seemed random, but may not have been.

Dr. Draper complimented two women on their remarks and intervened in one male/female conversation that was argumentative, emphasizing the "polite" nature of raising hands and not interrupting each other. She addressed this to the class generally. If this was a subtle way to get males to alter their interruptive behavior, it did not seem to work. Dr. Draper once discussed power differences in classrooms, between male and female students and between all class members and the professor. She redirected conversations when necessary to get back on track, sometimes firmly, though rarely.

The research was conducted in a research methods class at a major southern research university with a mixed population of M.A. and Ph.D. candidates. There were 16 men and 11 women enrolled, and all were there for at least 65 minutes of each 75-minute class. Six students were Ph.D. candidates (three men, three women), and 20 were M.A. students (13 men, 8 women). Ages ranged from mid-20s to mid-50s; Dr. Draper was a full professor in her early 40s. Observations were conducted during two late-afternoon class periods in the same week on September 28 and September 30. A trial coding test was performed on September 23 to refine the coding protocols and resolve any inconsistencies or confusions.¹

The classroom is of traditional design with the professor at the front of the room, flanked by two entry/exit doors. Student chairs are arrayed in a horseshoe design in three tiers, stadium style, and generally facing the professor. The chairs were connected to long desks, accommodating four chairs per desk. The chairs were attached to the desks and were somewhat awkward to slip in and out of. There were several accessible locations for wheelchairs. The walls are brick and freshly-painted an offwhite. The room is clean, organized, and well maintained and remodeled within the previous half-dozen years. The podium is a technology center with computer and the latest in classroom technology, including internet access. Typically, 10 of the men sat apart, separated by at least one seat. Only two women isolated themselves in this fashion. The groupings of students were self-gender-separated, except for David, who sat between Candace and Astrid, and Rose, who sat next to Stephen during both classes.

¹ The year has been deleted and dates slightly altered.

There are no windows in the ground-floor classroom, number 37 of Bunker Hall, occupied by the Department of Journalism. It is located on the northeast side of the building across from an outside exit. The ceilings are high, and there is no feeling of claustrophobia. Lighting is indirect and unobtrusive, although one student complained it could be brighter, with another agreeing. There were no outside distractions and no noises were heard from the outside corridor. The classroom doors were promptly closed by Dr. Draper at 4:00 p.m. when the class was scheduled to begin.

For the purposes of this study, interruptive behavior is defined as speaking without raising a hand, blurting out comments or questions, "stepping on" other students already speaking, talking over other students, refusing to allow themselves to be hushed when another student interrupts, and generally overwhelming other students when they are already speaking by not letting them "get a word in edgewise."

Method

The researcher used the method of disguised, discreet observation for coding and making field notes. This type of observational research (or field research) is a type of correlational (i.e., nonexperimental) research in which a researcher observes ongoing behavior. These types are organized by the extent to which an experimenter intrudes upon or controls the environment. It is a social research technique that involves the direct observation of phenomena in their natural setting. This differentiates it from experimental research in which a quasi-artificial environment is created to control for spurious factors and where at least one of the variables is manipulated as part of the experiment. It is typically divided into naturalistic (or nonparticipant observation) and participant observation. Naturalistic observation has no intervention by a researcher. It is simply studying behaviors that occur organically in natural contexts, unlike the artificial environment of a controlled laboratory setting. Importantly, in naturalistic observation, there is no attempt to manipulate variables. It permits measuring what behavior is really like. However, its typical limitations consist of its inability to explore the actual causes of behaviors and the incapacity to determine whether a given observation is truly representative of what normally occurs. Like experiments, observational studies attempt to understand cause-and-effect relationships. However, unlike experiments, the researcher is not able to control (1) how subjects are assigned to groups and/or (2) which treatments each group receives.

The researcher sat in the back row in the second tier to the "stage right" of Dr. Draper, separated by two seats from the nearest student who

might notice his note-taking. Joseph sat next to the researcher on the trial data-collecting session, September 23. He glanced down at the paperwork on only two observed occasions, but the researcher kept his handwriting covered. Although this made later transcription somewhat more difficult, it preserved confidentiality. Joseph never asked what the researcher was doing, and no one else did either. No one sat next to or behind the researcher on any of the actual coding dates.

Theoretical perspective

This research was approached from a post-positivist/constructivist perspective. The researcher undertook the study anticipating there would be a discernible difference between male and female classroom behavior, although perhaps not dramatically so. The method of analysis, then, was analytic induction. As the father of three children (two sons and a daughter) with a wife, the researcher witnesses the ongoing behavioral dynamics and interactions of a mixed gender group, albeit in a family setting. All three children are opinionated, self-assured, and sometimes stubborn. Despite being considerably younger than her brothers, the daughter is confident and assertive. The researcher's wife, mother, grandmother, and sister are or were equally demonstrative. The researcher's preconceptions are potentially complicated by personal experiences leading him to expect a particular outcome. However, the author welcomed data that did not confirm his expectations and attempted to devise a research model that obviated that bias.

Institutional Review Board

Permission was sought from the Institutional Review Board, but the IRB staff at the university determined the study fell under the exempt research category relating to research conducted in an educational setting. According to IRB Common Rule regulations in effect at the time, "If the project does not include any interaction or intervention with human subjects or include any access to identifiable private information, then the project does not require IRB review." Observations did not impact students and involved observation of behavior without identifiable or easily ascertainable information, data, or names of those observed. Other than the researcher, no one in the class knew about the study, including the professor.² Although a member of the class, the researcher did not interact on any of the study days, including the

² Dr. Draper was initially unaware of the study but was informed after IRB determination and data collection.

preliminary trial coding day, and was not called on. Given the dynamics of the class, the professor very rarely called on any student throughout the course of the semester, given that the students were voluble generally and needed little prompting to participate in classroom discussions. Dr. Draper did not call on anyone who did not otherwise volunteer during the three study periods. Given that the coding was done surreptitiously and without interaction, the researcher believed that reactivity was minimal to nonexistent.

Literature Review

Research specifically focused on interruptive classroom behavior by graduate students is scant, and much that does exist is dated and not entirely on-point. This underscores the potential value of the current study to augment the work of other scholars who look at classroom participation more broadly. The work of Roberta M. Hall and Bernice R. Sandler in 1982 is widely cited. They argue that women and minority graduate students are frequently devalued in the classroom by professors, who frequently interrupt or ignore them more often than male students (Hall & Sandler).

In a 1982 study, one of the very few looking at graduate students, scholar Virginia R. Brooks declared that "[g]reater assertiveness in males seems particularly evident in mixed group interaction" (Brooks, 684).³ She added women were "more easily interrupted" (Ibid.). Brooks constructed a study based on the assumption that "quantification of spontaneous verbal behavior in a natural competitive setting would be a more accurate index of male and female dominance behavior" than self-reporting, role-playing, and focus groups. She looked at a group of first-year social work master's students with data collected over 48 hours by two researchers, the time divided equally between male and female professors. The results were striking. In male professors' classrooms, there was no difference in the times male and female students spoke, but in female professors' classrooms, men spoke "significantly more often and significantly longer" than women (Ibid., 687).

Male students comprised 21% of students in the male and female professors' classrooms studied. They were responsible for 33.3% of interruptions in male professors' classes, but nearly double that at 63.8% in female professors' classrooms (Ibid.). According to Brooks, 74.2% of all male-student interruptions were of female professors, while 55.2% of female-student interruptions were of male professors, slightly more than

³ See: J.G. Hollandsworth, Jr., and K.E. Wall, "Sex Differences in Assertive Behavior: An Empirical Investigation, *Journal of Counseling Psychology*, 1977, *24*, 217-222.

50–50. When the students interrupted each other, 90% of men's interruptions were of women and, surprisingly, 83.6% of women's interruptions were of men. Brooks attributed the parity in interruptions between men and women in male professors' classrooms to the male professor's perceived "higher stature" (Ibid., 688). Women's behavior, she concluded, may have "felt less constrained" with a female professor in charge (Ibid.). She suggested the wide discrepancy by men could be attributed to the classroom style of the professor. Women's classes were more discussion-based, while men's were more lecture-based (Ibid., 689).

In Daniel J. Myers and Kimberly B. Dugan's study, the scholars found that the most self-aware professors avoided calling on men by default, but, overall, male professors called on men sometimes, often, or very often more than female professors (Myers & Dugan, 337). In a 35year-old study, scholars Myra Sadker and David Sadker found that training teachers to recognize their bias and counteract it "created higher rates of interaction [and] more precise reactions," resulting in "more intentional and more direct teaching" (Sadker & Sadker, 515). Most importantly, professors were open to training and embraced change, manifesting a "thirst" for it (Ibid., 514). In conclusion, they found that men "exhibit more powerful behaviors" and "[w]omen's comments are more likely to be ignored" (Ibid., 515). This puts female teachers "at a disadvantage in seeing that their ideas are heard" (Ibid.). Furthermore, "one of the ways that men dominate professional meetings is through interruptions" and by answering questions even when not addressed to them (Ibid.). According to Sadker and Sadker, "males and females are separated by a common language" from grade school through graduate school. Most pertinent to the present study, men "are given more time to talk in classrooms" (Sadker & Sadker, 512). The researchers determined that "patterns established" prior to college persisted. They noted, "Male students receive significantly more attention" and the sex bias manifested by calling on men more often persisted (Ibid., 514).

When sessions at one college were videotaped, female teachers were "surprised [at] their own bias in classroom interaction" and another was "stunned" watching her classroom management (Ibid.). Some award-winning professors for their teaching were "surprised" when they observed in their classrooms that "half of their students didn't receive a fair share of teacher time" (Ibid., 514-515). "The continuing influence of sexism has been well established by feminist scholars," according to scholars Myers and Dugan in a study of social science graduate students (Myers & Dugan, 331).⁴ "Beyond language," they continue, "gender bias occurs intentionally and unintentionally through professors' exclusionary behavior in the classroom" (Ibid.). These sexist actions can trigger "negative emotional reactions" depending on the "gender of the respondent and the salience of gender issues to them" (Ibid.). Reactions can change from distraction to discomfort to rage," according to Myers and Dugan (Ibid.).

Scholars Colin M. Burchfield and John Sappington pointed to a limiting factor in classroom participation behavior. In a study of both undergraduate and graduate classrooms, they found that students "realized that a small proportion of the class will do the majority of the talking" and that professors do not call on students to answer questions (Burchfield & Sappington, 290). Moreover, two pairs of scholars found that students self-rated their participation much higher than that by their peers and professors, leading to complacency when responding in class (Ibid., 291).⁵ Isabel Ruthotto and colleagues looked at graduate student interactions in online classrooms in computer science and worried that "chilly and unsupportive classroom environments" could reduce class participation (Ruthotto et al 2020). Large online classes "decrease[d] opportunities of interactions" with professors (Ibid.). Participation cues are fundamentally different. The classroom experience is short-circuited by technological tools, including message boards, chats, and emojis that double as raising hands, the scholars believe (Ibid.). Some students simply thrive more in or seek out online environments, making conclusions about any interruptive behavior problematic.

Scholar Polly A. Fassinger found a gender-based twist in studies of undergraduate classrooms. She agreed that men "participate more," but "interrupt other students more in female-taught classes," while having "higher involvement in women professors' classes" (Fassinger, 84). Fassinger argued that observational studies are more reductionist and focus on "rather blatant, overt forms of classroom interaction," such as frequency of asking questions (Ibid., 85). Those studies "assume[d] students are chiefly influenced by ... easily quantifiable acts" (Ibid.). Some social scientists contend that "perceptions and interpretations guide human conduct" and ignore "subtleties," such as tone of voice, Fassinger added (Ibid.). Following a survey she conducted, Fassinger

⁴ See: J.D. Corrigan, D.M. Dell, K.N. Lewis, and L.D. Schmidt "Counseling as a Social Influence Process: A Review," Journal of Counseling Psychology 27: 1980, 395-441; and M.F. Fox, "Women and Higher Education: Gender Differences in the Status of Students and Scholars," Women: A Feminist Perspective, 4th ed., edited by J. Freeman. Palo Alto, CA: Mayfield, 1989.

⁵ See: D.A. Karp and W.C. Yoels, "The College Classroom: Some Observations on the Meanings of Student Participation," Sociology and Social Research, 60: 1976, 421-439.

concluded a professor's interpersonal behavior and style were unrelated to student participation, again in an undergraduate classroom. Rather, it was the design of courses, including specific activities, that stimulated class participation, she surmised.

Observations

The effects of reaction to observation are particularly wellillustrated by the Hawthorne studies. During the late 1920s and early 1930s, employees at the Hawthorne plant of the Western Electric Company were observed in a study examining worker productivity. Various treatments were introduced into working conditions (e.g., lighting changes, work-hour changes). No matter which treatment was employed, worker productivity increased (Neale & Liebert 1980). Even the control groups, which received no treatment at all, experienced an increase in productivity (Goldstein 1987). This increase in performance due to the knowledge of being observed became known as the Hawthorne Effect.

Marla Royne Stafford and Thomas F. Stafford contended that some of the problems with overt research techniques argue in favor of covert observation (Stafford and Stafford 1993). They discussed other scholarly research and presented compelling arguments in its favor, while acknowledging the ethical dilemma facing a researcher. Sociologist Martin Bulmer believes "consent is not applicable in observational research where the intent ... is not harmful" (Bulmer, 219). Geoff Pearson agreed, contending, "[C]overt research may be justifiable in situations where the field would otherwise be closed to research" or "where overt techniques would unduly distort the field leading to inaccurate results" (Pearson, 243). However, "every effort is undertaken to prevent harm befalling the research subjects (e.g., by preserving anonymity)" (Pearson, 244). "Essentially," Pearson continued, "the issue is one of proportionality: where the 'harm' is minimal (e.g., a minor infringement of the right to privacy) and the research beneficial" (Ibid.).

Results

For the sake of parsimony and simplicity, comments from the two classes are conflated and contextualized as necessary. Men did talk over others in the class nearly twice as often, but were also twice as likely to raise their hand and wait to be called on by the professor. Women half-raised their hands before interrupting far more often than men (Figures 1, 2, and 3).



Figure 1. Aggregated interruptive behavior (September 28 and 30).



Figure 2. Interruptive behavior (September 28).



Figure 3. Interruptive behaviors (September 30).

Once compensating for the difference in numbers, men and women interrupted someone else in the class without raising their hands in virtually identical fashion, at 37 instances by women and 36 by men (Figure 4). Men did talk over others in the class much more often (15–9) than women. Perhaps unexpectedly, men were over twice as likely (41–18) to raise their hand and wait to be called on by the professor. Although the numbers are small, women half-raised their hands before half-interrupting someone (4–1). Men exclusively used humor in classroom interruptions (7–0). Figure 5 displays how men and women were far more similar than different, at least in terms of interruptions, if not demeanor.



Figure 4. Normative aggregated interruptive behavior (September 28 and 30).



Figure 5. Interruption frequencies.

Men's behavior

Most of the men sprawled across two chairs languidly. Several were sitting "side-saddle" and/or leaning on their arms. Overall, their approach to the class seemed informal and at ease. As the class periods progressed, they seemed less engaged, although none appeared bored. Several yawns were observed, and when they closed an eyeglasses case or binder they made no effort to minimize the noise. On at least three occasions, they made comments that demonstrated they were not closely following the flow of the classroom discussion. When they left during class, men appeared to make no efforts to be particularly quiet and let the door bang closed behind them on at least two occasions. Four men chewed gum.

At the start of each class, Dr. Draper asked if anyone had any general comments about the class topic for the day or anything in general. Five men (over the two periods) made comments. Three men were late during the first class, none the second class, presumably in response to Dr. Draper chastising them. Men frequently "talked over" others, several times effectively silencing other students, although none of those "stepped on" evinced any resentment.

Carl blurted out a comment, while Amir half-raised his hand, but was not called on. In turn, Amir interrupted another (female) student. Amir and Ted self-deprecatingly bantered back-and-forth, clearly comfortable with their interruptions. They were generally rambunctious and noisy as they shuffled papers and flipped pages in their notebooks. Amir raised his hand more during the second class. There were numerous "stage whispers" audible throughout the classroom. Stan interrupted Dr. Draper, prompting her to stop talking. Ray half-raised his hand on several occasions and then spoke almost immediately without being called on. His actions seemed to indicate he regarded the act of starting to raise his hand as sufficient invitation to interrupt or speak.

Women's behavior

In sharp contrast, women smiled and appeared to be more attentive. They seemed connected and always fully aware of the flow of conversation. Their interjections demonstrated they were "up to speed" at all times. However, the women made fewer comments, both as a percentage of their population and in actual numbers. When they left the classroom while class was still going on, women did so quietly and closed the door carefully behind them. Their postures were more erect and forward-facing. It appeared they were taking the class more seriously, at least outwardly. Only one woman chewed gum. Three women arrived late and one left early the first day; none were late the second period, again no doubt due to Dr. Draper's earlier comments. During the opening portion of the class, three women made comments in total over the two classes.

Marnie interrupted Dr. Draper on three occasions, once prompting the professor to good-naturedly chide her. Alone among the women, Marnie interrupted others in the class in similar fashion to the men. She interrupted men and women equally. Sandy raised her hand and never spoke without being called on. Isabella never interrupted any other student on any occasion.

Discussion and Conclusions

"And now, excuse me while I interrupt myself."

- Murray Walker

Results were mixed in this preliminary study. Percentagewise, men and women interrupted others in the class without raising their hands at virtually the same rate. Any conclusion that male graduate students interrupt in greater numbers in all circumstances is not supported by this study. Conclusions to the contrary are skewed by the substantial difference in numbers between men and women, leading to the perception of more interruptions by men. Converting the aggregated numbers to percentages compensated for the difference in student numbers, since there were approximately a third more men in the class (16 to 11), and significantly changed this assumption (Figure 4).

In the classroom studied, women and men interrupted each other to almost precisely the same degree; in fact, women did so ever so slightly more often. There were two main differences: Men raised their hands more often before interrupting, while women half-raised their hands more frequently than men, although the actual numbers are very low and possibly coincidental. Men joked and talked over fellow classmates more often than women. Men did display more respect than women when interacting with Dr. Draper by waiting to be called on by the professor. (See Table 1 in the Appendix for coding results.)

Study value and weaknesses

There are a number of weaknesses in the study. Most important is whether the results and conclusions can be generalized beyond this specific graduate student study group—and a small one at that—which may or may not be representative. The class studied was in the humanities, and its gender and racial mix was not consistent with national graduate school enrollment. According to one decade-old report, there were 2.7 million men and women enrolled in post-baccalaureate programs in the U.S.⁶ Of those, 59% were women (1.6 million) and 41% were men (1.2 million), relatively close to the reverse of the population in the classroom studied. There was one Black male in the class, well below the national average of three (11% of graduate students overall). The three nonresident and non-American students in the class were consistent with national averages (11%).

The researcher failed to code for men interrupting other men and women interrupting women, something that may or may not be relevant or important. He also neglected to code Ph.D. and M.A. student interruptions separately. Moreover, the reason women behaved differently or identically to men in a classroom setting is important: Was this because of societal expectations or cultural norms and acculturation? The "why" and "so what" questions are beyond the scope of this research, but the answers would be valuable.

The most troubling aspect of this study was its surreptitiousness, no matter how well grounded in the literature and theory. It seems somehow problematic or just uncomfortable to observe and study people, many of whom are friends. Can totally objective analysis come from such a study of friends and acquaintances? Will the conclusions and the observations on which they are based be unvarnished and nonprejudicial? Is there something just plain wrong about this sort of behavior? The researcher grappled with these questions and resolved none of them totally to his satisfaction. However, the knowledge and insights obtained could prove valuable to Dr. Draper as she continues to hone her classroom management style. It might also prove illuminating to the female and male students in the class studied pursuing careers as professors as well as provide the opportunity for all students to reflect on their interpersonal behavior.

⁶ "Status and Trends in the Education of Racial and Ethnic Minorities," National Center for Education Statistics of the Institute of Education Sciences, July 2010, at https://nces.ed.gov/pubs2010/2010015/indicator6_24.asp, accessed November 24, 2018.

The first female Secretary of State in U.S. history and a professor at Georgetown University cut through to the essentials.⁷ "One of the issues I kept saying to my students is you have to learn to interrupt," Madeline Albright recommended. "When you raise your hand at a meeting, by the time they get to you, the point is not germane. So, the bottom line is active listening. If you are going to interrupt, you look for opportunities." However, she concluded pointedly, "You have to know what you're talking about."

> "Sitting down for dinner not only helps you learn, but also teaches you how to listen, which I feel is the most important skill to have. I remember as a kid going around the table listening to everyone's day. It was hard to have the manners not to interrupt back then."

> > - Michael Symon

References

Brooks, V.R. (1982). "Sex Differences in Student Dominance Behavior in Female and Male Professors' Classrooms." *Sex Roles*. 8: 683-690.

Bulmer, M. (1982). "The Merits and Demerits of Covert Participant Observation." In M. Bulmer (Ed.), *Social Research Ethics*. New York: Holmes & Meier, 217-251.

Burchfield, C.M. and J. Sappington (1999). "Participation in Classroom Discussion." *Teaching of Psychology*, 26: 4, 290-291.

Fassinger, P.A. (1995). "Understanding Classroom Interaction: Students' and Professors' Contributions to Students' Silence." *The Journal of Higher Education*. 66:1, 82-96.

⁷ Albright was first U.N. ambassador (1993–1997) and then the first female secretary of state under President Bill Clinton from 1997–2001. Albright holds a Ph.D. in public law and government from Columbia University. Her family fled Czechoslovakia after the Nazis invaded and resettled there after the war, only to flee the Communists in 1948. Her father, Josef Korbel, eventually became a distinguished professor of international politics at the University of Denver, where one of his favorite doctoral students was future secretary of state Condoleezza Rice, who served under George W. Bush and was the second woman to serve as the top U.S. diplomat.

Goldstein, H. (1987). *Multilevel Models in Educational and Social Research*. London: Griffin and New York: Oxford Press.

Hall, R.M. and B.R. Sandler. (1982). "The Classroom Climate: A Chilly One for Women?" Washington, DC: Project on the Status and Education of Women, Association of American Colleges.

Myers, D.J. and K.B. Dugan (1996). "Sexism in Graduate School Classrooms: Consequences for Students and Faculty," *Gender & Society 10*, 3, 330-350.

Neale, J.M. and R.M. Liebert (1980). *Science and Behavior*, 2nd. ed. Englewood Cliffs, NJ: Prentice-Hall.

Pearson, G. (2009). "The Researcher as Hooligan: Where 'Participant' Observation means Breaking the Law." *International Journal of Social Research Methodology*, *12*, 3, 243-255.

Ruthotto, I., Q. Kreth, J. Stevens, C. Trively, and J. Melkers. (2020). "Lurking and Participation in the Virtual Classroom: The Effects of Gender, Race, and Age among Graduate Students in Computer Science." *Computers & Education*, 151, 103854.

Sadker, M. and D. Sadker. (1986). "Sexism in the Classroom: From Grade School to Graduate School." *The Phi Delta Kappan.* 67:7, 512-515.

Stafford, M.R. and T. Stafford. (1993). "Participant Observation and the Pursuit of Truth: Methodological and Ethical Considerations." *Journal of the Market Research Society*. 35:1, Jan 1993, 1-16.

Appendix

Table 1. Interruption Frequencies and Coding			
September 28	3		
Male	0111111111111110@@@1101*0#0		
	#000000#01#1110@@@		
Female	@ * 0 0 1 0 1 0 1 0 @ 0 1 0 0 1 0 0 0 1		
September 30)		
Male	001#001000##1@11@11@0@001@0		
	1 @ 1 @ 1 @ 1 1 0 0 1 0 1 0 1 0 @ 0 1 0 0 1 0 0 0 1		
Female	@ * 0 0 1 0 1 0 1 0 @ 0 1 0 0 1 0 0 0 1 0 @ 0 0 0 @ 0		
	1 * @ 1 0		

0 = interruption without raising hand

1 = raised hand and waited to be called upon

* = half-raised hand/half-interrupted

= joke interruption - hand never raised

@ = talked over someone else

Note: Frequencies are listed in the order they occurred during the class period. For ease and accuracy of coding, separate lines were used for men and women. So, the frequencies are not entirely in "real-time" order but do reflect the actual order of interruptions within each gender.

Analysis of Electrical Resistivity and Conductivity of Materials

Noah M. Swenson, Zachery N. Isaac, Ali S. Siahpush Southern Utah University

ABSTRACT

As the temperature of a material increases, the electrical resistance of the material rises in correlation; this linear relationship allows for a theoretical prediction of that material's electrical resistance using the coefficient of resistance. This coefficient of resistance differs for every material and must be found by experimentally determining a resistance at a specific temperature. Through performing tests that increase the temperature of a material, the linearity of temperature and resistance can be observed. The coefficient of resistance can be found with relative accuracy for the material through the linear relationship between material electrical resistance and temperature slope. A positive, linear correlation was experimentally observed, and an accurate theoretical value for the resistivity of copper was recorded. Therefore, a prediction of a material's resistance at any temperature is possible within 5% error, and a linear correlation can be confirmed.

NOMENCLATURE			
Symbol	Definition	Units	
А	Cross-sectional area	m^2	
Ι	Current	А	
L	Length	М	
R	Resistance	Ω	
R _{ref} or R ₀	Resistance at 22.5°C	Ω	
Т	Temperature	°C	
V	Voltage	V	
А	Temperature coefficient	1/°C	
ρ	Electrical resistivity	Ω·m	
α	Electrical conductivity	$1/(\Omega \cdot m)$	

INTRODUCTION

Electrical resistivity (ρ) is a material property that measures how much electrical conductivity a material can resist. Many studies have found that electrical resistivity in metals has a linear relationship with temperature. As temperature increases, so does the electrical resistivity of a material [1-3]. However, some experiments have suggested that this may not be true in extremely low temperatures [2]. The typical rate of change in temperature and electrical resistivity is linear starting at approximately -200°C. Using the slope of the temperature versus resistance relationship, the coefficient of resistance can be calculated.

These temperature versus resistance slopes have been determined in prior experiments (Table 1). Here we seek to validate these electrical conductivities (α) and derive an equation to theoretically predict resistance at a specific temperature.

Table 1. Values for conductivity, resistivity, and the temperaturecoefficient [4]						
Material	Material Conductivity, σ Resistivity, ρ Temperature $(\Omega \cdot m)^{-1}$ $(\Omega \cdot m)$ coefficient, α (°C) ⁻¹					
Copper	5.95×10^{7}	1.68×10^{-8}	0.004041			
Aluminum	3.77×10^{7}	$2.65 imes 10^{-8}$	0.004308			
Steel	0.50×10^7	20.00×10^{-8}	0.003			

THEORY

The resistance (R) of a material can be evaluated using Ohm's law, which relates resistance, voltage (V), and current (I) as [3]:

$$V = IR \tag{1}.$$

The resistance of a material depends on the resistivity, length, and diameter of the material. Electrical resistivity (ρ) is a measure of how much resistance to the flow of electrical charges a material has through the relationship [3]:

$$R = \rho \frac{l}{A} \tag{2}.$$

where A is cross-sectional area (m²) and l is length (m). Similarly, electrical conductivity (σ) is a measure of how well electrical charges can flow through a material and is the reciprocal of resistivity [3]:

$$\sigma = 1/\rho \tag{3}.$$

The more resistive a material is, the less conductive it is, and the more conductive it is, the less resistive it is [4]. Pure metals commonly have high conductivity and low resistivity, as shown in Table 1.

The relationship between a material's resistance (R), initial temperature (T₀), final temperature (T), and temperature coefficient (α), is expressed as [3]:

$$R_T = R_0 (1 + \alpha (T - T_0))$$
(4)

Equation (4) may be modified using Eq. (2), when solving for resistivity of both initial and final temperatures. The result is the resistivity of the material as:

$$\rho_T = \rho_0 (1 + \alpha (T - T_0))$$
(5)

EQUIPMENT

- DC power supply
- Imusa hot plate (Experiment 2 only)
- Ohmmeter
- Fluke 62 max+ infrared (IR) thermometer
- Wire cutters
- Caliper
- Wire samples (Table 2)

100 Engineering

Table 2: Diameter and length wires used for samples				
Wire type	Gauge	Diameter (mm)	Length (cm)	
Common	14	1.55	30	
Copper	18	1.11	30	
A 1,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	14	1.63	30	
Alummum	18	1.17	30	
Steel	16	1.54	30	
	18	1.12	30	
	22	0.58	30	

ASSUMPTIONS

To complete this experiment and obtain results, the following assumptions were made:

- 1. Constant temperature through the entire wire at steady state when measurements were taken.
- 2. Constant diameter for each wire gauge.
- 3. Pure material (within 99% composition) in each wire.
- 4. Uniform heating in hot plate coil at the desired temperature.
- 5. Power supply supplies constant current.
- 6. Constant initial room temperature.

EXPERIMENT ONE

Our initial experiment procedure consisted of a power supply that, theoretically, would supply a constant current to our wire samples (Fig. 1), allowing the voltage to be changed incrementally, increasing the temperature in tandem. However, when current was applied, a voltage overload was reached before ~ 1.0 mA of current was applied to the system, preventing voltage from exceeding ~ 0.003 mV. No temperature increase was observed because of the voltage overload, and no change of resistance was observed.



Figure 1. Initial failed experimental setup.

Data collected while attempting to perform Experiment 1 was highly inconsistent or nonexistent, because of the lack of accuracy of instruments used in this experiment. Ohm's Law, presented in Eq. (1), states that a system's resistance is proportional to the system's voltage divided by the current. The highly conductive metal wire samples allow current to easily flow through them, so they require incredibly small amounts of voltage to assist the current in flowing through the wire. Given that fact, along with Ohm's Law, each sample has incredibly small amounts of resistance, ensuring that a voltage overload of our power source was reached before a measurable voltage was reached. Thus, our method to determine the correlation of rise in resistance in proportion to rise of temperature in response to an increase of voltage was proved to be an impossible experiment.

EXPERIMENT TWO

The initial experiment was reworked, and a new procedure was developed. This procedure included an external heat source that was used to heat the samples as current flowed through them, as seen in Figure 2, and change of voltage was measured to then calculate resistance at different temperatures.



Figure 2. New experimental setup, measuring change in voltage with increase of temperature.

Procedure

1. Cut multiple samples of differing wire gauges to a length of 30 cm, as seen in Figure 3.



Figure 3. Equipment and material samples used for Experiment 2.

- 2. Measure the voltage of the room temperature samples using a constant current from the DC power supply of 2 amps.
- 3. With DC power supply turned off, place the sample on Imusa hot plate.
- 4. Turn on the power supply, leaving the same current settings as before, and turn the hot plate on.
- 5. Allow the hot plate to reach constant temperature, and the wire to reach the steady state.
- 6. Record the steady-state temperature of the hot plate coils using IR thermometer.
- 7. Measure the voltage of wire at new steady-state temperature using a constant current of 2 amps.
- 8. Repeat steps for each wire sample of differing gauges, allowing the hot plate to cool off to room temperature between each measurement.
- 9. Using resulting voltage and temperature measurements, calculate each sample's resistivity, conductivity, and temperature co-efficient.

Results

Tables 3–5 display the experimental voltage, temperature, and resistance for all gauges of copper, aluminum, and steel samples, respectively. Figures 4–6 display the linear relationship of the experimental resistance and temperature values for copper, aluminum,

and steel samples, respectively. The slope of these linear relationships,
which represents each samples' α , can also be found in Tables 3–5.

Table 3. Results of experiments on copper wire samples of differing gauges				
	Voltage (mV)	Temperature (°C)	Resistance (Ω)	Α
14 Gauge #1	4.4	22.5	0.002194514	6.6022E-06
14 Gauge #2	4.6	22.5	0.002294264	7.25459E-06
14 Gauge #1	9	370	0.004488778	
14 Gauge #2	9.8	380	0.004887781	
18 Gauge #1	9.5	22.5	0.004738155	1.07215E-05
18 Gauge #2	9.7	22.5	0.004837905	1.05696E-05
18 Gauge #1	17.4	390	0.008678304	
18 Gauge #2	17.7	400	0.00882793	
Average (α)				8.78697E-06



Figure 4. Temperature versus resistance plot for copper using experimental data.

Table 4. Rest	Table 4. Results of experiments on aluminum wire samples of				
differing gau	differing gauges				
	Voltage (mV)	Temperature (°C)	Resistance: V/I=R (Ω)	symb	
14 Gauge #1	7.8	22.5	0.003890274	1.0717E-05	
14 Gauge #2	8.1	22.5	0.0040399	9.52458E-06	
14 Gauge #1	14.3	325	0.00713217		
14 Gauge #2	15.5	410	0.007730673		
18 Gauge #1	11.4	22.5	0.005685786	1.2406E-05	
18 Gauge #2	11.9	22.5	0.005935162	1.78181E-05	
18 Gauge #1	18.8	320	0.009376559	1.21169E-05	
18 Gauge #2	23.6	350	0.011770574		
18 Gauge #3	21.8	430	0.010872818		
Average (α)				1.25165E-05	



Figure 5. Temperature versus resistance for aluminum using experimental data.

Table 5. Results of experiments on steel wire samples of				
differing gau	uges	-		
	Voltage	Temperature	Resistance:	a
	(mV)	(°C)	$V/I=R(\Omega)$	u
16 Gauge #1	44.7	22.5	0.022294264	4.77717E-05
16 Gauge #2	43.8	22.5	0.021845387	4.45041E-05
16 Gauge #1	79.9	390	0.039850374	
16 Gauge #2	350	0.064837905		
18 Gauge #1	440	0.072817955		8.1628E-05
18 Gauge #2	22.5	0.152369077	0.000215125	8.4579E-05
18 Gauge #1	22.5	0.149625935	0.000208069	
18 Gauge #2	230	0.197007481		
24 Gauge #1	430	0.234413965		
24 Gauge #2	300			
24 Gauge #1	395			
24 Gauge #2	470			
Average (α)				0.000113613



Figure 6. Temperature versus resistance for steel using experiment data.

Discussion

Finding the average slope of each of the temperature versus resistance graphs gives an average α -value for each of the experimental wire samples (Table 6). The equation derived from this experiment uses

the slope of our experimental data to determine the coefficient of resistance, and can be seen through the relation

$$R = \alpha(\Delta T) + R_{ref}$$
(6)

Table 6. Average experimental values of temperature			
coefficients of the wire samples			
Wire Experimental α (Ω/°C)			
Copper	6.46207E-05		
Aluminum	1.26164E-05		
Steel	0.000113613		

The α -values calculated in this experiment varied from the α -values in Table 1. Although these values are not similar, that does not mean that the experimental values for the coefficient of temperature were incorrect, as Eq. (4) is solved using a ratio of the resistance. This is explained by examining the units in the temperature coefficient derived in this experiment. The recorded α had the units (1/°C), and the α determined in this experiment by averaging the temperature versus resistance had the units (Ω /°C). To better compare these two values, as direct comparison is impossible because of the different units, random temperatures were selected to confirm the existence of a linear correlation between experimental values and found values. Theoretical resistance was calculated using both equations, with the reference resistance (R_{ref}) being the constant resistance measured experimentally at room temperature (22.5°C).

The copper, aluminum, and steel samples' experimental resistance found using Eq. (6), experimental temperature values, and theoretical resistance, found using Eq. (6) and theoretical temperature values, are shown in Tables 7–9. Listed also are theoretical temperature values and calculated percent error between the two values for resistance. The linear relationship between theoretical temperature and resistance is shown in Figures 7–9 for each sample, allowing for better comparison to each samples' experimental linear relationship.

Table 7. Theoretical resistance of copper samples compared with				
the resistance	e and experime	ental α [3]		
Temperature	Theoretical	Experimental resistance	Percent	
(°C)	resistance (Ω)	from derived Eq. 6 (Ω)	error (%)	
250	0.004307718	0.004243425	1.52	
345	0.005169327	0.005078188	1.79	
500	0.006575112	0.006440168	2.095	
150	0.00340076	0.003364728	1.07	



Figure 7. Theoretical temperature versus resistance of different gauges of copper samples.

Table 8. Theoretical resistance of aluminum samples compared with resistance calculated and experimental α						
Temperature (°C)	$ \begin{array}{c c} \hline cent \\ \hline cent \\ \circ C \end{array} & \begin{array}{c c} Theoretical re- \\ sistance (\Omega) \end{array} & \begin{array}{c c} Experimental resistance \\ from derived Eq. 6 (\Omega) \end{array} & \begin{array}{c c} Percent \\ error (\%) \end{array} $					
250	0.011505145	0.008657979	32.88			
345	0.013883139	0.009847048	40.99			
500	0.017763025	0.011787107	50.70			
150	0.005810474	0.007406329	21.55			



Figure 8. Theoretical temperature versus resistance for aluminum samples.

Table 9. Theoretical resistance of steel samples compared with					
Teststance calculated and experimental 0 Temperature Theoretical Experimental resistance Percent 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 00000 <t< th=""></t<>					
250	0.037132481	0.047916724	22.51		
345	0.043422382	0.058709934	26.04		
500	0.05368485	0.076319909	29.66		
150	0.030511534	0.03655545	16.53		



Figure 9. Theoretical temperature versus resistance for steel samples.

Comparing the published α -values through the calculated resistance, the copper wire had an average percent difference of 1.62%, the aluminum wire had an average difference of 36.53%, and the galvanized steel 23.69%.

SOURCES OF ERROR

Throughout the experiment, there were several contributing factors for sources of error, such as the temperature reading apparatus. The wire is smaller in length, and measuring temperature with an IR reader could have provided inaccurate results. Also, the hot plate used for this experiment did not maintain a sufficiently steady temperature to get an extremely accurate reading; this error propagated throughout the experiment, which would explain the higher degree of error as temperature increased.

Although the assumptions for the wires were that they were pure materials, they were likely within 90% of the pure metal, which would cause some degree of error in experimental results and calculations. In
addition, the equation derived from this experiment will only prove effective for the prediction of resistance when the temperature change is positive. More research is needed to derive an equation that also provides an accurate theoretical resistance for a temperature below 22.5°C.

CONCLUSION

Resistance and temperature have a positive, linear correlation [3], which was observed in Experiment 2 through increasing temperature of samples. To better prove a correlation between experimental and researched values, Eq. 4 was used to calculate the resistance of a conductor at an experimental temperature, as seen from the experimental values. Using the equation derived from this experiment, along with the α derived from the resulting slope from plotting Eq. 6, it cannot be conclusively stated that the theoretical α of galvanized steel and aluminum were confirmed in this experiment. Theoretical α -values for copper can be approximated with relative accuracy using this experiment methodology, as seen in Table 7. Therefore, using the experimental α -values, a prediction of a material's resistance at any temperature is possible within 5% of error, and a linear correlation can be confirmed.

RECOMMENDATIONS

For future experiments, the research conducted could be improved by implementing several changes, including:

- 1. More precise tools (hot plate, temperature gun/ thermometer, multimeter)
- 2. More efficient heating method
- 3. Increased tests at different temperatures.

More Accurate Tools

Using more accurate tools for the experiment would increase the validity of the experiment. The improvements of the tools could include a hot plate that stays at a set temperature until the temperature is either raised or the hot plate is turned off. A temperature gun or thermometer that solely measures the temperature of the wire and a multimeter that is made to measure smaller numbers would both improve accuracy.

Different Heating Method

A different heating method could help increase the accuracy of the experiment as well. A possible heating method could be to place a coiled wire in an electrically resistive liquid. The liquid can then be heated up and measured. The wire will be the same temperature as the liquid, which would make measuring the temperature easier. A constant current could be run through the wire, and the resistance could be measured continually as the temperature is increased.

More Tests at Different Temperatures

Running more tests of each wire at a wider range of temperature is another way to increase the validity and improve this experiment. Increasing the number of tests would help to show the relationship between resistivity and temperature by eliminating outliers and getting a more accurate average.

ACKNOWLEDGMENTS

This project would not have been possible without the financial support of the NASA Utah Space Grant Consortium and the Department of Engineering and Technology at S, which provided equipment for the experiment. We also thank Dr. Scott Munro, Dr. Jacob Bishop, and Dr. Sangho Bok for their assistance in re-evaluating and redesigning our procedure after our first experiment failed to produce results. Finally, we thank Alyssa Melling and Zachary Zufelt for their contributions.

REFERENCES

[1] Varma C.M., "Colloquium: Linear in temperature resistivity and associated mysteries including high temperature superconductivity." *Rev. Mod. Phys.* **92**, 031001 (2020)

[2] Guo H., Gu Y., and Sachdev S., "Linear in temperature resistivity in the limit of zero temperature from the time reparameterization soft mode," *Ann. Phys.* **418**, 168202 (2020)

[3] Callister W.D., and Rethwisch D.G., "Electrical properties," in *Materials Science and Engineering: An Introduction*, Ninth edition. Wiley, Hoboken, NJ. p. 726, Chap. 18 (2013).

[4] Ling S.J., Moebs W., Loyola J.S., "Resistivity and resistance," in *University Physics Volume 2*, Openstax, Houston. Chap. 9.3 (2016)

[5] Kuphaldt T. R., All About Circuits, In: *Lessons in Electric Circuits Volume 1*, Chap. 12. Online book. https://www.ibiblio.org/kuphaldt/ electricCircuits/DC/index.html (2000-2020; revised 2021).

Calibration and Testing of Budget Extensometer To Accurately Evaluate The Modulus of Elasticity of Steel Wire

Alicyn Astle, Collin Cutler, Cameron Pepi, Trayson Maxwell, Owen Telford, Jacob Bishop, Ali S. Siahpush Southern Utah University

ABSTRACT

The modulus of elasticity is one of many properties used when predicting the behavior of materials. Accurate measurement of the modulus of elasticity is evaluated using precise measurements of elongation and stress. Commercial testing machines use extensometers and load cells to measure these values; however, these machines are very expensive for educational lab use. Jacob Bishop (Engineering faculty at Southern Utah University) has built several cost-effective universal testing machines with extensometers. The purpose of this project is to calibrate the extensometer to give accurate results of elongation. Multiple tensile tests were performed on steel tie wire using the universal testing machine on the calibrated extensometer. The average modulus of elasticity found was 25,220 ksi with a percent error of approximately 13%. Performing the test very slowly with a strain rate below 0.05 (in/in)/hr resulted in poor data. The recommended strain rate to perform tensile tests is from 1 to 2 (1/hr), and a motor can be incorporated with the testing machine to allow consistent movement of the crosshead during multiple tests.

NOMENCLATURE					
Symbol	Definitions	Value/unit			
А	Cross-sectional area of specimen	m^2			
Е	Modulus of elasticity	29,000 ksi [1]			
F	Applied force	(lbf)			
Fy	Yield force	73.5 lbf			
d	Diameter	0.051 in			
Lo	Original length	2 or 4 in			
δL	Change in length	in			
3	Strain	in/in			
σ_{y}	Yield stress	36 ksi [1]			

INTRODUCTION

When performing engineering stress analysis on a specimen, the modulus of elasticity is an important factor to consider because it establishes a relationship between stress and strain. The modulus of elasticity can be evaluated using commercial testing machines that conduct tensile tests on specimens while recording the load and the change in length [1]. This task is typically performed with highly calibrated load cells and extensometers with high sample rates. These machines, however, are very expensive [2], and as a result, Southern Utah University (SUU) has only purchased one machine. For material testing laboratories, using the commercial testing machine is insufficient for all students to perform tests because of the amount of time required to perform a single test. Therefore, Jacob Bishop from Southern Utah University created cost-effective universal testing machines, shown in Figure 1, that perform small-scale tests including tensile tests. These machines use an encoder to track and record the vertical position of the crosshead. Using these data to calculate the modulus of elasticity yields extremely inaccurate results. A more accurate way of measuring the change in length is by using an extensometer that connects directly to the specimen. SUU has purchased an extensometer that is compatible with the universal testing machines.

The purpose of this project is to justify the purchase of additional extensioneters to be used in material testing labs. In this project, we calibrated the extensioneter and verifying its data by evaluating the modulus of elasticity of steel tie wire and comparing it with published values. For educational purposes, if the experimentally evaluated modulus of elasticity is within ~15% of the known value, then SUU will be confident in purchasing more extensioneters that are suitable for lab applications.



Figure 1. Universal testing machine used in material testing labs.

THEORY

The tensile test is a common test performed in strength of material laboratory courses to find the properties of materials. The tensile stress (σ) is defined as [1]:

$$\sigma = \frac{F}{A} \tag{7}$$

where *F* is the axial force acting on the member (lbf), and *A* is the crosssectional area (in²) perpendicular to the applied force. As the applied stress increases, the specimen will elongate. This elongation δL , when divided by the original length of the specimen (L_o) produces strain (ε) defined as [1]:

$$\varepsilon = \frac{\delta L}{L_o} \tag{8}$$

Within the elastic region, the specimen will return to its original length when the stress is removed. The relation of stress and strain in the elastic region is the modulus of elasticity shown as [1]:

114 Engineering

$$E = \frac{\sigma}{\varepsilon} \tag{9}$$

where E is the modulus of elasticity (ksi).

EQUIPMENT

- NCS extensometer
- Data acquisition control box
- Universal testing machine
- Wedge grips
- Steel tie wire
- 3D printed gauge block
- Calipers
- Wire cutters
- Multimeter
- Computer
- USB cord

PROCEDURE

Before testing a specimen, the equipment needed to be modified to be connected to the NCS extensioneter. To connect the extensioneter, the data acquisition box was modified by adding a 6-pin connection. Then, the extensioneter was modified to connect to the control box, by removing its 9-pin D-subminiature connector and soldering on a 6-pin circular connector as shown in Figure 2.



Figure 2. (a) 9-pin connector preinstalled onto the extensioneter. (b) New 6-pin connector soldered to the extensioneter.

A gauge block was 3D-printed with 3 known side values of 1.25 inches, 1.00 in, and 0.75 in. To calibrate the extensometer, a rubber band was wrapped around its arms to provide a constant clamping force. It was then connected to the data acquisition system to record data. Next, the block was inserted into the extensometer arms and the elongation rate data were exported into an Excel spreadsheet. These values were compared with the known value, and the difference between them was recorded. This was repeated for each side length until an accurate calibration factor was established to insert into the Arduino code shown in the Appendix. Figure 3 shows the setup for the NCS extensometer calibration.



Figure 3. Calibrating the NCS extensometer with gauge block.

Predictions were performed to ensure the maximum force needed to cause the specimen to fail would not exceed the maximum force the load cell could withstand. It was evaluated that the specimen should fail approximately at 125 lbs, which was well under the load cells' maximum load of 1100 lbs.

TEST 1

When initial testing took place, first the power adapter, extensometer, encoder, and load cell were all connected into the control box. An Arduino board (the program is presented in the Appendix) was within the control box. A computer was connected to the control box via a USB cord. The grips were then set to 4 inches apart, an arbitrarily chosen length based on previous tests. A wire specimen of 7 inches long and a diameter of 0.051 inches was inserted into the grips. The extensometer was then secured to the specimen (Fig. 4). The data acquisition system was then set up to record the data and save it as a CSV file. The hand crank was turned slowly and stopped when the specimen experiences failure. Using the recorded data, the modulus of elasticity was calculated.



Figure 4. Test procedure version 1 setup.

TEST 2

After multiple tests were completed, the testing procedure was altered to obtain more accurate results. The first change was that the wedge grips were moved to two inches apart from the original four inches (Fig. 5). Reducing the elongation outside the extensioneter allowed for more accurate readings.



Figure 5. Test procedure version 2 setup.

Another improvement made was a tare function for the extensometer. The user could tare the extensometer before testing. Originally, the extensometer readings would be manually zeroed when analyzing the data that caused errors. Taring the extensometer once it was secured on the specimen created a more uniform testing procedure resulting in more accurate results. Figures 6–9, below, show the experimental results.

The last issue was not enough decimal places were present in the data. This resulted in the program rounding up to the nearest decimal value, creating a stair-step pattern in the stress versus strain data. The pattern and corrections are shown in Figs. 7 and 9, below. When more decimal places were added in the Arduino program, linear data were obtained, leading to a more accurate calculation of the modulus of elasticity.

RESULTS

For each test procedure version (Test 1 and Test 2), four tests were performed. The strain rate, modulus of elasticity, and percent error for each test are summarized in Table 1. The modulus of elasticity for 1040 steel is 29,000 ksi [1]. The average modulus of elasticity for all tests was 25,220 ksi with a percent error of 13.03%. The tests with the lowest and highest percent errors were tests 5 and 8, respectively. The elastic region for each test is shown in Figs. 6 and 8. Within each test, the blue line is the experimental data, the green dashed line is a linear trendline from the experiment data, and the red line is the theoretical slope of the linear elastic region for test versions 1 and 2, respectively.

Table 1. Modulus of elasticity for tests 1-8				
Test	Strain Rate (1/hr)	Modulus of Elasticity, E (Msi)	% Error	
1	0.6955	25.27	12.9%	
2	0.8736	22.20	23.4%	
3	1.1697	30.08	3.7%	
4	0.3916	30.93	6.7%	
5	1.6931	27.98	3.5%	
6	0.6275	31.43	8.4%	
7	2.5843	24.40	15.9%	
8	0.0313	9.44	67.4%	

118 Engineering



Figure 6. Stress-strain curve of Test 1 (repeated four times).

Figure 6 shows the four tests conducted during the first version of testing. They all show an expected stress–strain trend of 1040 tie wire steel.

Figure 7 shows the stepping of the first version of test conducted. The sensor too data is slower than the strain rate, thus resulting in the "steps" shown in the data.



Figure 7. Test 1, Version 1: showing stepping.



Figure 8 shows the second set of tests with the calibrated code. It shows that each test is very similar during the entire duration.

Figure 8. Stress-strain curve of Test 2 (repeated four times).



Figure 9. Test 5, Version 2: No stepping

Figure 9 shows how the data changed with the second version of tests. The Arduino code was edited to ensure the sensor will record data fast, thus resulting in a smoother output in the data.

Test 8 shown in Figure 10 is the furthest away with an error of 67.4%. No parameters were changed during this test besides the variation of the rate of strain. This test has the lowest strain rate of 0.0313 1/hr. The next highest strain rate was 0.3916 1/hr from Test 4. This is more than 12 times faster than the strain rate from Test 8.



Figure 10. Stress vs. strain rate of all tests

Tests 3 and 5 resulted with a modulus of elasticity that was below 5% error. Figure 10 shows the strain rate for these tests were between 1 per hr and 2 per hr. The tests with lower and higher strain rates resulted in higher percent errors. It can be concluded that the optimal strain rate for performing tensile test is between 1 1/hr and 2 1/hr. Table 1 shows that Test 5 is the closest, being only 3.5% away from the predicted. This test was performed in the second version of testing. The second closest value of the data is shown in Figure 10 with an error of 3.7%. This has very low error as well, showing that both methods of the test can produce accurate results, the difference is that the second version shows more accurate strain values.

Sources of Error

A perfect measure for modulus of elasticity cannot be expected for several reasons. First, the budget extensometer cannot be expected to yield results as accurate as a more expensive one, like an Instron [3,4]. The build quality and design of the budget extensometer is such that it allows for deflection in the arms of the extensometer itself. This can cause error in the deflection measurement. Second, the specimens used were samples of steel tie wire. The tie wire is not made with a great amount of precision and therefore cannot be expected to give a consistent result. A dog-bone test specimen is more suited to find the modulus of elasticity; however, the testing machine is not equipped with a load cell large enough to handle the load required to conduct such a test. Another error is the speed at which the specimen is pulled. As seen in Test 8, which is a test conducted at a much lower speed compared with all the other tests, the speed at which a specimen is pulled can have a dramatic effect on the modulus of elasticity. In an ideal world, a motor would be attached to the testing machine so that the pulling speed is held constant throughout the testing period.

Even with these errors, the precision achieved with the budget extensioneter is still an improvement over testing with an encoder. Tests using the encoder could yield values for modulus of elasticity that are significantly different from known values. Given the cost-effective nature of the budget extensioneter and the quality of the test specimens, the values achieved from testing are accurate enough to be considered successful results.

CONCLUSION

With the adaptation of the Arduino code provided and after calibration and testing, an accurate measure for modulus of elasticity was found. Using the factor found from calibration, the budget extensometer was able to give precise values down to .0001 inches. Sources of error within the test procedure, like slack in the specimen, were also eliminated to give a more accurate result. With this more precise measure of elongation, a more accurate evaluation of the modulus of elasticity was found. Multiple tests were conducted to verify the accuracy of the extensometer by comparing the experimental values found with known values. The average percent error for all eight tests was 13.09%.

Although not perfect, the procedure and hardware developed within this experiment allow for accurate measurement of modulus of elasticity. An improvement that can be made to the testing machine is to motorize the movement of the cross head. This will allow for more consistent tests. It is recommended that SUU purchases more NCS extensometers to be implemented into material testing labs.

REFERENCES

[1] Hibbeler, R. (2016). *Mechanics of Materials* (10th), Hoboken, NJ: Pearson.

[2] Instron Testing Solutions. *Instron Extensometers*. Retrieved December 2019 from https://instron.us/.

[3] Everbright High Tensile Wire. (2019). *Rebar Tie Wire*. Retrieved December 2019 from https://www.hightensilewire.org/ tensilewire/rebar-tie-wire.html.

[4] NCS Testing Technology. *Calibration*. (2019). Retrieved December 2019 from http://english.ncstest.com/service-136.html.

APPENDIX

Arduino code

This program converts the analog signals from each input (encoder, load cell, and extensioneter) and converts it to a value, then outputs that value to a computer.

```
enum PinAssignments {
encoderPinA = 2,
encoderPinB = 3.
loadCellClk = 5.
loadCellDat = 6,
extensDat = 9.
clearButton = 8
}:
volatile unsigned long encoderPos = 0;
unsigned long lastReportedPos = 1;
unsigned long previous Millis = 0;
long interval = 100; // Serial reporting interval.
boolean A set = false;
boolean B set = false;
#include "HX711.h"
HX711 scale:
```

HX711 extensometer; void setup() { pinMode(encoderPinA, INPUT); pinMode(encoderPinB, INPUT); pinMode(clearButton, INPUT); digitalWrite(encoderPinA, HIGH); // turn on pull-up resistor digitalWrite(encoderPinB, HIGH); // turn on pull-up resistor digitalWrite(clearButton, HIGH); // encoder pin on interrupt 0 (pin 2) attachInterrupt(0, doEncoderA, CHANGE); // encoder pin on interrupt 1 (pin 3) attachInterrupt(1, doEncoderB, CHANGE); Serial.begin(9600); // Scale Setup scale.begin(loadCellDat, loadCellClk); scale.set scale(3958.970118); // This is the calibration factor for lbs. scale.tare(); // Extensometer Setup extensometer.begin(extensDat, loadCellClk); // extensometer shares clock pin with load cell. extensometer.set scale(10233479.0); // Sets Extensometer Calibration Factor extensometer.tare(); } void loop() { while (Serial.available() > 0) { // Tares the extension when you press 'x' if (Serial.read() == 'x') extensometer.tare(); } unsigned long currentMillis = millis(); if (currentMillis - previousMillis >= interval) { **Serial**.print(currentMillis); // Time, measured in milliseconds since boot. Serial.print(","); Serial.print(-unwrap(encoderPos) / 31200.0, 6); // Crosshead position in inches (to the tousandth). Serial.print(","); Serial.print(scale.get units(), 4); // Weight in lbs. **Serial**.print(","); **Serial**.print(extensometer.get_units(), 7); // Extensometer reading.

```
Serial.println();
 previousMillis = currentMillis;
}
if (digitalRead(clearButton) == LOW) {
 encoderPos = 0;
}
}
// Interrupt on A changing state
void doEncoderA() {
// Test transition
A set = digitalRead(encoderPinA) == HIGH;
// and adjust counter + if A leads B
encoderPos += (A set != B set) ? +1 : -1;
}
// Interrupt on B changing state
void doEncoderB() {
// Test transition
B_set = digitalRead(encoderPinB) == HIGH;
// and adjust counter + if B follows A
encoderPos += (A set == B set) ? +1 : -1;
}
// Function to allow the encoder
float unwrap(unsigned long encData) {
if (encData > 2147483648) {
 return (float)encData - 4294967296;
}
else {
 return (float)encData;
}
}
```

Direct Evaporative Cooling: Simple Analysis

Skyler Ipsen, Matt Bennion, Colby Thorton, Andrew Logan, Austin Banks, Ali S. Siahpush

Southern Utah University

ABSTRACT

Evaporative coolers are an excellent alternative to air conditioning (A/C) systems for dry climates. Contrary to A/C removing moisture from the air, evaporative coolers lower temperatures by the latent heat of evaporation and increasing air moisture. Warm air energy is used in evaporative cooling to evaporate water, resulting in cooler temperatures. There are three types of evaporative coolers: direct, indirect, and hybrid systems. This paper focuses on direct evaporative cooling (DEC). The efficiency, cooling capacity, consumption of water, and volume capacity of DECs can be calculated by measuring inlet and outlet temperatures and relative humidities. To support the theory and measure these attributes, a simple in-house DEC cooler was built and tested. Ultimately, even though not as efficient as commercial coolers, this evaporative cooler decreased the temperature and increased the relative humidity of the ambient air.

NOMENCLATURE					
Symbol	Definition	Unit			
C_p	Specific heat	J/kg.K			
h_1	Enthalpy at state 1	kJ/kg			
h_2	Enthalpy at state 2	kJ/kg			
h_{g1}	Enthalpy of water vapor at T_1	kJ/kg			
h_{g2}	Enthalpy of water vapor at T_2	kJ/kg			
\dot{m}_a	Mass flow rate of air	kg/s			
\dot{m}_w	Mass flow rate of water	kg/s			
P_{g1}	Saturation pressure at state 1	kPa			
P_{g2}	Saturation pressure at state 2	kPa			
P_{v}	Vapor pressure	kPa			
Ż	Cooling capacity rate	kW			
T_1	Inlet (ambient) temperature	°C			
T_2	Outlet temperature	°C			
T_{db}	Dry-bulb temperature	°C			
T _{wb}	Wet-bulb temperature	°C			
V	Volumetric flow rate	m ³ /s			
ω_1	Inlet (ambient) absolute humidity	kgmoisture/kgdry			
ω_2	Outlet absolute humidity	Kgmoisture/kgdry			
З	Efficiency				
φ_1	Inlet (ambient) relative humidity				
φ_2	Outlet relative humidity				

INTRODUCTION

All organisms depend on moderate, controlled temperatures to survive and thrive. Over the centuries, humans have found clever ways to cool or heat spaces, so the concept of local temperature control is not new. Before the modern age, humans warmed themselves with fire and cooled with water. Now, there are sophisticated apparatuses to cool and heat spaces, such as space heaters and air conditioning (A/C) systems. Many studies have been performed on the theory and application of cooling. The two most common methods of cooling are A/C systems and evaporative coolers (also known as swamp coolers).

Evaporative cooling is a brilliant alternative to A/C systems. A/C works well in wet, humid environments because it is designed to remove moisture from the air. If there is little moisture in the air for the A/C system to remove, the efficiency will decrease significantly. The evaporative cooler works on the principle of *increasing* humidity in the air. Thus, whereas A/C is an excellent candidate for humid climates,

evaporative cooling is the preferred choice for dry, arid climates. The purpose of this paper is to analyze the basic thermodynamic and heat transfer principles behind evaporative cooling and support the theory by measuring the actual cooling performance of an in-house built swamp cooler (DEC).

Many papers have been written on evaporative coolers. Shrivastav et al. [1] published a review that gives good detail in how to analyze and calculate the efficiency of evaporative cooling systems. Bhatia [2] also published an online resource outlining principles and processes of evaporative cooling. This paper encompasses more aspects of direct evaporative cooling in one paper. It starts from the theory of evaporative cooling and then describes how to construct, test, and analyze a cooler with an Arduino system.

THEORY

There are three types of evaporative cooling systems: direct evaporative cooling (DEC), indirect evaporative cooling (IEC), and hybrid systems (Fig. 1).



Figure 1. (a) DEC, (b) IEC, and (c) hybrid systems [1].

In a DEC system, air at an ambient room temperature is forced through a wet medium (usually straw or wood) with a large surface area by a fan. Heat from the air vaporizes small amounts of water (heat of vaporization) within the medium, and the air exits the medium at a lower temperature with greater relative humidity.

To analyze direct evaporative cooling, it is assumed that:

- 1. The cooling process is adiabatic because the process happens so quickly.
- 2. The temperature of the water used to saturate the medium is at room temperature.
- 3. The atmospheric enthalpy stays constant $(h_1 = h_2)$.
- 4. The wet bulb temperature (T_{wb}) stays constant.

If these assumptions are met, the relative humidity (φ) of the air increases, and the dry bulb (room) temperature (T_{db}) decreases. To predict the cooling capacity and temperatures of an evaporative cooling system, a psychrometric chart can be used to find the final temperature when the values of three properties are known. In this case, it is assumed that T₁, φ_1 , and φ_2 are known. On the chart, first, vertically, follow the dry bulb temperature of the ambient air (T₁) until you reach the ambient relative humidity (φ_1). By traveling up the line of constant enthalpy to the higher relative humidity (φ_2), the exit air temperature (T₂) can be estimated for a desire final temperature. For the psychrometric analysis of the system tested, see the Appendix.

The efficiency of a DEC system is calculated using the ratio of exit air temperature and inlet air temperature, and the temperature of air if it were fully saturated. The efficiency of a DEC is defined as [1]

$$\varepsilon = \frac{T_1 - T_2}{T_1 - T_{wb}} \cdot 100 \tag{1}$$

where T_1 is the inlet temperature of the air (°C), T_2 is the exit temperature of the air (°C), and T_{wb} is the wet bulb temperature (°C).

The cooling capacity of the DEC can be expressed as [1]

$$\dot{Q} = \dot{m}_a c_{p_a} (T_1 - T_2) \tag{2}$$

where \dot{Q} is the cooling capacity rate (kW), \dot{m}_a is the mass flow rate of the dry air (kg/s), and c_{p_a} is the specific heat of air (J/kg·K). The rate of water evaporation can also be calculated as [1]

$$\dot{m}_w = \dot{m}_a(\omega_2 - \omega_1) \tag{3}$$

where \dot{m}_w is the mass rate of water being evaporated (kg/s), and ω_1 and ω_2 are the inlet and outlet absolute humidities of the atmospheric air

(kg/kg), respectively. The values for ω_1 and ω_2 can be either calculated analytically or estimated using the psychrometric chart.

To calculate ω_1 and ω_2 the following relationships can be used [3]:

$$P_{\nu} = \varphi P_g \tag{4}$$

$$\omega = 0.622 \frac{P_v}{P - P_v} \tag{5}$$

$$h_1 = h_2 = c_{p_a}T + \omega h_g \tag{6}$$

$$h_a = 2500.9 + 1.82T \tag{7}$$

where P_{v} is the vapor pressure, P_{g} is the saturation pressure of vapor at a given temperature, φ is the relative humidity, P is the atmospheric pressure, h_{g} is the enthalpy of water vapor, and h_{1} and h_{2} are the enthalpies of the air at the inlet and outlet, respectively.

Equations 1–7 help to understand the characteristics of a DEC system, but it is also important to know more generally how quickly a system could cool a room, or the size of a room a particular system could maintain at a certain temperatures. To cool any given space, the hot air needs to be replaced with cooler air. Typically, this is described by the number of times an entire volume of air gets replaced, or the number of air changes per hour. To keep a room cool, 20 air changes per hour is a good estimate [2]. The relationship between the flow rate of the cooler and the number of air changes per hour is presented as [2]:

$$Volumetric flow rate = \frac{Volume of the Space}{Number of Changes}$$
(8)

This relationship can be used to determine the size of the cooler needed to cool a given space, or the size of a room for given cooling requirements.

EQUIPMENT/MATERIAL

- 1/4-inch acrylic plexiglass (4 ft×8 ft) (https://jonespg.com/ fiberglass-composite-windows/)
- 6 ft of 1/2-inch hose (https://www.amazon.com/Eastman-48022-Faucet-Water-Supply/dp/B01IWM85PO/ref=sr_1_3? dchild=1&keywords=6ft%2B1%2F2%2Bwater%2Bhose& qid=1634833296&sr=8-3&th=1)
- 3. 20-in box fan (https://www.amazon.com/Genesis-Settings-Cooling-Technology-Handle/dp/B0854FY793/ref=sr_1_1?

crid=2CLZTAVSK7Q0R&dchild=1&keywords=genesis+box +fan+white&qid=1602608884&sprefix=genesis+box+fan+%2 Caps%2C182&sr=8-1)

- Dial UL550 pump (https://www.amazon.com/Dial-Ul5500-Cooler-Pump-1150/dp/B000RF8D48/ref=psdc_554568_t3_ B0002YTQJK)
- Aspen Snow Cool evaporative cooler pad (https://www.lowes. com/pd/Aspen-Snow-Cool-Aspen-Wood-Evaporative-Cooler-Replacement-Pad/4176929)
- GE advanced silicon sealant (https://www.homedepot.com/p/ GE-Advanced-Silicone-2-10-1-oz-Clear-Window-and-Door-Silicone-Sealant-Caulk-GE5000-12C/100026175?)
- 5-minute JB weld epoxy (https://www.homedepot. com/p/J-B-Weld-25-ml-ClearWeld-Quick-Set-Epoxy-Syringe-50112/204986141)
- 8. Protomex digital temperature and humidity meter
- 9. Arduino system with humidity/temperature sensors [4]

A price list is shown in Table 1. The most expensive item was the acrylic plexiglass. It may be replaced by 0.25-inch-thick clear plastics or glass. We chose acrylic plexiglass to be able to observe the process.

Table 1. Component prices				
ITEM	COST			
¹ /4-in acrylic plexiglass	\$198.99			
¹ /2-in hose	\$4.48			
Box fan	\$45.99			
Dial UL550 pump	\$29.99			
Aspen Snow Cool cooler pad (1)	\$4.89			
GE advanced silicon sealant	\$5.91			
5-minute JB epoxy	\$4.84			
Arduino system [4]	\$30.00			
Total	\$325.09			

The DEC system consisted of plexiglass panels glued together into a roughly 2-foot square container. Wood shaving medium was inserted and fastened in place in the middle of the cube, and a 1710 CFM 20-inch box fan was mounted directly behind it to move the dry air into the system. A 10-liter water reservoir directly underneath the medium with a 0.546-CFM pump continuously supplied water to the top of the medium. The water supply tube at the top of the medium included several spray nozzles to distribute the water evenly and keep the medium as wet as possible. Figure 2 shows the inlet opening where the fan would pull the air. Thick foam insulation surrounded the fan to mitigate air blowback as it passed through the medium.



Figure 2. Inlet side of the DEC system.

Figure 3 shows the outlet side of the DEC. A sensor to measure temperature and humidity was installed on both the inlet and the outlet sides.



Figure 3. Outlet side of the DEC system.

The sensors were powered and programmed using an Arduino board shown in Figure 4. The Arduino humidity sensor system was composed of an Arduino UNO, DHT-22 sensors, and DIY electrostatic protection cables. The DHT-22 is a sensor that can simultaneously detect environmental humidity and temperature.



Figure 4. Arduino location on the system.

The sensing range and error value of the sensors are shown in Table 2. The working voltage of the DHT-22 sensor is 3-5V, so 3.3V and 5V power can be used directly from the Arduino UNO board.

Table 2. Technical details of DHT-22 Sensor [4, 5]					
	Unit	Value	Error Range		
Power	V	3–5	-		
Humidity	%	0–100	±2-5		
Temperature	°C	-40 to 80	±0.5		

The thermocouple used in the Digital Thermometer SD Logger often encountered static electricity shut down, so a USB cable with electrostatic protection was adapted for the Arduino wires. The Arduino PINs were soldered to the wire and then covered with heat shrink, making sure male and female pins were used to adapt the DHT-22 sensor to the Arduino board. The wiring diagram and subsequent build of the setup are shown in the Appendix. Arduino IDE was the programming software used to control the Arduino board. To control two sensors at the same time, the direction presented in a video by "G6EJD-David" on YouTube was used [6, 7]. Before the sensors were used to take measurements from the DEC system, a test was conducted in a similar environment to ensure the stable operation and accurate reading of the data. It was concluded that the temperature readings of the two DHT-22 sensors were almost identical, but the humidity readings had a discrepancy of 4–5%. According to the error range in Table 2, this was an acceptable error range.

PROCEDURE

The assembled system is shown in Figure 5, and the procedure to test the direct evaporative cooler is as follows:

- 1. Fill water basin.
- 2. Run pump for approximately ten minutes to saturate cooler pad.
- 3. Record entrance dry bulb temperature and relative humidity.
- 4. Turn on the fan.
- 5. Place measuring instrument centered in the exit until it reaches steady state.
- 6. Record steady-state values of temperatures and humidities.



Figure 5. Fully constructed DEC.

Measurements of temperature and relative humidity of the inlet and outlet sides of the DEC were taken over a period of 2000 seconds (approximately 34 minutes). Collecting data was stopped when the system's outlet temperature was no longer dropping, indicating it had reached the steady state, or its maximum cooling capacity. Two frames of reference were used for the data collection: (1) the Arduino system with sensors at both the inlet and outlet areas of the cooler; and (2) data taken by a handheld digital temperature/humidity meter once the system was at steady state. These two data sets were then compared with the predicted values from the psychrometric chart.

RESULTS

The Arduino sensors took data for ~2000 seconds with data recorded every 5 sec. The steady-state temperature of T_1 was 20.2°C with a relative humidity of 43.6%, and T_2 was measured at 13.8°C with a relative humidity of 88.8%. The values of T_1 and T_2 at steady state as measured by the handheld digital tester were 20.6°C and 12.5°C, with 22.6% and 75.4% relative humidities, respectively. The value of φ_2 as estimated by the psychrometric chart using 20.2°C and 43.6% relative humidity as initial conditions and 13.8°C outlet temperature was 87%. The results are summarized in Table 3 showing steady-state values.

Table 3. Results for the DEC system						
	T ₁ inlet	T ₂ steady state	Φ1 inlet	Φ ₂ steady state		
Arduino	20.2°C	13.8°C	43.6%	88.8%		
Digital meter	20.6°C	12.5°C	22.6%	75.4%		
Psychrometric chart	20.2°C	13.8°C	43.6%	87%		

Figure 6 shows the values of T_1 and T_2 , and Figure 7 shows ϕ_1 and $\phi_2,$ respectively.



Figure 6. Temperatures of inlet and outlet over time.



Figure 7. Relative humidity at entrance and exit over time.

DISCUSSION

The Arduino values shown in Table 1 for T_1 and T_2 , using a wetbulb temperature (T_{wb}) of 12.3°C (value taken from the psychrometric chart), were substituted into Eq. (1) to evaluate the efficiency of the DEC (81%). The volumetric flow rate of the air through the cooler was assumed to be 570 CFM (0.269 m³/s, roughly 1/3 of the capacity rating of the fan). Multiplying this value by the density of air (1.007 kg/m³) yields a mass flow rate of 0.271 kg/s. Using this value for m_a , a specific heat of 1.005 kJ/kg·K for c_{pa} [3], and the values of inlet and outlet temperatures from the Arduino sensors in Table 3, the cooling capacity was calculated as 1.74 kW.

The values for absolute humidity in and out of the system were calculated using Eqs. (4–7), and also estimated using the psychrometric chart. Using the steady-state inlet temperature and relative humidity from Table 3 of 20.2°C and 43.6%, P_g as 2.372 kPa [3], P_{v1} was calculated using Eq. (4) to be 1.034 kPa. Using this value for P_v and 100.75 kPa for the ambient air pressure P in Cedar City, UT, ω_1 was calculated using Eq. (5) to be 0.0065.

To calculate the value of ω_2 , the assumption that enthalpy stays constant during the evaporative process was used in Eq. (6). Using 0.0065 for ω_1 , the inlet temperature of 20.2°C, and 2537.76 kJ/kg for h_g [3], h₁ was calculated to be 36.67 kJ/kg. Using this value in Eq. (6) again, and now using the outlet temperature of 13.8°C and 2526.02 kJ/kg for h_g [3], ω_2 was calculated to be 0.009. Using this value, Eqs. (4) and (5) were used to find P_{v2} and subsequently φ_2 . These values were then compared

.

Table 4. Calculated and estimated (psychrometric) values of absolute humidity								
	h1 (kJ/kg)	φ1 (%)	P _{v1} (kPa)	ω1	h ₂ (kJ/kg)	φ ₂ (%)	P _{v2} (kPa)	ω2
Calculated	36.67	43.6	1.034	0.0065	36.67	90.6	1.441	0.009
Estimated	39	-	-	0.0074	39	87	-	0.010

with those found using the psychrometric chart. The results are shown in Table 4.

Using the calculated values of ω_1 and ω_2 shown in Table 4 and 0.271 kg/s for \dot{m}_a , Eq. (3) gives the rate at which the water is being evaporated to be $\dot{m}_w = 0.00068$ kg/s. To calculate the space the system is capable of keeping cool, the assumption is made that the number of air changes per hour needs to be 20 changes/hour [2]. Converting this to air changes per minute yields 0.333 changes/min. Using Eq. (8) and assuming the volumetric flow rate of the fan to be 570 CFM, the size room the DEC would be able to handle was calculated.

SOURCES OF ERROR

Using the psychrometric chart gives the user good estimates of values, but with that comes the inherent measuring source of error of the user not accurately following a line exactly. The human error can introduce a major error in evaluating relative humidities. Another source of error came from the evaporative cooling system. It did not have a perfect seal around the fan so there was some air flow coming back at the initial sensor. This resulted in the relative humidity increasing slightly as seen on the graph along with the increase of the ambient humidity increasing. The last sources of errors are inaccuracy and the error range of each instruments. The error and uncertainty analysis are beyond the scope of this paper.

CONCLUSIONS AND RECOMMENDATIONS

Evaporative cooling is a great alternative to A/C systems, especially for dry, arid climates. Rather than complex cooling systems, evaporative coolers are simple and cost effective. We supported the theory of evaporative coolers using a simple self-built DEC. We showed that it is possible to cool air simply by evaporating small amounts of water into the system. We assumed the process of evaporation to be

adiabatic because the process happens so quickly and showed that as the relative humidity of the air increased, the temperature decreased. The prediction of values such as relative humidity can be done analytically and by the use of a psychrometric chart.

The SUU DEC system had an efficiency of about 81%, and it supported and validated the evaporative cooling theory. The air was cooled as it passed through the wet medium, creating a higher relative humidity. There were a few interesting phenomena that occurred, however. First, the relative humidity of the inlet side increased over the 30-minute testing period. As the cooler pumps humid air out, the ambient relative humidity of the entire room increased. The increase in humidity of the inlet air was in part due to the ambient air being humidified. In industrial or home applications, the swamp cooler would be placed with the inlet duct outside the building, and the outlet duct directed into the building. In this manner, the outside (inlet) air acts as a large reservoir of nonhumidified air, while the outlet duct blows cool air into the space to be cooled.

Additionally, as expected, there were some discrepancies between the Arduino data, digital device data, and psychrometric estimates of outlet temperature. However, all the values were within ± 1.8 °C and ± 5 % humidity.

When constructing future evaporative cooling systems, it is imperative that top-quality medium, filtration system, and fan location in the evaporative cooler are used to increase the efficiency of the system. Quality medium makes a large difference in the resulting relative humidity. Switching the medium in our separate experiments resulted in a 17% increase in humidity levels. A filtration system around the pump would also be important for the functionality of the system. Particulates got through the pump and clogged the hose, which resulted in the pump overheating. The fan location was put right up next to the medium. This caused some water to flow into the fan. There was not enough to become a concern, but moving the fan back away from the medium an inch would be a great improvement to this system to remove any safety concerns. The DEC does not need to be constructed out of plexiglass. This caused some issues with the structural integrity of the system so other materials should be explored to see what material is best for the structure of the DEC.

ACKNOWLEDGMENTS

This project was funded by the Department of Engineering and Technology at Southern Utah University. We would like to thank The Utah NASA Space Grant Consortium for supporting this undergraduate research. We are also thankful for SUU letting us work in the Thunderworks Makerspace and store our equipment there.

REFERENCES

[1] Maurya, R., Shrivastav, D. and Shrivastava, V., 2014. Performance and Analysis of an Evaporative cooling System: A Review. International Journal of Scientific & Engineering Research, Volume 5 (Issue 10), p. 1064.

[2] A. Bhatia, "Principles of Evaporative Cooling System" Retrieved September 15, 2020, from https://www.pdhonline.com/courses/m231/m231content.pdf.

[3] Çengel Yunus A. and M.A. Boles, *Thermodynamics: An Engineering Approach*, 6th edition, New York, NY: McGraw-Hill Education, 2016.

[4] Arduino. "Getting Started with Arduino UNO," Retrieved September 28, 2020, from https://www.arduino.cc/en/Guide/ArduinoUno

[5] Arduino. "Arduino - Humidity Sensor," Retrieved September 28, 2020, from https://www.tutorialspoint.com/arduino/arduino_humidity_sensor.htm

[6] "Tech Note 012 - ESP8266 Reading Multiple DHT Sensors0", G6EJD - David (Nov 4, 2016). Retrieved October 7, 2020, from https://www.youtube.com/watch?v=Yv80KrQEIYo&t=118s

APPENDIX

Figure A1 shows the psychrometric analysis for the DEC system. T_1 and ϕ_1 as labeled indicate the initial temperature and relative humidity as was measured and shown in Table 3. The initial relative humidity was measured by reading the initial value from the Arduino humidity sensor at the beginning of the test. To predict the steady-state temperature, a line with constant enthalpy was drawn up to the measured value of relative humidity, ϕ_2 , also a value taken from the humidity sensor. The outlet dry bulb temperature, T_2 , was found by reading the corresponding temperature directly underneath the new intersection of enthalpy and relative humidity.



Figure A1. Psychrometric measurements for the DEC system.

Figures A2-A4 depict components of the Arduino UNO system.



Figure A2. Wire selection and build-up. Available at TEKCOPLUS. Thermometer Thermocouple K Type 4-Channel Multi Channel SD Card Data Logger Temperature with Beeper and LED Alarm + 2 Bead Type Probe Wire Sensor," Retrieved 9/25/20 from September 20, 2020, from https://gainexpressdealer.com/products/ a0188598?variant= 1027526230041.



Figure A3. Wire connection diagram for Arduino UNO and DHT-22 sensor.



Figure A4. Actual connection for Arduino UNO and DHT-22 sensor.

Figure A5 shows the hand calculations done to analytically solve for ϕ_2 given T_1 , T_2 , ϕ_1 , ω_1 , and ω_2 .

T, 202°C Ø, 143.6% Tz = 13.8°C Øz = 1 17 17 No. 7 Mi 0.271 Als P= 100175 HZ Pg = 2.372 HZ Pg = 1.591 HPA 4. - R. + A. R. = Q436 (2372) = 1.034 kP. 0.622 PM = 0.622 (1.024) = 0.00645 from (-w), P-R, = 100.75-1034 Fiz dz, wie his he - cpt, why, scpte +withge Cp + 1005 + 3/9+ From +ABLE -0 " ly = 2537.76 49/9 ly = 2000.9 +1.82 % = 2500.9 - 142 (13.8) hys = 25.26.04 1/4 h, = (p.7.+2, hy, = 1005 (20.2) + 0.00045 (25.37.76) = 36.669 1/4 h, = 6pt many, h, = h, - 0 36.499 = 6pt + 13/hgs 36.669 = 1005 (22) + 102 (2526.06) 36.669 = 1005 (22) + 102 (2526.06)
$$\begin{split} \omega_{2}^{*} &= \frac{O422}{P-P_{4}}\frac{R_{4}}{R_{4}} = -\frac{\omega_{1}P-\omega_{2}R_{4}}{\omega_{1}P+O422R_{4}} + \frac{R_{4}}{R_{4}} \\ &= \frac{\omega_{1}P+O422R_{4}}{\omega_{1}P+O422R_{4}} + \frac{R_{4}}{R_{4}} \\ &= \frac{\omega_{1}P}{P+O422R_{4}} + \frac{\omega_{1}P}{O422R_{4}} \\ &= \frac{\omega_{1}O((10077))}{O422R_{4}} \end{split}$$
B. R. = 1.441 B. R. = 1.441 B. - 1.541 - 0.906 = 90.6%

Figure A5. Hand calculations for the DEC analysis.

Heat Transfer Analysis of Eicosane During Melting

Sabrina Kim, Bill Maxwell, Ali S. Siahpush

Southern Utah University

ABSTRACT

This paper is a continuation of an ongoing study concerning energy storing phase-change material (PCM) at Southern Utah University (SUU). Previous research was conducted to study the inward freezing of the PCM eicosane (paraffin, $C_{20}H_{42}$) in a cylindrical enclosure. The scope of this project includes evaluating the performance of eicosane for releasing thermal energy (melting). The melt-testing and performance of the paraffin PCMs were investigated. Data from thermocouples were collected, and heat transfer analysis consisted of (1) conducting a melting incremental convection heat transfer analysis using data from thermocouples; (2) implementing a calorimetric heat transfer analysis; and (3) evaluating the melt front vs. time data. Predictions from previous experimentation are also presented to further validate the results of this work.

NOMENCLATURE					
Symbol	Definition	Unit			
c_p	Specific heat capacity	kJ/kg°C			
CTB	Constant temperature bath	dimensionless			
М	Mass of component	kg			
'n	Mass flow rate	kg/s			
PCM	Phase-change material	dimensionless			
Ż	Heat transfer rate	kW			
Т	Time	S			
Т	Temperature	°C			
TC	Thermocouple	dimensionless			

INTRODUCTION

Materials exist in three phases that can be characterized by the amount of energy stored in each substance. Energy is required for the phase change to occur in a material, which can be accomplished by heating or cooling [1]. As material is absorbing or releasing energy during phase change, the temperature will remain constant. With energy efficiency becoming a growing concern, efforts made to increase energy efficiency can be tied to the usage of thermal energy. This includes the application of thermal energy in heating, ventilation, and air conditioning (HVAC) systems and even passive heating and cooling of satellites. Effects of energy absorbed and released in material phase change can even be seen in the study of earth's crust formation. By analyzing heat transfer and energy release from a phase-change material (PCM), a better understanding of stored thermal energy can be developed and even applied to further implement more efficient forms of energy.

To better understand the behavior and importance of melting PCM in heated/cooled cylinders, a literature review was conducted. Melting has been studied for many years. Previous studies have been performed to evaluate how thermal energy is stored and released when the effects of heating and cooling are implemented on a PCM. Evaluating the effects of thermal energy can be achieved by observing the solid–liquid phase change of a PCM in insulated cylinders [2,3]. One application in understanding the melting phenomenon is seen in using a PCM as a medium for thermal energy storage [3]. Another application of this field of study is seen in an experiment in which a PCM is stored in copper porous foam to analyze how it affects the performance of solid–liquid phase change [4]. A more recent study did a similar experiment investigating the melting properties of eicosane in a horizontal cylinder, where melt flow patterns and heat rate values were determined [5]. The
ideal PCM is one with a low-to-medium phase change temperature, and eicosane, used in this experiment, fulfills that requirement [6].

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 suitable PCM candidate:

- 1. High heat of fusion per unit of mass and volume
- 2. Proper melting point and reversible solid-to-liquid transition
- 3. Relatively high thermal conductivity, density, and specific heat
- 4. Low vapor pressure
- 5. Noncorrosive and nontoxic
- 6. Low coefficient of thermal expansion
- 7. High flash point
- 8. Good wetting characteristics
- 9. Stable and pure

In this experiment, the PCM paraffin ($C_{20}H_{42}$) is enclosed in an insulated copper cylinder to be heated and cooled with fluid flowing from the constant temperature bath (CTB) as shown in Figure 1. Once melt testing was performed, data from thermocouples (TCs) were obtained to evaluate heat transfer analysis. The analysis focused on the incremental melting performance of conduction to natural convection heat transfer analysis for this study was conducted by evaluating the effects of melting and plotted time-dependent volumetric temperature distribution. This included analysis of time-dependent temperature distributions of total heat transfer of the CTB fluid and the experimental components, such as the copper cylinder, copper tubes, aluminum flanges, and acrylic lids.



Figure 1. Setup of the test system [4].

PREVIOUS WORK

This project expanded on the research conducted by previous students for a period of over three years. The previous students designed and constructed a test system to be used to research the thermal behavior of the solid–liquid PCMs [4]. The system consisted of a vertical copper test cylinder that was heated and cooled inwardly by using copper tubing wrapped in a counterflow arrangement around the outside of the test cylinder (Fig. 1, shown without insulation). The tubing was connected to a 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 TCs.

Before 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. Melting of the eicosane from 10°C to 50°C was provided by the fluid flow of a CTB system with a counterflow heat exchanger wrapped tightly around the test cylinder.

RESULTS & DISCUSSION

Melting Region

In the presence of natural convection in the melt region, there are four main melt regimes, which are shown in Figure 2. In this figure, the dashed line represents the phase-change interface front. On the right of the dashed line is the liquid region and, on its left, the solid region. The melt progresses from right to left toward the centerline.

The "conduction regime" (I) is dominated by pure thermal diffusion. The "transition regime" (II) occurs when a natural convection flow carves its own convection-dominated zone in the upper part of the liquid region, while the lower part remains ruled by conduction. The "quasi-steady natural convection regime" (III) begins when the convection-dominated zone of the preceding regime fills the entire height of the cylinder. Finally, the arrival of the liquid–solid interface at the centerline marks the beginning of the "variable-height regime" (IV). From this time, the height of the liquid–solid interface decreases steadily until the solid region disappears entirely [2].

As the eicosane is heated to 50° C, the melt front gradually exhibits a shape typical of convection-dominated melting. The interface moves faster near the top where the liquid, heated by the hot wall, changes the form of heat transfer. The melt rate decreases toward the bottom, because the liquid cools down as it descends along the interface.



Figure 2. The four melt regimes [2].

Once the results were obtained, the data were analyzed to determine the time at which each TC reached 36.5°C (melting temperature of eicosane). This evaluation provides a visualization of how the melt front progresses inwardly over time. These data were compiled in Figure 3. Each of the lines shows a distance from the outer wall of the cylinder. This behavior is expected based on the melt regimes, which will be discussed later in this section. In the beginning of the heating process, the temperature is nearly identical down the wall of the cylinder, showing a conduction-driven heat transfer method. As time progresses, the top TCs begin to reach the melting temperature much faster than the bottom TCs. This is caused by the natural convection loop that forms as the liquid eicosane is heated and moves to the top. It is cooled as it approaches the solid eicosane, and as it cools, it moves in a downward motion across the solid region. This further decreases the temperature, which slows the melting and forms the triangular melting face outlined in Figure 3.



Figure 3. The approximate time at which each TC reaches melting temperature.

To place these findings in perspective, the behavior of the melt front in the presence of various heat transport modes needs to be considered. If radial conduction were the sole form of heat transfer, the inward movement of the melt front would be uniform along the height of the tank, so that the front would appear to be a vertical line at a given instant of time. At small values of time and in the lower portion of the tube, the melting front is vertical, thereby indicating the dominance of conduction.

There are two factors that contribute to the departure of the actual behavior of the melt front from that of pure conduction. First is the density decrease that accompanies melting. As eicosane melts (decrease in density), it expands and the melted eicosane moves to the top of the cylinder because of the buoyance force. The displaced liquid causes melt to occur at the upper surface of the solid as well as at the adjacent side surface. It is this volume-change-driven motion that is believed to be responsible for the initial departures of the melt front from that for pure conduction. Second, as time passes, natural convection motion develops in the melt layer, with an up-flow adjacent to the tank wall and a down-flow adjacent to the melt front. This circulation pattern delivers relatively hot liquid to the upper reaches of the solid, where its presence accelerates the rates of inward and downward melting. Natural convection and the volume-change-driven motions are mutually aiding, but natural convection is the dominant factor during most of the melting period.

Another important understanding to gain from the analyzed data involves the period during which the eicosane is changing from a solid to a liquid. As materials change their phase, there is a plateau in the temperature profile. The heat that is added to the material during this time changes the phase, rather than increasing or decreasing the temperature. These regions of phase change are outlined in Figs. 4-8. Each of these plots shows a different column of TCs, with the temperature given at different heights in the cylinder. Note that "Ch" indicate the location of a TC (different row, but the same column).



Figure 4. Temperatures of TCs in the A column.

As shown in these graphs, there is a time at which the temperature increase stagnates as it rises from 10° C to 50° C. This pause in temperature change occurs as each TC reaches 36.5° C, when the eicosane changes from a solid to a liquid. Both before and after this temperature, the increase is rather rapid, until it reaches equilibrium with the CTB fluid. This behavior is due to the sensible heat added to eicosane. The TCs closest to the wall, shown in Figure 4, have the fastest increase through the entire process. However, the TCs closest to the top, shown in Ch 4 in Figs. 4-8, all show a very similar curve, reaching the melting temperature at very similar times. This further supports the evidence of convection at the top of the cylinder.



Figure 5. Temperatures of TCs in the B column.



Figure 6. Temperatures of TCs in the C column.



Figure 7. Temperatures of TCs in the D column.



Figure 8. Temperatures of TCs in the E column.

Heat Transfer Analysis

In addition to analyzing melting regions, the cooling fluid from CTB was analyzed, and the results were applied to the eicosane tests. From the second law of thermodynamics, thermal energy moves from high to low temperatures. Types of heat transfer in thermodynamics include conduction, convection, and radiation. For this project, because the system is insulated, radiation is not considered as a form of heat transfer as the energy exchange of the PCM is evaluated. As the first law of thermodynamics indicates energy balance for a system, a closed system with heat transfer and no work interactions across its boundary can be expressed as [7]

$$\dot{Q} = \dot{m}c_p\Delta T \tag{1}$$

where \dot{Q} is the heat transfer (kW), \dot{m} is the mass flow rate (kg/s), c_p is the specific heat capacity (kJ/kg°C), and *T* is the temperature (°C).

Heat transfer analysis is conducted to obtain instantaneous heat transfer and cumulative heat transfer on the experiment. Eq. (1) is used to find the heat transfer for the heating fluid flowing through the copper vessels at a given time step.

Heat transfer was calculated at every time step from the CTB fluid and evaluated to determine the total heat transfer. The heat transfer of the components, including the tank, copper tubes, flanges, and lids of the apparatus, may be expressed as

$$Q = \frac{mc_p \Delta T}{\Delta t} \tag{2}$$

where m is mass of the component (kg) and t is time (s). After calculating these values, the instantaneous and cumulative heat transfer data were plotted to compare CTB fluid and the components.

Instantaneous heat transfer rates for the CTB fluid and the various components were evaluated using Eq. (1) at each time step and are represented in Figure 9. This figure shows that the entire system reaches equilibrium with the CTB fluid in less than 30,000 seconds (approximately 8.4 hours). It also shows the insignificance of the heat transfer from the CTB to the copper tank, copper tubes, aluminum flanges, and acrylic lids after 1800 seconds (30 minutes). However, net transfer to the eicosane is not shown in the graph and is beyond the scope of this study.



Figure 9. Instantaneous heat transfer for CTB fluid and experimental components.

In Figure 10, the cumulative heat transfer for CTB flow and the components are plotted over time. As in Figure 9, the system reaches equilibrium within 500 minutes. At this point, there is no longer heat transfer between the CTB fluid, the eicosane, and the experimental components. As a result, the curve becomes flat and has a slope of zero. In contrast, the heat transfer for the CTB fluid is indefinite and does not reach a zero slope. Lost heat transfer is due to the heat diffusion through the insulation.

Figure 10 shows the cumulative heat gained by components and heat lost 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 gained by the eicosane.

Figure 10. Cumulative heat transfer for CTB fluid and experimental components, with a corrected data trajectory for CTB fluid.

Because of this discrepancy in the 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 m plot (dashed line in Fig. 10). By considering the parasitic heat, the heat transfer from the CTB fluid becomes flat and parallel to the heat transfer to 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 10, the difference between the corrected CTB heat transfer and the heat transfer to components is the heat gained from eicosane.

The heat removed by m in Figure 10 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 the steady state.

CONCLUSION

In previous research, the study of the PCM eicosane was observed by evaluating the inward freezing of the substane in a cylindrical coordinate system. With the completion of these studies, the analysis to predict the inward freezing of the PCM system allowed for more exploration of heat transfer analysis in eicosane.

In conducting this experiment, the study was successfully able to (1) conduct an incremental convection heat transfer analysis, (2) implement a calorimetric heat transfer analysis, and (3) evaluate melt regions vs. time. By collecting and utilizing data from TCs, the analysis of the experiment was compared with previous work to gain a better understanding of the results.

This analysis helps provide a better undedrstanding of how PCMs can be utilized in creating more energy-efficient applications. By evaluating the melt front behavior and heat transfer analysis of melting eicosane in insulated cylinders, the study recreated very similar data obtained in previous experiments. Measuring the effects of thermal energy storage and how they relate to the PCM will increase the ability for engineers to develop more efficient forms of energy use in the future.

ACKNOWLEDGMENTS

This project would not have been possible without the help and support of the Department of Engineering and Technology at Southern Utah University. Their contributions included providing the equipment and assistance from faculty. We would also like to thank The Utah NASA Space Grant Consortium for supporting this undergraduate research.

REFERENCES

[1] Viskanta, R., Bathelt, A.G., and Hale, N.W., *Latent Heat-of-Fusion Energy Storage: Experiments On Heat Transfer During Solid-Liquid Phase Change*, Proceedings of the Third Miami Conference on Alternative Energy Sources, December 1980.

[2] Siahpush, A., O'Brien, J., Crepeau, J., and Sabharwall, P., *Experimental and Scale Analysis Results of a Solid/Liquid Phase-Change Thermal Storage System*, IMECE2014-39786, ASME 2014 International Mechanical Engineering Congress & Exposition (IMECE 14), November 14-20, 2014, Montreal, Canada.

[3] Shrivastava, A., Williams, B., Siahpush, A., Savage, B., and Crepeau, J., "Numerical and Experimental Investigation of Melting with Internal Heat Generation Within Cylindrical Enclosures," Applied Thermal Engineering 67 (214) 587-596, ATE 5413, June 2013.

[4] Siahpush, A., O'Brien, J., and Crepeau, J., Phase Change Heat Transfer Enhancement Using Copper Porous Foam, ASME Heat Transfer Journal, 130(8), 082301, 2008.

[5] Benbrika, M., Teggar, M., Benbelhout, M., Ismail, K.A.R., "Numerical study of N-Eicosane melting inside a horizontal cylinder for different loading rates." International Journal of Heat and Technology, 38(1), 125-130, 2020.

[6] Pelicano, K., Navarro, E., and Siahpush A., "Analytical Solutions for Inward Solidification of a Phase Change Material in a Cylindrical Coordinate System," Journal of the Utah Academy of Science, Arts, and Letters, 97, 205-215, 2020.

[7] Çengel, Y.A., and Ghajar, A.J., *Heat and Mass Transfer Fundamentals and Applications*, Fifth Edition, McGraw-Hill Education, New York, 2015.

Lumped Capacitance Method: Analytical and Experimental Evaluation

Collin Cutler, Kyler Reinhold, Owen Telford, Ali S. Siahpush

Southern Utah University

ABSTRACT

In this paper, a simple experiment was conducted to evaluate the limitation and validity of assumptions associated with the lumped capacitance method. This method evaluates temperature variations due to transient convection heat transfer. The experiment was conducted using a small aluminum cylinder, first placed into hot water, and then in cold water. The results of the experiment were compared with three different analytical approaches. These approaches are an incomplete response method, an τ approximation method, and a graphical $\frac{d\tau}{dt}$ method. The validity and limitations of the lumped method are then discussed. This study shows that the incomplete response method provides the best results.

NOMENCLATURE				
	Definition	Value/unit		
h	Heat transfer coefficient	$\frac{W}{m^2K}$		
As	Surface area	0.0030451 m ²		
ρ	Density of aluminum	2700 $\frac{\text{kg}}{\text{m}^3}$ [1]		
C_p	Specific heat of aluminum	896 <u>Ј</u> [1]		
V	Volume of aluminum	0.0000129 m ³		
L	Characteristic length of cylinder	0.004233881 m		
k	Thermal conductivity of aluminum	$167 \frac{W}{m K} [1]$		
Ż	Convection heat transfer	W		
Bi	Biot number			
τ	Time constant	Sec		
t	Time	Sec		

INTRODUCTION

Convection heat transfer is defined as the heat transfer between a surface and a fluid flowing in contact with it. The fluid can be a gas or a liquid, and the fluid can be removing or adding heat to the surface. The overall heat transfer, $\dot{Q}_{\rm conv}$, depends on the surface area, surface and ambient temperature, flow rate of the fluid, and the convection heat transfer coefficient. The surface area, flow rate, and temperature can be measured directly, but the convection heat transfer coefficient is empirically evaluated through experimentation. This paper discusses three methods to evaluate the convection heat transfer coefficient from experimental data. The three methods are an incomplete response method, a τ approximation method, and a graphical $\frac{d\tau}{dt}$ method.

EXPERIMENT

For the experiment, multiple aluminum cylinders (0.02538-m height and 0.02545-m diameter) were constructed with a 2-mm diameter and 0.75-cm-deep holes drilled in the center. A thermocouple was inserted into the holes and sealed with silicon as shown in Figure 1. These cylinders (at room temperature, 21°C) were then placed into a large container of water at 85°C while the temperature was recorded. After the steady state was reached (approximately 78°C), the cylinders were then removed and place into a large container of water at

approximately 3°C until a steady state temperature was achieved. The initial temperature of the cylinder for cooling was approximately 70°C.



Figure 1. Experiment cutaway for the experiment.

INCOMPLETE RESPONSE METHOD

In this section, the lumped method [1] is proposed for the temperature change of the aluminum cylinder. The lumped method assumes that the cylinder temperature is uniform throughout the cylinder. This assumption is validated in this section.

To evaluate the temperature profile of the aluminum cylinder, the first law analysis was calculated as [1]

$$A_{s}h(T_{\infty} - T(t)) = \rho c_{p} V \frac{dT}{dt}$$
⁽¹⁾

where A_s is the surface area of the cylinder (m²), h is the convection heat transfer coefficient ($\frac{W}{m^2\kappa}$), T_{∞} is the ambient temperature (°C), T(t) is the cylinder temperature (°C) as a function of time (sec), ρ is the density of cylinder (kg/m³), c_p is the heat capacity of aluminum, V is the volume of the cylinder (m³), and $\frac{dT}{dt}$ is the change of temperature with respect to time.

With the initial temperature of T(t=0), the first order, ordinary differential equation may be solved. The result is the lumped method temperature profile of the cylinder [1]

$$\frac{T(t) - T_{\infty}}{T_i - T_{\infty}} = e^{-(\frac{A_s h}{\rho c_p V})t}$$
(2)

where t is time (sec). To meet the requirement of the lumped method, the Bi (Biot) number has to be constant and less than 0.1. The Bi number is defined as [1]

$$Bi = \frac{hV}{kA_s}$$
(3)

where k is the thermal conductivity of cylinder (W/m·K). The time constant (τ) is defined as [1]

$$\tau = \frac{\rho c_p V}{A_s h} \tag{4}$$

Note that a small value of the time constant indicates that the cylinder will approach the ambient temperature in a short time. Substituting Eq. (4) into Eq. (2) yields

$$\frac{T(t) - T_{\infty}}{T_i - T_{\infty}} = e^{-\frac{t}{\tau}}$$
⁽⁵⁾

For the lumped method to be valid, τ also has to be constant. Considering this assumption, the only variable in Eq. (5) is T(t). The experimental data are presented in Figure 2. This figure shows how the cylinder temperature increased rapidly, and then after approximately 50 seconds, the slope significantly decreased.



Figure 2. Incomplete response method analysis for heating.

Taking the natural log of Eq. (5) gives

$$\ln\left(\frac{T(t)-T_{\infty}}{T_{i}-T_{\infty}}\right) = -\frac{t}{\tau}$$
(6)

As indicated earlier, τ is constant for the lumped method. If from the experimental data, values of T(t) with the corresponding time (t) are substituted in Eq. (6), the result is many τ values. It makes sense to choose the τ value where the slope of the experimental results (T) is the steepest and has the least changes with respect to time. The steepest slope is between T_{∞} and T_i, approximately at 50°C, halfway between T_{∞} and T_i. Define P^{*} as the logarithm of the incomplete response (proportionality limit) [2]. This logarithm of the incomplete response corresponds to T^{*}(t^{*}) as

$$P^* = \frac{T^*(t^*) - T_{\infty}}{T_i - T_{\infty}} = e^{-\frac{t}{\tau}}$$
(7)

Rearrange this equation to have $T^*(t^*)$ as

$$T^{*}(t^{*}) = T_{\infty} + p^{*}(T_{i} - T_{\infty})$$
 (8a)

or

$$T^*(t^*) = T_i + p^*(T_{\infty} - T_i)$$
 (8b)

This equation may also be presented as

$$\tau = -\frac{t^*}{\ln\left(1-p\right)}\tag{9}$$

In Eq. (8), T_i (21.2°C) and T_∞ (78°C) are experimentally evaluated. If we assume p*=50%, then T*(t*) is 49.6°C. At this temperature, from the data, t* is 21.29 seconds. Substituting these two values into Eq. (9) gives the τ of 22.126 seconds.

Now, we have the constant τ value. Using this value with T_i and T_{∞} values, marching through time, T(t) may be predicted. The same approach is taken for p* of 63.2%. This value is based on the mathematics of exponential decay associated with first-order systems (such as our system). If the response starts at unity (t=0), then after one "unit of time," the response is e^{-1} =0.36788. When we are looking at a rise time (one unit of time), this is subtracted from unity, giving 0.63212 or 63.2%.

This percentage may also be shown mathematically, as we assume at T^* , t^*/τ is equal to one. Considering this assumption, we can demonstrate

$$\frac{T^*(t^*) - T_{\infty}}{T_i - T_{\infty}} = e^{-\frac{t^*}{\tau}} = e^{-1} = 0.367$$
(10)

Rearranging this equation gives

$$T^{*}(t^{*}) = T_{i} + p^{*}(T_{\infty} - T_{i})$$
(11)

Comparing Eqs. (10) and (11) with Eq. (8b) shows that p^* is 63.2%. Figure 2 also presents the results of the predictions for the heating case. Results for p^* for heating and cooling are presented in Table 1. As can be seen, the results for 50% and 63.3% are very close to each other, and in both cases, the calculated Bi numbers are less than 0.1. This validated the lumped method assumption.

Table 1. Parameters from the predicted values of τ -heating and				
τ-cooling				
P*	T [*] (° C)	t [*] (sec)	τ (sec)	
Heating				
50%	57.09	21.29	21.29	
63.2%	49.60	15.33	22.12	
Cooling				
50%	28.09	24.57	24.57	
63.2%	37.10	16.80	24.24	

From the mathematical model, Eq. (6), and an estimated value of τ , the predicted values of T(t) may be evaluated over the range of time (t). The predicted temperatures using these two values of τ are also presented in Figs. 2 (above) and 3. These figures show that predicted values are very close to the experimental results.



Figure 3. Incomplete response method analysis for cooling.

After the heating experience, the aluminum cylinder was placed into the cooler with water and ice at approximately uniform temperature of 3°C. The initial temperature of the cylinder was approximately 70°C. Following the same analysis as presented in the heating section, the result is shown in Figure 3 (above). After 50 seconds, the predicted values diverged from the experimental values. Studying the experimental data reveals that the experiment was terminated when temperature of the cylinder was recorded to be $7.2^{\circ}C$ (slow change of temperature).

The measured and the predicted temperature profiles are much more in agreement in the heating case than the cooling case. The heating and cooling curves qualitatively are similar and validate the lumped method assumption. The results of the cooling experiment are presented in Table 1. Because the experiment was terminated early, the error is much higher than the heating experiment as expected. Nevertheless, the results are valid and validate the lumped method approach.

τ APPROXIMATION METHOD

In this section, we used the "guess and check method" to find an accurate value for τ . Because τ is a constant value, it does not make sense to graph the value of τ as time changes. Instead, the experimental data was compared with a calculated temperature value. Solving Eq. (5) for T(t) yields

$$T(t) = T_{\infty} + e^{-\frac{t}{\tau}}(T_i - T_{\infty})$$
⁽¹²⁾

In this equation, the only unknowns are T(t) and τ . A value for τ will be predicted and T(t) will be evaluated. The value for τ will be changed until the predicted and experimental values of temperatures match as closely as possible. An error % was also calculated to establish how close the temperatures are over the entire time domain.

After the suitable value of τ is determined, the heat transfer coefficient, h (W/m²·K), from Eq. (4), can be expressed as

$$h = \frac{\rho c_p V}{\tau A_s} \tag{13}$$

By using the τ that was evaluated using the predict and check method, the value for h was then determined. This method was performed for both the heating and cooling of the aluminum cylinder.

In Table 2, the τ prediction for the heating experiment is closer to the experimental value. The error percent is almost zero. Figure 4 presents temperatures that are consistently close to the experimental values. Figure 5 shows that the predicted values of T(t) diverge from the experimental values at approximately 35 seconds.

Table 2. τ approximation method results				
Parameters	$\tau\left(\frac{1}{s}\right)$	$h\left(\frac{W}{m^2K}\right)$		
Heating	18.0	635.4		
Cooling	21.0	544.7		



Figure 4. τ approximation method for heating.



Figure 5. τ approximation method for cooling.

The values of τ that were found for heating and cooling experiments are similar, as expected. The value of τ is also related to h, which in turn is dependent on the material type and size of the cylinder, so the values should be close to each other.

The error percent for the predicted cold temperatures are further off, as shown in Figure 5. When the cylinder temperature is close to steady state, the calculated temperature starts to diverge away from the temperatures measured experimentally. As explained earlier, the lumped method is valid for transient convection heat transfer and, close to steady state, the validity of this method diminishes. The calculated data are ending close to the ambient temperature value whereas the actual temperature is about 5°C higher. The predicted Biot number is in the range that an aluminum cylinder is predicted to be, well under 0.1.

GRAPHICAL $\frac{d\tau}{dt}$ APPROXIMATION METHOD

In this section, it was assumed that time constant, τ , is constant throughout the entire experiment (as dictated by the lumped method). This section describes how the time constant was calculated.

The first step in this analysis is to discard the irrelevant data gathered from the experiment. The data imported are the temperature of the cylinder at one-second intervals. When the cylinder was placed in hot or cold water, the temperature change is greatest at the initial time. The heat exchange between the water and the cylinder slows down when the cylinder temperature approaches the water temperature. To define when the experiment starts, we located the greatest change of temperature and deleted all previously collected data. To define when the experiment ends, the data were deleted once the change of slope was within $\pm 0.1 \frac{dT}{dt}$. Initially, different slope tolerances were used, but 0.1 removed the unnecessary data the best. If a larger number was used, too many data points would be removed; if a smaller number was used, too many unnecessary data would be available.

After defining the beginning and the end of the experiment, the convection heat transfer coefficient was calculated for each temperature at that time. Starting from Eq. (5), and rearranging Eq. (6) yields

$$\tau = \frac{\rho V c_p}{h A_s} = \frac{-t}{\ln\left(\frac{T_{(t)} - T_{\infty}}{T_i - T_{\infty}}\right)}$$
(14)

Solving for h gives the final equation for h

$$h = \frac{\ln\left(\frac{T_{(t)} - T_{\infty}}{T_i - T_{\infty}}\right)\rho V c_p}{-tA_s}$$
(15)

The time constant and h were calculated for each point of time using Eqs. (14) and (15), respectively. The slope of τ , $\frac{d\tau}{dt}$, at each point was calculated and analysis was performed to verify whether $\frac{d\tau}{dt}$ was between -0.1 and 0.1. Once having an array of all instances where $\frac{d\tau}{dt}$ is between ±0.1, the average was taken and that was the final τ of the experiment. Similar to trimming the data, it was found that ±0.1 provided the best result.

After finding τ of the experiment, linear approximation was used to approximate the corresponding final time constant (Fourier number). Using this time and value for τ , the convection heat transfer coefficient, *h*, was calculated. The results are presented in Table 3.

Table 3. Graphical $\frac{d\tau}{dt}$ method results			
Parameters	$\tau\left(\frac{1}{s}\right)$	$h\left(\frac{W}{m^2K}\right)$	
Heating	14.30	716.29	
Cooling	19.20	533.44	

Next, the theoretical temperature of the aluminum cylinder was calculated using the final Fourier number calculated from the experimental data earlier. The temperature versus time plots of the experiment and theoretical for heating and cooling are shown in Figs. 6 and 7.

COMPARING THE METHODS

The summary of the results is presented in Table 4. The method that produced the most accurate τ and h is the incomplete response method using p = 0.633. This was chosen because both for heating and cooling, the experimental and theoretical temperature versus time plots closely resemble each other.



Figure 6. Graphical $\frac{d\tau}{dt}$ method for heating.



Figure 7. Graphical $\frac{d\tau}{dt}$ method for cooling.

Table 4. Summary of the results								
Analysis	Incomplete Response		τ Approximation		Graphical $\frac{d\tau}{dT}$		Average	
Method	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Convection Heat Transfer Coefficient, h, $\left(\frac{W}{m^2k}\right)$	481.16	416.99	635.4	544.7	716.29	533.44	610.95	498.37
Fourier's Number τ , (s)	21.30	24.41	18.0	21.0	14.30	19.20	17.86	21.53

For both the τ approximation and the graphical $\frac{d\tau}{dT}$ methods, the theoretical cooling plots diverged from the experimental data around 30 seconds into the experiment. The reason for this discripancy is that the approximations of τ is not as accurate as with the incomplete response method.

CONCLUSION

This experiment was simple and very cost effective. It introduced different mathematical methods to predict the behavior of the system and how to compare them with the experimental results. It can be used in an undergraduate lab when the topic is transient conduction.

In conclusion, all three methods show merit. The incomplete response method was the most accurate because of its consistency across both heating and cooling. All three methods can be used to predict the temperature of the cylinders, although all three methods deviated from the experimental data at the beginning and the end of the experiment. This shows that these methods are most useful when the change in temperature with respect to time is the most consistent.

REFERENCES

[1] Çengel, Y.A. & Ghajar, A.J. *Heat and Mass Transfer*. Fifth Edition, McGraw-Hill Education, New York, 2015.

[2] Rose Hulman Institute of Technology. *Experimental testing: Is a system really first-order?* Retrieved January 20, 2020, from https://www.rose-hulman.edu/ES205/PDFs/lab07_incompl_response.pdf.

Effectiveness of Plane Wall Radiation Shielding

Collin Cutler, Owen Telford, Cierra M. Salcido, Rebekah Yamashita, Ali Siahpush

Southern Utah University

ABSTRACT

The concept of a radiation shield is to reduce the thermal radiation heat transfer by using materials whose surfaces have high reflectivity and low emissivity. This experiment replicates thermal radiation shielding by placing two identical steel plates parallel to each other and heating one of the steel plates with heating pads. After recording the temperature of each steel plate, a reflective aluminum plate was placed between the steel plates to shield one of the plates from thermal radiation generated by the heating pads. Heat transfer analysis was performed to calculate the theoretical temperatures of the steel plates The experimental and analytical temperature difference of the steel plates was 1.15% different with no shielding and 13.78% with shielding. The experimental heat transfer rate was significantly greater than the theoretical, meaning the experiment required more heat to maintain the final temperatures of the steel plates.

NOMENCLATURE				
Symbol	Definition (Unit)	Value		
As	Surface area	m^2		
<i>F</i> _{1,2}	View factor			
R	Electrical resistance	Ω		
T_1	Temperature of front plate	Κ		
T_2	Temperature of back plate	K		
$\dot{Q}_{ m shield}$	Heat transfer rate	W		
$\dot{Q}_{ m no\ shield}$	Heat transfer rate	W		
ε_{Al}	Emissivity of aluminum plate	0.19 4		
\mathcal{E}_{St}	Emissivity of steel plate	0.66 [1]		
σ	Stefan-Boltzmann constan	$5.67 \times 10^{-8} \frac{W}{m^2 K^2}$		

INTRODUCTION

Recent graduate engineering students are unfamiliar with the concepts and processes of real engineering practice. Applying and understanding real-world engineering processes and comparing them with the theoretical predictions are crucial for students' transition to professional engineers. The contributing author, Siahpush, has decades of experience as a professional engineer and educator. He has seen many graduating students who lack the skills necessary for real-life engineering problems. Therefore, he has emphasized the need for undergraduate research programs for his students with the hope they will conduct real-life engineering research, learn to solve problems with minimum guidance, and have experience in working with a diverse group of people.

To contribute to Southern Utah University's (SUU) undergraduate research program and gain vital real-world experience, we conducted a heat transfer experimental analysis of thermal radiation between two parallel steel plates. Once this task was complete, an aluminum shield was added between the two steel sheets to study the effect of the radiation shield and the radiation heat transfer rate from one steel sheet to the other. In the heat transfer analysis, we assumed no other forms of heat transfer such as convection and conduction in the plates by developing an experimental design to justify these assumptions [2]. Because of the surface properties of an aluminum sheet, we predicted the amount of heat transfer from one steel plate to the other would decrease when the aluminum shield was in place, and furthermore, that aluminum, because of its surface properties, is an effective shield for thermal radiation [3].

EQUIPMENT/MATERIALS

- Wood planks
- Wood spacer (×8)
- Clamp (×2)
- $24 \times 24 \times .019$ -in steel plate ($\times 2$)
- 24×24×.019-in aluminum plate
- 200×200-mm heating pads (×4)
- Thermocouple (×4)
- Timer
- Tape
- Data logger
- 1-in solid foam insulation

HEAT TRANSFER ANALYSIS

Radiation heat transfer depends on many factors. These factors include the distance between two surfaces, the difference in the size of surfaces, how two objects see each other (view factor), the temperatures of the plates, and the surface conditions. These are then used to determine how much of the radiation transfers from one body to the next.

In this experiment, we attempted to use a view factor of approximately 1 by setting up all plates parallel to one another and using plate surface dimensions (length by width) that were much larger than the distance between plates as seen in Figure 1. This setup ensured that plates saw only each other (infinite plates) The view factor for the plates were evaluated first by discussing the geometry.



Figure 1. Side profile of experiment.

The view factor for two parallel plates, *i* and *j* is defined as [4]

$$F_{i \to j} = \frac{\left[(W_i + W_j)^2 + 4\right]^{1/2} - \left[\left(W_j - W_i\right)^2 + 4\right]^{1/2}}{2W_i} \tag{1}$$

where W_i is defined as $W_i = \frac{w_i}{L}$ and $W_j = \frac{w_j}{L}$ with w_i and w_j being the width of plate *i* and *j*, and *L* being the distance between the two plates (Fig. 2).



Figure 2. Parallel plate view factor.

For this experiment, the width of all the plates will be the same, so the equation is simplified

$$F_{i \to j} = \frac{[W^2 + 1]^{1/2} - 1}{W}$$
(2)

Using the plates' dimensions, the view factor for no shielding $(F_{1,2})$ was 0.9875 and those for shielding were 0.9938 for $F_{1,3}$ and 0.9937 for $F_{3,1}$. Two view factors were calculated for the experiment with shielding because the distance between plates 1 and 3 did not match the distance between plates 2 and 3. This was due to the thickness of each spacer not being identical.

After the view factor has been calculated, the heat transfer rate can be evaluated. A control volume is considered around the two outer steel plates. The heat transfer between the outer steel plates can be represented with thermal resistance as presented as [4]

$$\dot{Q}_{1,2} = \frac{\sigma(T_1^4 - T_2^4)}{R_T} \tag{3}$$

where σ is the Stefan-Boltzmann constant $(\frac{W}{m^2K^4})$, T_1 is the temperature of the front surface (K), T_2 is the temperature of the back surface (K), and R_T is the total thermal resistance of the system. There are two

thermal resistances with radiation: surface resistance and space resistance. Surface resistance is defined as [4]

$$R_{Surface} = \frac{1 - \varepsilon_i}{A_i \varepsilon_i} \tag{4}$$

where ε_i is the emissivity of the surface and A_i is the surface area (m²). The space resistance to radiation is presented as [4]

$$R_{space} = \frac{1}{A_i F_{i,j}} \tag{5}$$

where $F_{i,j}$ is the view factor from surface *i* to surface *j*. For two plates, 1 and 2, with no shielding, the total thermal resistance from plate 1 to plate 2 is

$$R_T = \frac{1 - \varepsilon_1}{A_1 \varepsilon_1} + \frac{1}{A_1 F_{1,2}} + \frac{1 - \varepsilon_2}{A_2 \varepsilon_2} \tag{6}$$

where $F_{1,2}$ is the view factor from plate 1 to plate 2, ε_1 is the emissivity of plate 1, ε_2 is the emissivity of plate 2, A_1 is the surface area of plate 1, and A_2 is the surface area of plate 2. When plate 1 and plate 2 have the same emissivity and surface area, the total thermal resistance simplifies to

$$R_T = \frac{2(1-\varepsilon_1)}{A\varepsilon_1} + \frac{1}{AF_{1,2}} \tag{7}$$

Substituting the total thermal resistance from Eq. (7) into Eq. (3) yields the total heat transfer rate between two identical plates.

$$\dot{Q}_{1,2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{2(1 - \varepsilon_1)}{A\varepsilon_1} + \frac{1}{AF_{1,2}}}$$
(8)

When a third, thin surface is placed in between the two outer plates, there is additional thermal resistance added to the system. This result is a total resistance as

$$R_T = \frac{1 - \varepsilon_1}{A_1 \varepsilon_1} + \frac{1}{A_1 F_{1,3}} + \frac{1 - \varepsilon_{3,1}}{A_3 \varepsilon_{3,1}} + \frac{1 - \varepsilon_{3,2}}{A_3 \varepsilon_{3,2}} + \frac{1}{A_1 F_{3,2}} + \frac{1 - \varepsilon_2}{A_2 \varepsilon_2}$$
(9)

where ε_1 is the emissivity of plate 1, ε_2 is the emissivity of plate 2, $\varepsilon_{3,1}$ is the emissivity of plate 3 facing plate 1, $\varepsilon_{3,2}$ is the emissivity of plate 3 facing plate 2, A_1 is the surface area of plate 1, A_2 is the surface area of plate 2, A_3 is the surface area of plate 3, F_1 is the view factor from plate 1 to plate 3, and $F_{3,2}$ is the view factor from plate 3 to plate 2. Because the emissivity of plate 3 is the same on both sides, and the area is the same for all plates, the total resistance reduces to

$$R_T = \frac{1}{A} \left[\frac{2(1 - \varepsilon_{1\&2})}{\varepsilon_{1\&2}} + \frac{1}{F_{1,3}} + \frac{2(1 - \varepsilon_3)}{\varepsilon_3} + \frac{1}{A_1 F_{3,2}} \right]$$
(10)

where ε_3 is the emissivity of plate 3. Substituting Eq. (10) into Eq. (3) yields the final equation

$$\dot{Q}_{1,2} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1}{A} \left[\frac{2(1 - \varepsilon_{1\&2})}{\varepsilon_{1\&2}} + \frac{1}{F_{1,3}} + \frac{2(1 - \varepsilon_3)}{\varepsilon_3} + \frac{1}{A_1 F_{3,2}} \right]}$$
(11)

Equation (8) can be rearranged to solve for the temperature of the back plate, T_2 . For two plates that have no shielding between them, the temperature of the back plate, T_2 is represented by

$$T_{2} = \left[T_{1}^{4} - \frac{\dot{Q}_{1,2}}{\sigma A} \left(\frac{2(1-\varepsilon_{1})}{\varepsilon_{1}} + \frac{1}{F_{1,2}}\right)\right]^{\frac{1}{4}}$$
(12)

If there is a plate that is shielding radiation from plate 1 to plate 2, then rearranging Eq. (11) yields

$$T_2 = \left[T_1^4 - \frac{\dot{Q}_{1,2}}{\sigma A} \left(\frac{2(1 - \varepsilon_{1\&2})}{\varepsilon_{1\&2}} + \frac{1}{F_{1,3}} + \frac{2(1 - \varepsilon_3)}{\varepsilon_3} + \frac{1}{A_1 F_{3,2}}\right)\right]^{\frac{1}{4}}$$
(13)

Equations (8), (11), (12), and (13) were used to calculate the temperature and heat transfer rate.

CIRCUIT ANALYSIS

To calculate the theoretical temperature of the backplate, T_2 , the heat transfer rate, $\dot{Q}_{1,2}$ needs to be calculated. This experiment uses four heating pads wired in two parallel as shown in Figure 3.

The resistance of each heating pad is represented by R_{HP} , the current generated from the power supply is I_{Sup} , and the power supply voltage is V_{Sup} . Using Kirchhoff's current law [5] at node A, we get

$$I_{Sup} - I_1 - I_2 = 0 (14)$$



Figure 3. Wiring of heating pads.

where I_1 and I_2 are the currents going through rung 1 and 2. Because the R_{HP} are equal, the current going through each rung of the parallel circuit is the same ($I_1 = I_2$). Then, I_2 may be presented as

$$I_2 = \frac{I_{Sup}}{2} \tag{15}$$

A single rung of the parallel circuit is shown in Figure 4.



Figure 4. Single rung of heating pad circuit.

To calculate the voltage drop across a single heating pad, $V_{\text{HP}},$ Ohm's law [5] was used as

$$V_{HP} = V_{Sup} - \frac{I_1}{R_{HP}} \tag{16}$$

Electric power is defined as [5]

$$P = VI \tag{17}$$

where V is voltage (V), and I is the current (A). Substituting the V_{HP} from Eq. (18) and I₁ from Eq. (17) results in

$$P_{HP} = \left(V_{Sup} - \frac{I_1}{R_{HP}}\right) \frac{I_{Sup}}{2} \tag{18}$$

where P_{HP} is the power generated by a single heating pad (W). Assuming no loss of power in the wires, the power generated by the heating pad is fully converted to heat. Thus, the heat transfer of a single heating pad is equal to the power generated by a single heating pad as shown as

$$\dot{Q}_{HP} = \left(V_{Sup} - \frac{I_1}{R_{HP}}\right) \frac{I_{Sup}}{2} \tag{19}$$

It should be noted that the heating pads were distributed evenly across the front plate, resulting in a total heat transfer equal to the heat transfer generated by a single heating pad.

RESULTS AND DISCUSSIONS

Figure 5 displays the temperature versus time graph for plates 1 and 2 as well as the final temperature of each plate with and without shielding. Table 1 summarizes the experimental and theoretical final temperature of steel plate 2 for both tests with and without shielding. The theoretical temperatures were calculated with Eq. (13) using the temperature of plate 1 and the heat transfer rate calculated in Eq. (19).



Figure 5. Temperature of front and back plates with and without shielding.

Table 1. Steel plate 2 temperature results					
	Experimental Theoretical % Error				
Temperature with					
no shielding (K)	313.95	310.32	1.15%		
Temperature with					
shielding (K)	311.50	268.57	13.78%		

Table 2 displays the experimental and theoretical heat transfer rates of the experiment with and without shielding. The theoretical heat transfer rate was calculated using Eq. (8) and the final temperatures of plate 1 and plate 2 from each test.

Table 2. Heat transfer rate results					
Experimental Theoretical % Error					
$\dot{Q}_{ m no \ shield}$ (W)	9.77	5.71	41.53%		
$\dot{Q}_{ m shield}$ (W)	9.77	2.09	78.56%		

Figure 5 shows that the temperature of the back plate was greater with the shield than without shielding. This is due to radiation reflecting off the middle shielding plate and going back to the front plate. This is evidence that the aluminum sheet is shielding the back steel plate from radiation.

For both tests, the theoretical heat transfer rate required to maintain T_1 and T_2 was much less than the actual heat generated by the heating pads. This means the experiment needs more heat transfer from the heating pads than was theoretically required to heat the back plate to the final experimental temperature, T_2 . The greater heat transfer rate measured from the experiment contributed to the difference in theoretical and experimental temperature of the back plate.

The test with shielding had the greatest difference between the experiment and theoretical values. The value for the emissivity of aluminum affected the theoretical values for T_2 and $\dot{Q}_{no \ shield}$. Many sources list the emissivity for various surfaces. Finding an emissivity that represented the aluminum sheet was difficult. If the selected emissivity was too small, the calculation of T_2 would not be possible due to the fourth root.

SOURCES OF ERROR

In this experiment, only radiation heat transfer was considered because the plates were only 7 mm apart from one another. Alternatively, if the plates were too far apart, convection heat transfer should have been considered as well. In the thermal radiation analysis, the considered distance between the plates was deemed large enough to make conduction heat transfer negligible, but also small enough to neglect convection heat transfer through the air. However, these assumptions can lead to error because the heat from the heating element could dissipate in the air. The results may be skewed because of small amounts of heat loss via convection heat transfer.

Although the experiment was conducted in an isolated room where the ambient temperature was constant, it is difficult to prevent all heat transfer from the environment to the system. As a result, energy will not be perfectly conserved within the system. We expected the experimental results would differ slightly from the theoretical results because of a small amount of heat loss through the air, which was assumed to be negligible in the heat transfer analysis. These issues could be minimized if the experiment were conducted within a vacuum.

CONCLUSION

To improve future experiments, the sides of plates facing the room need to be insulated to avoid heat transfer between plates and surroundings. Another improvement would be to perform the experiment with higher voltage and current through the heating pads to increase the temperature of the front steel plate. The increase of temperature would result in a greater radiation heat transfer because the temperature of the plates would be raised to the fourth power while the temperature for convection would not. An additional improvement would be to create a vacuum around the system. Removing air from the system will prevent heat loss by convection from the surrounding air. The last suggestion to improve future experimentation is to use spacers around the border of each plate. This would allow the distance between the plates to be uniform to produce uniform radiation. Using additional spacers with the same width as the aluminum plate should be considered to make sure the distance between the steel plates is the same in all trials of the experiment.

REFERENCES

[1] Transmetra. *Table of Emissivity of Various Surfaces*. 1999, Retrieved January 20, 2020, from https://www.transmetra. ch/component/jifile/download/NjEyOGJhN2M4YTNkZDNmN2ExMz hmODBkOGJiNmI3NmE=/emissivity-table-pdf. [2] Viskanta, R., "Effectiveness of a layer of an absorbingscattering gas in shielding a surface from incident thermal radiation," Journal of the Franklin Institute, 280 (6) pp. 483-492, 1965.

[3] Cheung, C.S., "Shielding Effectiveness of Superalloy, Aluminum, and Mumetal Shielding Tapes," Master's thesis, California Polytechnic State University, 2009.

[4] Çengel, Y.A. & Ghajar, A.J., *Heat and Mass Transfer, Fifth Edition*, McGraw-Hill Education, New York, 2015.

[5] Nilsson, J.W., and Riedel, S.A., *Electric Circuits, Eleventh Edition*, Pearson, New York, 2019.
Cost-Effective Solar Water Heater

Kyler A. Reinhold, Omar R. Campos, Noah A. Mollner, Aaron J.G. Dockins, Ali S. Siahpush

Southern Utah University

ABSTRACT

Hot water has been used around the world for centuries for bathing, medical purposes, cleaning, and cooking. In today's society, the source that is used to heat water is typically a water heater that utilizes a nonrenewable energy source to heat the water. In this paper, a passive solar-powered water heater was constructed and tested to verify whether the sun's energy can be an alternative source of energy in locations where other options are limited. Before testing, a solar water heater was constructed, and heat transfer theoretical values were predicted. The theoretical values were then compared with the experimental results. The theoretical water temperature values were much higher than the actual experimental temperature, but the overall water temperature still increased to a comfortable temperature. Thus, the sun's radiation could be a potential alternative energy source under certain conditions.

NOMENCLATURE				
Symbol	Definition	Value/unit		
A _{s,t}	Surface area of the tank	m^2		
C _{p, W}	Specific heat of water	4180 J/kg·K 2		
$\Delta E_{\rm w}$	Change of internal energy of water	J		
m _w	Mass of water	kg		
Q	Heat	J		
$\dot{q}_{ m solar}$	Solar flux	W/m^2		
$\dot{q}_{ m s,t}$	Solar flux on the tank	W/m ²		
T _{Sky}	Effective temperature of the sky	270 K 2		
T _{s,t}	Temperature of the tank surface	Κ		
Tw	Temperature of water	Κ		
T_w^i	Temperature of water at time step	Κ		
T_{w}^{i+1}	Temperature of water at next time step	Κ		
$\alpha_{\rm b}$	Solar absorptivity of carbon black paint	0.96 [1		
Δt	Change in time	sec		
ε _b	Emissivity of carbon black paint	0.88 [1		
σ	Stefan-Boltzmann constant	5.67×10 ⁻⁸ W/m ² ·K 2		
$\tau_{\rm g}$	Transmissivity of acrylic pane	0.88 2		

INTRODUCTION

One of the first notable advancements of utilizing solar energy occurred in the 1760s when scientist Horace-Benedict De Saussure built an insulated black box, covered the top with two panes of glass, and then pointed the box towards the sun. De Saussure noted that the temperatures inside this box reached temperatures higher than the boiling point of water and theorized his device had the potential to be useful. The potential of De Saussure's design was proven in 1891 when an American plumber Clarence Kemp created a box similar to De Saussure's design and placed a black water tank inside. Similar to De Saussure's experiment, the water in the tank was heated to a suitable temperature for bathing and dishwashing [3].

Today, heating water is responsible for a significant amount of energy use in many day-to-day activities. Some of these activities require the use of electricity or gas as sources to heat water. However, many countries around the world may not have convenient access to these sources. One alternative is a simple and cost-effective solar waterheating system. Solar water-heating systems use the sun's energy instead of electricity or gas to heat water. Sunlight strikes a storage container's surface where the heat is absorbed to warm the water. There are 4 types of solar water heating systems that can be used to heat water. The first is an active system, which utilizes a water collector outside of a facility from which water is pumped inside to a storage container once the water is heated to a specified temperature [4]. Another type is a passive system, which uses natural convection to circulate the heated water from a collector to storage [4]. The third is a direct system that uses solar energy to directly heat the water inside a collector. The last is an indirect system that uses a heat transfer fluid inside the collector and a heat exchanger to transfer heat to the potable water source [4].

The costs, reliability, and performance of each system varies. Active solar water heaters tend to be more expensive and require more maintenance based on the use of a pump. Although the active systems tend to be more expensive, the performance is typically the most efficient, because the pump actively circulates the heated water. Passive systems tend to have less maintenance and cost less than active systems. Because the passive system does not use a pump to actively circulate the water, it will tend to have lower efficiency than the active system. The direct solar water heater is the simplest of solar water-heating systems and therefore the most reliable, the least expensive, and the least efficient [5]. Indirect solar water heaters are complicated because of the use of two different fluids exchanging heat. The trade-off for the complication is efficiency because of the radiator circulating the fluid [6, 7].

For this experiment, a direct heating system was constructed similarly to De Saussure's design. This particular solar water heater design was selected because of the overall simplicity and the materials that are needed for construction are affordable. The box was assembled using acrylic and sanded plywood painted black. The base and back side of the box was plywood and the remaining sides were acrylic as seen in Figure 1. After the system was assembled, the initial temperature and final temperatures of the water were predicted and experimentally validated.



Figure 1. Surface and cross-sectional views of direct solar water heater.

THEORY

Applying the first law of thermodynamics, a governing equation for the temperature of the water can be derived. The first law of thermodynamics may be expressed as

$$\Delta E_{\rm w} = \Sigma Q_{\rm in} - \Sigma Q_{\rm out} \tag{10}$$

$$\Delta E_{\rm w} = Q_{\rm solar,in} - Q_{\rm rad,tank} \tag{11}$$

where ΔE_w is the change in internal energy of the system (J), ΣQ_{in} is the total heat entering the system (J), and ΣQ_{out} is the total heat leaving the system (J). As shown in Eq. (2), heat transfer has the two modes for the system. These are the solar energy entering the system and the hot water radiating back out into the atmosphere (J). To simplify Eq. (11), any convection or greenhouse effects due to the trapped air between the sidings and the tank were not considered. Eq. (2) may be expanded to express the change in internal energy, solar flux, and radiation 2 as

$$m_w C_{p,w}(T_{2w} - T_{1w}) = \dot{q}_{s,t} A_{s,t} \Delta t - \varepsilon_b \sigma A_{s,t} \Delta t (T_{s,t}^4 - T_{sky}^4)$$
(12)

where m_w is the mass of the water in the tank (kg), $C_{p,w}$ is the specific heat of water, 4180 J/kg·K 2, T_{2w} and T_{1w} are the temperatures (K) of the water in its final and initial state, respectively, $\dot{q}_{s,t}$ is the solar flux that will reach the tank (W/m²), $A_{s,t}$ is the total surface area of the tank (m²), Δt is the total time (s), ε_b is the emissivity of a carbon black surface, 0.88 [1], σ is the Stefan-Boltzmann Constant, 5.67×10⁻⁸ W/m²·K [2], $T_{s,t}$ is the temperature of the tank's surface (K), and T_{sky} is the effective temperature of the sky, 270 K 2.

As the solar energy passes through the acrylic, some of it is absorbed while some is transmitted through the acrylic (Fig. 2). The relationship between the solar flux from the sun and the solar flux that reaches the tank can be expressed as

$$\dot{\mathbf{q}}_{\mathrm{s},\mathrm{t}} = \dot{\mathbf{q}}_{\mathrm{s}} \boldsymbol{\tau}_{\mathrm{g}} \boldsymbol{\alpha}_{\mathrm{b}} \tag{13}$$

where $\dot{q}_{s,t}$ is the total amount of solar flux from the sun that will reach the tank's surface (W/m²), \dot{q}_s is the total amount of solar flux that enters the system from the sun (W/m²), τ_g is the transmissibility of the acrylic, 0.88 2, and α_h is the absorptivity of the carbon black tank, 0.96 [1.



Figure 2. Diagram of solar flux that reaches the tank.

Substituting Eq. (13) into Eq. (12) and then solving Eq. (12) for $T_{\rm 2}$ yields

$$T_{2w} = \frac{A_{s,t} \Delta t(\dot{q}_{s} \tau_{g} \alpha_{b} - \varepsilon_{b} \sigma (T_{s,t}^{4} - T_{sky}^{4})}{m_{w} C_{p,w}} + T_{1w}$$
(14)

Assuming that $T_s = T_w$ yields

$$T_{2w} = \frac{A_{s,t}\Delta t(\dot{q}_s \tau_g \alpha_b - \varepsilon_b \sigma (T_w^4 - T_{sky}^4)}{m_w C_{p,w}} + T_{1w}$$
(15)

Using Eq. (15), we can predict the temperature of the water in the tank.

EQUIPMENT

- Water source
- 10-gallon Rubbermaid BRUTE heavy-duty round trash can (https://www.amazon.com/Rubbermaid-Commercial-Products-FG261000RED-Heavy-Duty/dp/B01B19T5KY/ref= sr_1_5?crid=231C4YRVN9JT7&dchild=1&keywords=10%2 Bgallon%2Btrash%2Bcan&qid=1602693214&sprefix=10%2 Bgallon%2B%2Caps%2C755&sr=8-5&th=1)
- 10-gallon Rubbermaid BRUTE heavy-duty round trash can lid (https://www.amazon.com/Rubbermaid-Commercial-Vented-Trash-Gallon/dp/B004MDM8LA/ref=sr_1_1?dchild= 1&keywords=rubbermaid+lid+10+gallon&qid=1602693306& sr=8-1)
- Two OPTIX 24×48×1/8 ¹/₈-in. acrylic sheets (https://www. homedepot.com/p/Falken-Design-36-in-x-36-in-x-1-8-in-

Thick-Acrylic-Clear-Sheet-Falken-Design-ACRYLIC-CL-1-8-3636/308669890

- One sanded 2 ft.×4 ft.× 1/2½-in. plywood sheet (https://www. homedepot.com/p/Sanded-Plywood-Common-1-2-in-x-2-ft-x-4-ft-Actual-0-451-in-x-23-75-in-x-47-75-in-300896/202093833)
- One 1/2 ¹/₂-in.×10 ft. Schedule 40 PVC plain end pipe (https://www.homedepot.com/p/1-2-in-x-10-ft-600-PSI-Schedule-40-PVC-Plain-End-Pipe-530048/100113200)
- Two 1/2 in. PVC Schedule 40 slip-joint × slip-joint ball valve (https://www.homedepot.com/p/Homewerks-Worldwide-1-2in-PVC-Schedule-40-Slip-Joint-x-Slip-Joint-Ball-Valve-VBVP40E3B/202370031)
- One 1/2 ¹/₂-in. PVC Schedule 40 S×S×S Tee (https://www. homedepot.com/p/Charlotte-Pipe-1-2-in-PVC-Schedule-40-Sx-S-x-S-Tee-PVC024000600HD/203812195)
- One 1/2 ¹/₂-in. PVC hose adapter (https://www.homedepot.com/ p/1-2-in-PVC-Hose-Adapter-10118H/100373234)
- Weld-On 4 acrylic adhesive with Weld-On applicator bottle with needle (https://www.amazon.com/Weld-Acrylic-Adhesive-Applicator-Bottle/dp/B0096TWKCW/ref=sr_1_4? dchild=1&keywords=acrylic+cement&qid=1602877542&sr=8 -4)
- Weld-On 700 PVC solvent cement, clear, low VOC, high strength (https://www.homedepot.com/p/Weld-On-Weld-On-700-PVC-Solvent-Cement-Clear-Low-VOC-High-Strength-Regular-Bodied-Fast-Setting-1-2-Pint-8-Fl-Oz-10081/202309206)
- Foam
- Loctite plastics bond
- Hot glue gun
- Hot glue gun sticks
- Two GE all purpose clear silicone all purpose caulk sealants
- One garden hose

RESULTS AND DISCUSSION

Eq. (15) may be modified to use in a finite difference MATLAB code as

$$T_{w}^{i+1} = \frac{A_{s,t}\Delta t(\dot{q}_{s}\tau_{g}\alpha_{b} - \varepsilon_{b}\sigma(T_{w}^{i^{4}} - T_{sky}^{4})}{m_{w}C_{p,w}} + T_{w}^{i}$$
(16)

where the superscript i denotes the current time step in the code. Using the solar flux data in Table A1, an hourly temperature of the water can be predicted. The MATLAB code prediction begins at 1:00 a.m. and runs for 24 hours with an initial water temperature of 280 K ($44.3^{\circ}F$)

Figure 3 is the MATLAB prediction and hourly solar flux data from Table A1 of the Appendix. Figure 3 shows that the predicted maximum water temperature will be 318.3 K (113.3°F) and will occur at 5:00 PM.



Figure 3. Theoretical water temperature and solar heat flux.

In this evaluation, we made three assumptions. Firstly, it was assumed that the temperature of the water was the same as the surface of the container. The second assumption was that the air trapped between the acrylic and the tank did not affect the system. The amount of heat that the trapped air absorbed can be considered small when compared with the amounts absorbed by the water, the tank, and the acrylic. Lastly, the geometry of the system was assumed to be flat, unlike the cubic geometry of the actual heater.

The tank was designed to maximize the potential temperature that the water could reach and maintain during daylight. Figure 4 shows the data from the thermocouples for the temperatures of the water, the surface of the tank, and the air in the enclosure.

188 Engineering



Figure 4. Test #1 water temperature, air temperature, and surface temperature vs. time.

The maximum temperatures and the time in the day throughout the experiment are shown in Table 2. The results of the test in Table 2 show that the water reached a temperature of 309.8 K (97.97°F). Before testing, a temperature of 308 K (95°F) was determined to be a comfortable temperature for use. This comfortable temperature was achieved and maintained from 2:40 p.m. to 5:10 p.m. and then began to decrease as the sun was setting.

Table 2: Maximum temperatures for test #1				
Thermocouple	Maximum temperature,	Time of day for maximum		
	K (° F)	temperature		
Water	309.80 (97.97°F)	3:40 p.m.		
Tank surface	348.05 (166.42°F)	1:40 p.m.		
Trapped air	335.45 (144.14°F)	2:00 p.m.		

The water temperature increased a total of 14.3 K throughout the test, from 295.5 K (72.23°F) to 309.8 K (97.97°F). This was not consistent with the increase in temperature of the surface of the tank. This means that the assumption for the predicted behavior where the temperature of the water and the surface of the tank was not quite accurate. This is shown in Figure 5 where the rate that the temperature of the water increased was not completely dependent on the temperature of the surface of the tank.



Figure 5. Theoretical water temperature vs. experimental water temperature.

The predicted temperature of the water at most times during the day was much higher than the actual values. The predicted maximum temperature of the water was $318.3 \text{ K} (113.27^{\circ}\text{F})$ while the test reached a maximum of $309.85 \text{ K} (97.97^{\circ}\text{F})$. The percent difference between the predicted and tested maximum temperatures is 19.7%.

SOURCES OF ERROR

Many variables have contributed to errors in this experiment. First, after the tank was filled with water, there were three small leaks. Two of the leaks were at each of the handle's points of contact between the lid and the trash can. The third leak was at the bottom outlet of the trash can. The water mass reduction in the tank caused less accurate correlation with the theoretical predictions.

Additionally, the water leakage caused small puddles to form within the acrylic box. Because of this, there was a high level of humidity in the box that created an accumulation of condensation on the acrylic walls. This condensation partially blocked the sunlight from entering the system.

Another source that could have impacted the data was the orientation of the system. For the device to receive the most direct sunlight, it would need to face south towards the sun; however, because of the way the heater was constructed, it had to be oriented in the southwest direction. Additionally, the test day was fairly cloudy, which is unusual when compared with the predicted solar flux.

CONCLUSIONS

The purpose of this experiment was to determine whether solar radiation from the sun could be a viable alternative energy source to heat water for countries that do not have access to electric or gas water heaters. Although the theoretical water temperature values were much higher than the actual experimental temperature values as seen in Figure 5, the water temperature still increased because of the solar radiation. There were many factors of error involved in this experiment that can account for the efficiency of the overall performance of the direct solar water-heating system. However, this experiment proved that under the correct conditions in future experiments, the direct solar water heating system could use the sun's thermal energy to heat water to a comfortable level.

RECOMMENDATIONS

Future tests could be improved by incorporating changes to the design and testing process. One change that would improve future experiments would be to use a container that is watertight. A watertight container would prevent the potential acquisition of major leaks, keep the volume of water consistent during the experiment, and prevent the accumulation of condensation on the acrylic walls. The loss of water can create an inconsistent reading of the thermocouples and introduce inaccuracies of the temperature measurements. Condensation can create a fog-like texture on the acrylic walls and prevent the full amount of solar heat flux from entering the system. A watertight sealed container would improve this experiment and reduce the overall error involved.

Another recommendation that could improve in future testing is to test the effects of having the system in or outside of an enclosure. There is currently not enough data to determine whether the acrylic enclosure heated the air enough to impact the results of the test.

ACKNOWLEDGMENTS

This project was made possible with the support of the Department of Engineering and Technology at Southern Utah University. Southern Utah University provided the funding and equipment required to complete this experiment. We would also like to thank the Utah NASA Space Grant Consortium for supporting this undergraduate research.

REFERENCES

[1] Johnson, D. "Absorptivity & Emissivity table 1 plus others." Retrieved on January 20, 2020, from http://www.redrok.com/concept. htm#emissivity.

[2] Cengel, Y.A., and Ghajar, A.J., *Heat and Mass Transfer, Fifth Edition*, McGraw-Hill, New York, 2015

[3] Perlin, J., "Workhorse of the solar industry." *Pacific Standard*. February 22, 2008; updated June 14, 2017. Retrieved on January 20, 2020, from https://psmag.com/environment/workhorse-of-the-solar-industry-4736

[4] Walker, A., "Solar water heating." *Whole Building Design Guide*. Updated November 16, 2016. Retrieved on January 20, 2020, from https://www.wbdg.org/resources/solar-water-heating

[5] House Energy, "ICS (Batch) solar water heaters are outdated." Retrieved on January 20, 2020, from https://www.house-energy.com/Solar/ICS.htm

[6] Ksenya, "Active solar water heating," *Solar Tribune*. July 7, 2011. Retrieved on January 20, 2020, from https://solartribune. com/active-solar-

energy/#:~:text=A%20direct%20circulation%20system%20 pumps,system%20is%20susceptible%20to%20freezing

[7] Office of Energy Saver, Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy. "Siting your solar water heating system," Retrieved on January 20, 2020, from https://www.energy.gov/ energysaver/siting-your-solar-water-heating-system

[8] Western Regional Climate Center, "Station frequency distribution/histogram. Station: St. George, Utah." Retrieved on January 20, 2020, from https://wrcc.dri.edu/cgi-bin/wea_freq.pl?utUSTG

APPENDIX

Table A1 presents the average hourly solar flux for November 5, 2020 [8]. It should be noted that sunrise was at approximately 7 a.m., and sunset was at 6 p.m. Table A2 shows the MATLAB code.

Table A1. Hourly solar flux				
Time	$\dot{\mathbf{q}}_{solar}\left(\frac{\mathbf{W}}{\mathbf{m}^2}\right)$			
1:00 a.m.	0			
2:00 a.m.	0			
3:00 a.m.	0			
4:00 a.m.	0			
5:00 a.m.	0			
6:00 a.m.	0			
7:00 a.m.	0.08			
8:00 a.m.	19.95			
9:00 a.m.	200.82			
10:00 a.m.	366.98			
11:00 a.m.	442.08			
12:00 p.m.	566.32			
1:00 p.m.	607.12			
2:00 p.m.	578.92			
3:00 p.m.	498.97			
4:00 p.m.	339.03			
5:00 p.m.	165.25			
6:00 p.m.	20.39			
7:00 p.m.	0			
8:00 p.m.	0			
9:00 p.m.	0			
10:00 p.m.	0			
11:00 p.m.	0			
12:00 a.m.	0			

```
Table A1: Hourly Prediction MATLAB Code
%Solar Water Heater Hourly Temperature Approximation
%HT Solar Water Heater
%Kyler Reinhold
clc
clear
%%Inputs
qdot_solar = load('HourlySolarFluxData.txt'); %Import solar flux
data (W/m^2)
qdot_solar = transpose(qdot_solar); %Transpose flux data
times = [1:1:24]; %Create time array
As c = (2*3.14*(0.396/2)*0.439)+(2*3.14*(0.396/2)^2); % surface
area of container (m^2)
dt = 3600; % Time the experiment ran (s)
T sky = 270; %Temp of sky (K)
Tw int = 296; %Initial temperature of water (K)
m_w = 37.78; %Mass of water (kg)
Cp w = 4182; %Cp of water (J/kg^*K)
alpha b = 0.96; %Absobtivity of black paint
epsilon b = 0.88; %Emissivity of black paint
tau g = 0.88; %Transmisibility of plexiglass
sigma = 5.67*10^-8; %Stefan-Boozman Constant
%%Calculate
T_w = zeros(1, length(qdot_solar)); %Create blank array for water
temperature
T w(:,:) = Tw int;
                     % fill array with intitial water temperature
for i = 1:length(qdot solar)-1;
  A = tau_g*alpha_b*qdot_solar(:,i);
  B = epsilon \ b*sigma*((T \ w(:,i)^4)-(T \ sky^4));
  C = m_w * Cp_w;
  T_w(:,i+1) = ((dt^*As_c^*(A-B))/(C)) + T_w(:,i);
end
%%Plot
hold on
vyaxis left
plot(times,T w,'-sb','Linewidth', 1)
ylabel('Temperature (\circK)')
yyaxis right
```

194 Engineering

plot(times,qdot_solar,'-*r','Linewidth', 1) title('Solar Water Heater Flux/Temperature vs Time Prediction') ylabel('Solar Flux (W/m^2)') xlabel('Time (hrs)') legend('Water Temperature (\circK)', 'Solar Flux (W/m^2)') legend('Location', 'northwest') xlim([1,24]) grid on grid minor

Semi-Translucent Concrete: Thermal, Structural, and Optical Properties

Matthew Bayreder, Mako Bennett, Tanya Jones, Ali S. Siahpush

Southern Utah University

ABSTRACT

The need for energy efficiency and strength in building materials is growing across the United States and the world. Concrete is a commonly used high-strength building material but significantly lacks in aesthetic characteristics and translucent properties: it is gray, dark, and dull. Semi-translucent concrete is an alternative being studied extensively by universities and companies across the globe. This experiment studies the feasibility of using glass to substitute for gravel as an aggregate in concrete. This study includes testing the structural, optical, and thermal properties of concrete with varying amounts and types of glass when used as aggregate in concrete. The resultant data indicated that the maximum stress of regular concrete was 16.26 MPa, whereas the maximum stress of the glass aggregates ranged from 11.48 to 18.77 MPa. The optical tests indicated that although some light was able to pass through the clear and blue glass specimens, the completed product would not be transluscent. Instead, it would add character to lighting in a room. The coffee cup calorimeter thermal tests indicated minimal differences between the glass aggregate and the control mix of concrete at 2.2 J/g·°C (avg.) and 3.00 J/g·°C, respectively. The data suggest that using different sizes of glass as an aggregate would be an effective replacement for gravel and sand in concrete for aesthetic and structural elements, but more developments need to be done to make it semitranlucent.

NOMENCLATURE				
Symbol	Definition	Unit		
m_w	Mass of water	kg		
c _w	Specific heat of water	$\left(\frac{kJ}{kg^{\circ}C}\right)$		
T_{i_W}	Initial temperature of water	°C		
T_f	Final temperature of water and concrete at equilibrium	°C		
m_{C}	Mass of concrete	kg		
c _p	Specific heat of concrete	$\left(\frac{kJ}{kg^{\circ}C}\right)$		
T_{i_C}	Initial temperature of concrete	°C		

INTRODUCTION

In 2019, over 102 million metric tons of concrete were consumed in the United States. The use of concrete in construction has increased since the recession in 2008 as concrete is being used in all forms of construction from foundations to high-rise buildings. One of the drawbacks to concrete is the increased cost due to the inability of concrete to transmit natural light. The lack of natural lighting creates the need for additional lighting and increased energy consumption in buildings. Glass is an easily obtained recyclable material [1]. Broken glass destined for landfills could easily be used as an aggregate in semitranslucent concrete.

Semi-translucent concrete could be a viable and effective replacement for traditional concrete. Semi-translucent concrete may be used in eco-friendly recycling, effective lighting, and higher-strength yields under certain conditions. Dehghanpour and Yilmaz at Sakarya University, Turkey, completed a similar experiment that involved using recycled glass as the aggregate in concrete and found significant improvements in the strength and thermal properties of the concrete when glass was added compared with traditionally used concrete [2].

An experiment by Pagliolico and LoVerso analyzed the effects that glass in concrete could have on energy consumption and found

considerable data to support claims that translucent concrete reduces energy consumption in household settings as rooms become naturally lit [3]. The objective of this experiment is to compare the optical, thermal, and structural properties of concrete mixes using varying types of glass aggregates versus a control mix. In this experiment, glass was added as part of the aggregate to show whether natural light can pass through concrete. This project examines the feasibility of glass as a suitable replacement for gravel and sand as an aggregate. Information obtained in this experiment can be used to predict whether semi-translucent concrete could be a viable substitute for traditional concrete in structures and architectural elements. Procedures from these previous studies will be used as examples [2-3].

EQUIPMENT

- For mixing and forming the concrete specimens:
 - o Scale
 - Wheelbarrow, shovel, and a mixing pan
 - Molds and containers for making concrete shapes
 - Tin foil
- For performing compression tests:
 - Hydraulic compression strength-testing machine
- For determining the specific heat:
 - Four-channel temperature measurement data logger and accompanying thermocouples
 - Coffee straws
 - High-temperature silicone sealant
 - Electric cooktop and pots
 - Square Styrofoam containers with lids
 - Black plastic garbage bags
- For the optical tests:
 - An electric ceramic/concrete saw
 - Spectrometer

COST

To perform this experiment, materials that are readily available were used. See Table 1 for the cost of materials. This was a low-budget experiment. Further testing requires a larger budget.

Table 1. Cost of materials use in concrete mixes				
Items	Cost			
Portland cement type I/II – 60 lb	\$4.00			
Sand – 50 lb	\$5.00			
Aggregate - Pebbles – 0.5 cu ft	\$5.00			
1" (25 mm) fibers for concrete cement countertops, AR	\$9.00			
glass fiber GFRC chopped strands, 1 lb.				
Mr. Fire glass 1/2-inch reflective fire glass for fireplace	\$30.99			
fire pit and landscaping, 10 lb. high luster platinum				
Mr. Fire glass 1/4-inch reflective fire glass for fireplace	\$20.99			
fire pit and landscaping, 10 lb. high luster cobalt blue				
Reflective glass beads for road marking, curb paint, traffic	\$17.95			
paint, 1 lb.				
Mr. Fire glass 1/4-inch reflective fire glass for fireplace	\$18.97			
fire pit and landscaping, 10 lb. high luster cobalt blue				

RESEARCH

Preliminary research was the first step in understanding the purpose of this experiment. Articles of previous experiments and discussions with qualified campus faculty led to the determination of many of the unknown values involved in this study. A brief list of those challenges is given below.

- 1. The type of concrete used was determined based on the experiment conducted by Deghanpour and Yilmaz [2]. Portland Cement, Type I/II was determined to be the best option for our experiment because of its abundant uses as well as the fact that is the most common type used for most general applications and in most construction applications [4].
- 2. An article by Afshinia [5] guided the decision to use recycled glass and reflective road glass (the particles placed in the paint to create the reflective properties of the white and yellow lines) as the large and small aggregate, respectively. This also gave cause to test a fiberglass sample as a separate test aggregate. These glasses are ideal because they limit the alkali–silica reactions (ASRs) that occur in cement–glass mixtures. Experimentally, it was discovered that the smaller the aggregate, the less active the ASRs would be. Additionally, this recycled glass fits the eco-friendly model of the experiment [5, 6].
- 3. The ratio for cement, large aggregate, small aggregate, and water was determined based on the experiment conducted by Deghanpour and Yilmaz [2]. However, that experiment was

conducted under different circumstances and resources so a hybrid ratio model was developed that fit the resources of the present experiment.

4. Research optical tests were conducted in partnership with Dr. Jacob, Dean of the Southern Utah University Department of Chemistry [7]

CEMENT MIXING

Our research indicated that the best mix ratio of aggregates by weight was 1.5:3:1 (ratio of cement:glass aggregate:glass powder) [2]. Because of the budget limitation, a mixed ratio for the experiment was selected. Using the ratio of 1.5 lb of Portland Cement Type I/II to 0.75 lb of sand to 0.25 lb of small aggregate (reflective glass) to 2 lb of 1-lb rock to 0.5 lb of large aggregate and glass to 0.5 lb of water, the concrete mixtures were created with different types of large glass aggregate. Pictures of selected aggregates are shown in Figure 1. A control specimen of typical cement was also made, replacing the small aggregate glass and the large aggregate glass with more sand and rock, respectively. The control specimen was important in comparing the translucent experimental data with common concrete. The different types of large glass aggregate included 1/2-inch reflective fire glass, 1/4-inch colored fire glass, and 1-inch glass fibers. The small glass aggregate was a mixture of half glass beads and half glass powder, both typically used in traffic paints on roads and concrete surfaces.



Figure 1. Materials used in the concrete mixes. (A) Large aggregate clear fire glass, (B) small aggregate glass powder, (C) small aggregate glass beads.

The selected ratio was used in all measurements to ensure the greatest consistency among all concrete mixes. Each concrete mixture was poured into 2 test cylinders (4-in diameter \times 8-in height), 2 spheres, and a half-cylinder. The cylinders were used for compression testing. The spheres were used for thermal testing, and the half-cylinders were used for optical testing. Approximately 9 lb. of each concrete mix were needed for all the experiments. Table 2 shows the average measurements for each of the mixtures. The mixtures changed according to the large aggregate tested and depending on the availability of materials.

Table 2. The mixture weight for test cylinders								
Sample ID	Туре	Cement (lb)	Sand (lb)	Small glass (lb)	Large rock (lb)	Large glass (lb)	Water (lb)	Total (lb)
1-7	Glass fibers	2.25	1.5	0	4.125	0.375	0.75	9
2-7	Fire glass clear	2.25	1.125	0.375	3	1.5	0.75	9
3-7	Fire glass colored	2.25	1.125	0.375	3	1.5	0.75	9
4-7	Control	2.25	1.5	0	4.5	0	0.75	9

Once the concrete was mixed, it was placed in labeled containers (Fig. 2). The spheres were roughly spherical, with a diameter of about 6 inches. While being poured, the concrete was shaken and vibrated by hand to remove air bubbles and ensure the best packing possible. When the cylinders were filled, they were sealed to ensure the highest moisture curing environment for the cylinders. Specimens were left untouched while curing.



Figure 2. Materials after being poured in the concrete cylinders, and the aluminum foil spheres.

STRUCTURAL TESTING

To test the structural properties of the concrete mixes, compression tests were performed to examine the critical stress of the concrete. To perform a compression test, a force is applied along the vertical axis of the material being tested. The force was increased until the material failed under the compression.

Procedure

Concrete cylinder compression tests were completed 7 days and 28 days after the mixing was completed. The strengths of the cement specimens after 28 days were compared with the strengths of the specimens after 7 days to record the effect of curing.

A hydraulic compression testing machine was used for the compression tests. Each cylinder was placed under the hydraulic ram, which recorded the maximum breaking compression stress that the cylinder could withstand.

Results and Discussion

The compressive strengths of the concrete cylinders are presented in Table 3.The cylinders with the colored glass aggregate had the least compressive strength in both tests, measuring 1167.4 psi (8.049 MPa) and 1664.8 psi (11.48 MPa). The strongest specimen overall was the clear recycled specimen, which recorded 2946.8 psi (20.32 MPa) after 7 days of curing. The strongest specimen measured after 28 days was the glass fiber aggregate cylinder, with a compressive strength of 2722.3 psi (18.77 MPa).

Table 3. Maximum stress found during compression test,measured in psi (MPa)					
The second se	7-day cure	9	28-day cure		
Type of aggregate	psi	MPa	psi	MPa	
Glass fiber	2654.2	2654.2	2722.3	18.77	
Clear recycled glass	2946.8	2946.8	2494.0	17.20	
Colored recycled glass	1167.4	1167.4	1664.8	11.48	
Gravel (control)	1788.9	1788.9	2358.7	16.26	

After the tests were completed, failure modes were observed. All of the specimens except the glass fiber aggregate failed by cracking and breaking off large pieces in short shear or columnar failure [8]. The ones with the glass fiber aggregate failed by slowly morphing, with some of the material being forced or pressed outward. Failure modes of the individual cylinders are presented in Figure 3 (7-day compression tests) and Figure 4 (28-day compression tests).



Figure 1. Compression tests after 7 days of curing. (A) Glass fiber aggregate, (B) clear glass aggregate, (C) gravel aggregate, (D) colored glass aggregate.

The specimens with regular gravel aggregate as well as the ones with clear and colored glass aggregates showed failure expected of concrete cylinders. The fiberglass cylinders had cracks that propagated quickly through the material following a direction parallel to the applied force. This type of fracture resulted in large pieces that fell off the



Figure 2. Compression tests after 28 days of curing. (A) Glass fiber aggregate, (B) clear glass aggregate, (C) colored glass aggregate, (D) gravel aggregate.

specimen. This is also known as cone failure (Fig. 4C). The shear or columnar modes of failure (Figs. 3D and 4D) suggest that there was some allowance for lateral expansion in the testing methods or that the insets in the plates caused loading to be concentrated on one side of the specimen [9]. The failure of cylinders with the glass fibers happened slowly and without any propagation of large cracks through the cylinder. Although the glass fiber cylinder was not the strongest, complete failure did not happen abruptly.

Although there were differences observed in the compressive strength of the 7-day tests compared with the 28-day tests, a larger sample size of each specimen type would be required to draw definite conclusions. The different aggregate types followed independent trends. The specimens with colored glass aggregate were significantly weaker than the others. This may have been caused by an inadequate amount of water in the mixture.

OPTICAL TESTING

Optical properties are tested by measuring the lumens and wavelengths that can pass through and be reflected off a material. Because this experiment is focused mostly on the translucent properties of the concrete, only the light that passes through the concrete will be measured. Effective optical testing involves placing a light source on one side of a piece of a material and measuring the light that passes through by measuring the brightness of the light in lumens or by measuring the wavelengths. As light passes through concrete, a room will be brightneed as light is dispersed through space [8]. This would assist in decreasing energy costs [9].

Procedure

When testing for optical properties, each cement specimen was tested for its ability to allow light to shine through a slice with a thickness of 1 inch. This test was performed using a visible light receiver to determine the wavelengths of visible light shining through the specimen. Cement mixes were prepared and poured into 4×4 -in. cylinders (Fig. 5).



Figure 5. (A,B) Light passing through specimen. (C) Ocean Optics spectrometer.

Once cured, 1/2-in.-thick slices were cut off the cylinders to allow for greater light to pass through the specimen. An Ocean Optics spectrometer (Fig. 5C) was fastened and used to measure the intensity of wavelengths that pass through specific spots in the cement specimens. An iPhone LED light was used as the light source. The intensity of wavelengths was recorded for the light source without any cement to know the intensity of wavelengths produced from the light source. Each slice of cement specimen was then placed between the light source and the spectrometer light receptor to measure the wavelengths that passed through the cement. Results were compared with the original intensity of wavelengths produced by the LED light.

Results and Discussion

The wavelengths of light produced by the LED iPhone light source were about 450 nm and 550 nm. The intensity of light shining through each specimen is shown in Figure 6, which also shows to what intensity LED light can pass through translucent cement. It was observed that light can pass through the cement specimens containing clear glass and blue glass but not through other cement specimens tested. It was noted that the light transmittance was decreased in intensity through the blue glass and magnified through the clear glass. The visible light produced by the light source was violet and green with wavelengths of about 420 nm and 530 nm, respectively. The same colors and wavelengths were consistent with the clear glass, only intensified. However, in the blue glass, little to no orange and red light was recorded by the spectrometer. No light protruded through the control and the glass fibers specimens. The clear glass specimen intensified the wavelengths, and the blue glass softened the intensity of the LED wavelengths.

The results confirm that clear glass allows light to pass through better. Optical testing led to predictions on the behavior of light and the effect it would have in a room surrounded by translucent cement similar to that used in the experiment. Ideally, the light transmitted through the translucent cement would not glitter or sparkle. Instead, light permeating the cement would be dispersed throughout space to brighten a room without any distinct light source. The cement tested in this experiment would not allow light to pass through a thick wall. Any light passing through the concrete would shimmer and distract those in the room. However, further testing could lead to a more translucent cement that allows for more light to pass through.



Figure 6. Intensity of wavelengths (nm) passing through samples. (A) Glass fiber aggregate, (B) clear glass aggregate, (C) gravel aggregate, (D) colored glass aggregate.

THERMAL TESTING

To perform a thermal property test, the concrete materials were placed in a calorimeter with hot water. Thermocouples were used to measure the temperature of the water and the material being tested. The temperatures of the material and the water will gradually reach equilibrium at the same temperature. The steady-state heat transfer, ΔQ (kJ) may be defined as

$$\Delta Q = mc_p (T_i - T_f) \tag{1}$$

where c_p is the specific heat (kJ/kg.K), T_i is the initial temperature (°C), and T_f is the final temperature of the mass being measured (°C). Because ΔQ is the same between the water and the material, except for c_{p_c} , all variables are known after measuring the mass and temperature of the water and materials. The specific heat (c_{p_c}) of the concrete material is expressed as:

$$c_{p_{C}} = [m_{w}C_{p_{w}}(T_{i_{w}} - T_{f})]/[m_{C}(T_{i_{C}} - T_{f})]$$
(2)

Thermal Procedure

A concrete ball was formed and placed in aluminum foil; a straw was placed in the center during formation to enabled the temperature reading of the core during testing. The straw was then sealed on both ends to prevent water entering from the surroundings and altering the temperature readings at the center of the concrete as seen in Figure 7.



Figure 7. Concrete balls with thermocouples.

The water was brought to a boiling temperature and the concrete ball was left at room temperature. Both the water and the concrete ball were weighed and placed in an insulated cooler with thermocouples to

208 Engineering

record the temperature change. The lid was secured, and the data were collected. Equilibrium was reached in minutes (Fig. 8).



Figure 8. (A) Concrete balls in the isolated cooler. (B) Temperature logger used to take readings.

Results and Discussion

The specific heat of the concrete balls was calculated using Eq. (2). The results are presented in Table 4. Because of the limited sample size, no conclusions could be made even though it would appear that the concrete with the glass would be a good insulator.

Table 4. The calculated specific heat for each sample					
Sample	Glass fibers	Clear glass	Colored glass	Gravel	
$c_{p_{C}}$ (kJ/kg°C)	1.74	3.00	Inconclusive	1.84	

Table 5 presents the specific heat of some common materials for comparison.

Table 5. The specific heat of some common materials [10-11]			
Common materials	C _p (kJ/kg°C)		
Concrete, dense	0.8		
Copper metal	0.387		
Glass	0.837		
Wood	2.301		

When the readings for sample #3 were taken, there was something wrong with either the wire or the controls. The data on the cement ball #3 started at 73.9°C, which is unreasonable for room temperature where

a reading around 20°C would be much more reasonable. It is suspected that there was a faulty wire or temperature data logger.

SOURCES OF ERROR

After completing this experiment, several areas needed improvement. First, after deciding the theoretical mixes, more time should have been spent on the actual mixes. This would have been helpful to get a feel for the concrete and to see whether the mixes were close to what was desired. At the time of mixing, it was not realized that the mixes were too dry and needed more water. Because of this deficiency, the test was not as accurate as desired.

Not all research was completed before the mixing date. Research continued throughout the curing time, and it was learned that having fiber optics as the reinforcement would have improved the light that was allowed through the concrete.

One thermocouple did not work properly at the time of our thermal testing. In retrospect, it would be beneficial to do the test 2–3 times to compare the data collected. This can also be applied to our test cylinders for our compression test. Having 3–4 samples would have been better to record more accurate data.

It was difficult to complete the optical test. The Chemistry department was very helpful, but they usually test light through aqueous solutions and cement is not aqueous. Another apparatus could have been used, but the sample size was too small and would not accommodate the experiment. We were able to find a rudimentary apparatus that allowed for some translucent measurements.

CONCLUSION

Based on the collected data, semi-translucent concrete would be a suitable replacement for regular concrete. However, the sample size used in this experiment was minimal. It was observed that cement specimens with glass aggregates behaved very differently than typical concrete. Some types of glass aggregates may have played a role in a higher compressive strength than normal concrete. In the end, each specimen of concrete containing a different type of glass aggregate presented different properties optically, thermally, and structurally. The results of this research necessitate the need for more testing of the different types of cement. A larger budget and sample size would lead to more specific and quantifiable results.

RECOMMENDATIONS

The lack of water caused the samples to dry too fast and the mixtures turned brittle. Although water amounts may vary, adequate amounts of water should be added to the mixture. A better method for shaping the concrete into spheres should be analyzed because the spheres for this experiment were too porous, affecting the thermal measurements. A plastic container similar to those used for cylinders might suffice. This issue was also a product of the lack of water. Better spectroscopy techniques would greatly enhance future experiments as well.

In another experiment, it could be beneficial to analyze cement with glass fibers as the aggregate because it performed differently than typical cement. Lastly, it is recommended to have a larger sample size in future experiments to fix precision issues in recorded data. This experiment had 3 different samples recorded at 2 different periods resulting in 6 total samples. A larger number of samples should be recorded for better results.

ACKNOWLEDGMENTS

This project would not have been possible without the financial and technical support and expertise of the Department of Engineering at Southern Utah University. We thank our community partners: The Home Depot of Cedar City for donating cement mix and sand, and Rocky Ridge Rock, Inc., for their donation of the gravel used as aggregate in the concrete control mix. We would also like to thank Dr. Jacob Dean and the Chemistry Department at Southern Utah University for their expertise and equipment in collecting data for the optical testing of our concrete specimens.

REFERENCES

[1] Best, R.D. (2020, November 19). Apparent cement consumption U.S. 2019. Retrieved November 29, 2020, from https://www.statista. com/statistics/273367/consumption-of-cement-in-the-us/

[2] Dehghanpour, H., & Yılmaz, K. (2019). Evaluation and Investigation of Waste Glass Aggregates and Powders in Architectural Mortars. *Scientific Herald of the Voronezh State University of Architecture & Civil Engineering*, 44(4), 28–42.

[3] Pagliolico, S.L. (2015, November). A Preliminary Study on Light Transmittance Properties of Translucent Concrete Panels with Coarse Waste Glass Inclusions. *Energy Procedia*, *78*, 1811–1816.

[4] Portland Type 1/2/IL Cement. (n.d.). Retrieved January 22, 2021, from https://www.argos-us.com/Cement/Bulk-Cement-Products/ Portland-Type-I-II-IL-Cement

[5] Afshinnia, K. (2020, May 01). Waste Glass in Concrete has Advantages and Disadvantages. *Concrete Decor*, *19*(8). Retrieved November 05, 2020, from https://www.concretedecor.net/ decorativeconcretearticles/vol-19-no-8-november-december-2019/waste-glass-in-concrete-has-advantages-and-disadvantages/

[6] Cai, Y., Xuan, D., Poon, C.S. (2019). Effects of nano-SiO2 and glass powder on mitigating alkali-silica reaction of cement glass mortars. *Construction & Building Materials*, 201, 295–302.

[7] Dean, J., Personal communication, November 3, 2020.

[8] ASTM C1231/C1231M-15, Standard Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA, 2015, Retrieved on February 10, 2020, from https://www.astm.org.

[9] Phatak, M. (2020, July 12). Translucent Concrete and Smart Glass. Retrieved November 05, 2020, from https://www.smartglassworld. net/translucent-concrete-smartglass

[10] The Engineering ToolBox. (2003). *Specific heat of some common substances*. Retrieved on February 10, 2020, from https://www.engineeringtoolbox.com/specific-heat-capacity-d_391.html.

[11] Thermtest, Inc. (2021, January 15). *Materials Database - Thermal Properties*. Retreived on February 10, 2020, from https://thermtest. com/materials-database.

"Something Large and Old Awoke"¹: Ecopoetics and Compassion in Tracy K. Smith's *Wade in the Water*

Kaitlin Hoelzer

Brigham Young University

Abstract

Tracy K. Smith's volume Wade in the Water: Poems (2018) connects environmental degradation and racial injustice and responds to these issues with a call for compassion. In this paper, I situate Smith's work within Black ecocriticism, which moves beyond pastoral aesthetics to identify the oppressive structures that tie racial injustice to environmental degradation. I also argue that Wade in the Water engages with the work of contemporary Black theorists such as bell hooks, Brittney Cooper, and Charlene Carruthers, who assert that compassion is necessary to a sustained and successful fight against oppression. The poems "Watershed," "Wade in the Water," and "An Old Story" discuss both racial and environmental injustice and violence, but at the same time, Smith's book is infused with a compassion the book and other Black

¹ Smith, Tracy K. "An Old Story." Wade in the Water. Graywolf Press, 2018, p. 75.

women scholars are beginning to recognize as essential to dismantling unjust systems and bringing about healing.

Both historical and contemporary Black poets have used their work to identify, condemn, and suggest solutions to problems stemming from racism in American society. Indeed, as Arnold Rampersad notes in his introduction to *The Oxford Anthology of African American Poetry*, many Black poets use "poetry as a vehicle of protest against social injustice in America" (xxiv). Art is inherently political, even when its arguments do not overtly engage in political debates. As Lorraine Hansberry argues, all art is rooted in a particular social and political consciousness. The choice is "not whether one will make a social statement in one's work but only *what* the statement will say" (5). According to these Black theorists, to fully understand any piece of art, readers must understand the social and political context of the work.

Pulitzer Prize-winner and former U.S. Poet Laureate Tracy K. Smith's work is often understood only in terms of its formal and aesthetic qualities, rather than its political components. However, the two are actually interconnected-Smith's formal choices serve to support her political arguments. Her fourth volume of poetry, Wade in the Water: *Poems* (2018), examines racial and environmental injustice, participating in what Katherine R. Lynes has termed "African American reclamation ecopoetics." Whereas ecocriticism has traditionally focused on pastoral aesthetics, Lynes, Angela Hume, Camille Dungy, and other Black critics have expanded ecopoetics to address environmental degradation and the structural oppressions that connect environmental damage with ongoing racial injustice through both formal and thematic elements (Lynes 51). Black poets, such as Robert Hayden, Melvin Dixon, and Lucille Clifton, for instance, have often been particularly sensitive to the connections between these injustices, having seen both racial violence and environmental degradation in their communities. African American reclamation ecopoetics is "a protest of human injustices to both other humans and nonhuman nature" (Lynes 55) and is a strong part of the contemporary Black poetic tradition.

My paper will discuss Smith's examination of the connection between environmental degradation and racial injustice as well as her response to these issues with a call for compassion. In so doing, I will situate Smith's work in a particular African American conversation about restorative justice, demonstrating how her focus on compassion extends contemporary African American reclamation ecopoetics. Many prominent Black liberation theorists and activists, including bell hooks, Brittney Cooper, and Charlene Carruthers, have noted the importance of what they variously call love, solidarity, empathy, community, and compassion in movements for social justice. They identify a feeling for others that respects differences, motivates people toward liberation for all, and does not shy away from reality as vital to any successful liberation movement. I will use the term "compassion," which literally means "to feel with," to describe this revolutionary feeling. *Wade in the Water* identifies the link between racial injustice and environmental degradation, and readers are "confronted by the real, / By the cold, the pitiless, the bleak" (72 lines 7-8); at the same time, Smith's book is also infused with a compassion that provides optimism in the face of oppression. The poems "Watershed," "Wade in the Water," and "An Old Story" in particular draw attention to the damage done to both the environment and Black people in America, countering these injustices with a compassion deemed essential to countering unjust systems and bringing about healing.

African American Reclamation Ecopoetics in *Wade in the Water*

The critical ecopoetic tradition has failed to recognize and address the ways in which Black poets connect racial injustice to environmental degradation in their ecopoetry. Often, scholars identify African American poets who write about nature simply as race poets, ignoring their themes of nature. Although race undoubtedly informs the work of Black nature poets, analyzing these poems from the perspective of race alone erases the connection of environmental degradation and racial injustice addressed in the poems and thus perpetuates this violence. However, contemporary conversations about Black nature poetry are beginning to address the intersection between race and the environment in what has become known as African American reclamation ecopoetics.² This important theoretical understanding has yet to be applied to Smith's work. Attention to racial injustice, environmental degradation, and the ways in which these issues overlap is present throughout Wade in the Water, making it part of the African American reclamation ecopoetic tradition. Smith's poems "Watershed," "Wade in

² See, for instance, Dungy, "On Black Nature"; Hume, "Toward an Antiracist Ecopoetics"; and Lynes, "African American Reclamation Ecopoetics." See also "'The Light That Insists on Itself in the World': Lucille Clifton and African American Consciousness" by Bonnie Raub in *CLA Journal*, vol. 51, no. 4, June 2008, pp. 356-77 as well as "Going Overboard: African American Poetic Innovation and the Middle Passage" by Evie Shockley in *Contemporary Literature*, vol. 52, no. 4, 2011, pp. 791-817.

the Water," and "An Old Story" synthesize issues of both environmental and racial injustice, illustrating the connection between the two.

"Watershed" is an African American reclamation ecopoem that uses long lists and global imagery to reveal the overarching system that creates both environmental degradation and racial injustice. Pulling lines and phrases from a 2016 New York Times Magazine article titled "The Lawyer Who Became DuPont's Worst Nightmare" as well as excerpts from narratives of survivors of near-death experiences, "Watershed" tells the story of a single instance of environmental degradation before universalizing the DuPont chemical crisis to argue that incidents of pollution and other environmental damage are indicators of an overall system that disregards the health and safety of both land and people. The poem opens with descriptions of the effects of the chemical perfluorooctanoic acid (PFOA), which caused "deranged" and "skinny" cattle with "hair missing," "brilliant chemical blue" eyes, "malformed hooves." "lesions" and that are recorded "suffering and slobbering / staggering like drunks" (47-53 lines 10, 20, 21, 23, 27-28). These horrifying descriptions come in short, disjointed phrases, illustrating the disturbing way the symptoms quickly cropped up in farmers' cattle, and are repeated throughout the poem. Smith tells the story of one tragic occurrence of environmental degradation in lurid

detail, thereby illustrating the dire consequences of such careless actions. Compared with more traditional ecopoetry, the images of environmental horror in "Watershed" may seem out of place. However, Camille Dungy, a Black nature poet in her own right and editor of the anthology Black Nature: Four Centuries of African American Nature Poetry, writes that the category of ecopoetry must be expanded beyond the "placid and pastoral tradition," noting that "as we advance our view of what it means to interact with the natural world and include conversations about environmental justice, ecology, and historicallyinformed environmental practices, there will be more room for nature poetry that might be viewed as politically-charged, historically-based, culturally-engaged" (762). Smith's work enters this expanded region of ecopoetics, using nature poetry as a way to make an argument about the oppressive structures that create environmental degradation and racial injustice as well as the ways in which they might be dismantled. "Watershed" makes it clear that ecopoetry is far more expansive that has been recognized, acknowledging not just the beauty of the natural world but also the dangers it faces.

Smith moves beyond chronicling a single event as she describes the global problem PFOA has become and introduces a chorus of voices affirming the importance of protecting the environment. "Watershed" details PFOA's widespread effect on livestock, wildlife, and plants
through contamination of the water table in long lists. Smith writes, "Hundreds of thousands of pounds" of PFOA was "pumped... / into the Ohio river / [and] dumped... / into open unlined pits" (lines 57-60). Another section reads,

PFOA detected in:

blood or vital organs of: Atlantic salmon swordfish striped mullet gray seals common cormorants Alaskan polar bears brown pelicans sea turtles sea eagles California sea lions Laysan albatrosses on a wildlife refuge in the middle of the North Pacific Ocean (lines 130-46)

PFOA has been found in water and animals throughout the world, making it a global concern. The global imagery of "Watershed" demonstrates that single instances of environmental degradation are part of a global attitude that is dismissive of the environment. Angela Davis and Macarena Gómez-Barris each assert that extractive capitalism creates the need to dominate the land, stripping it of salable resources and contaminating it with the toxic byproducts of production (Davis 163; Gómez-Barris xvii). Thus, environmental damage is a symptom of a worldview that disregards the land in favor of domination and profit. The danger extractive capitalism poses to the environment is evident in "Watershed." The DuPont chemical crisis does not only affect those in its immediate vicinity, nor is it the only environmental problem we face today-PFOA spreads throughout ecosystems and evokes other contemporary environmental issues. Spliced alongside these chilling descriptions and separated by italics are narratives of near-death experiences that call for better care for the earth, which continues to frame this problem as not an isolated incident but a global issue. In the poem, those near death are "swept away by some unknown force" and realize that "every individual thing glowed with life" and that the earth "is a true living being" that "has been weakened considerably" (lines 35-36, 79, 109). In "Watershed," the earth seizes people near death and demands better treatment. Those near death see the world as an interconnected and interdependent whole, representing the way in which individual environmental threats become global problems.

"Watershed" also pays careful attention to the ways PFOA has affected the human population, arguing that individual environmental problems not only indicate a larger disregard for the environment but also disregard for the common humanity of oppressed populations. PFOA is toxic to humans, and, through contamination of blood transfusions and drinking water, it has caused birth defects, cancer, eye problems, vomiting, and fever (lines 67-76, 115-19, 123-26). Black people are particularly threatened by the systems of domination and oppression created by extractive capitalism, and "Watershed" recognizes the "long history of environmental subjugation in which nature is contaminated by past acts of racial violence" as well as the fact that slave patrols, lynchings, and police brutality often make it unsafe to be outdoors as a Black person (Hume 80; Dungy 761). The environmental damage caused by extractive capitalism is tied to the historical and current domination and exploitation of Black people through slavery, which was one of the earliest manifestations of extractive capitalism. Thus, the poem's condemnation of DuPont's individual actions calls for a justice that acknowledges the worth and freedom of Black people and all humans.

"Wade in the Water" also exposes the violence that extractive capitalism inflicts on both Black people and the land by evoking slavery. Smith wrote this poem after seeing the Geechee Gullah Ring Shouters perform. At first glance, "Wade in the Water" seems to be about a lively performance with "handclaps" and "stomps" (15 lines 13-14); however, the dance in question has a tragic history that recounts the enslavement of the dancers' ancestors. Geechee Gullah, which is the area along the Atlantic coast that includes parts of North Carolina, South Carolina, Georgia, and Florida, also refers to the enslaved people who once worked there in cotton, rice, and indigo fields as well as the unique language and art that evolved in this isolated region ("The Gullah Geechee"). The Geechee Gullah Ring Shouters perform dances and songs created when their ancestors were enslaved in the Geechee Gullah region. The "rusted iron / Chains someone was made / To drag" (lines 15-17) are not simply an artful metaphor for the freedom that comes from creation but are the literal history of Geechee Gullah dance. Smith describes the beauty of the dance causing "a terrible new ache" and "scraping at / Each throat" (lines 4, 25-26)-feelings caused by beauty's juxtaposition with the horrors of slavery that inform Geechee Gullah dance.

"Wade in the Water" demonstrates that the environmental degradation exposed in "Watershed" is rooted in extractive capitalism's long history of slavery, domination, and exploitation. Extractive capitalism relies not just on domination of the land but also on an underclass of exploited laborers, created by the historical enslavement and disenfranchisement of African and Indigenous populations and maintained by modern-day anti-Black racism (Davis 163; Gómez-Barris xvii-xviii). The acknowledgement of the legacy slavery has left in the United States in "Wade in the Water" can be linked to environmental degradation. This legacy of human and natural plunder is depicted in "Wade in the Water" as the dancers pretend to wade in the water, invoking the water that carried enslaved people from Africa to the Geechee Gullah region. Like the descriptions of the claps and stomps in the dance, the image of water connects the performance to the injustices caused by slavery; however, this description of "the water / Where they pretended to wade" (lines 20-21) in particular also allows "Wade in the Water" to hint at the environmental degradation discussed in more detail elsewhere in the book.

In "Wade in the Water," the Atlantic Ocean is metaphorically tainted by the forcible importation of enslaved Africans. With the knowledge that extractive capitalism created slavery, it follows that the waters of the world also have been and will be literally threatened by the environmental practices of extractive capitalism. In Unapologetic: A Black, Queer, and Feminist Mandate for Radical Movements, community organizer Charlene A. Carruthers asserts that "Capitalism, patriarchy, anti-Blackness, and white supremacy work together to destroy people and the land we depend on. ... We see this collusion in extraction of land and exploitation of people" (113-14). This collusion is evident in the context of slavery expressed in "Wade in the Water"; plantation slavery relied on unethical practices toward both human life and agriculture. Like other Black nature poems, "Wade in the Water" "register[s] the structural forces and forms of power that both racialize and subject raced bodies and environments to degradation and violence" (Hume 80). Therefore, "Wade in the Water" participates in the tradition of African American reclamation ecopoetics by articulating an understanding of the ways in which extractive capitalism links both environmental degradation and racial injustice.

"An Old Story" closes Smith's book with a haunting image of the devastation caused by domination and exploitation of both the land and Black bodies in the United States, therein arguing that these inextricably linked injustices are structural, not individual. The poem voices a land that is "livid" and "ravaged" and a people whose "every hate [has] swollen to a kind of epic wind" (75 lines 3-4), describing the damage

done to both the earth and humans as "the worst in us... taken over" (line 5). "An Old Story" asserts that individual beliefs become codified by the dominant group, making the individual "hate" swell to "epic" proportions, cementing structural injustice in the United States that is more far-reaching than any one individual's action. That the poem presents the end of the world as something that involves both structural environmental degradation and institutionalized human hatred argues that when racial injustice goes unchecked, so does environmental degradation, and vice versa. Because environmental degradation and racial injustice "work together" (Carruthers 113), these oppressions multiply for Black people. Black people not only face the daily threat of racial violence but also are more likely to live in areas where the environment is poor, because of environmentally harmful governmental policies and corporate actions that disproportionately affect poor communities of color (Cole and Foster, 10-11, 54-58; Hume 83). "An Old Story" asserts the structural nature of the problems of environmental degradation and racial injustice.

Like "Watershed" and "Wade in the Water," "An Old Story" connects racial injustice and environmental degradation; however, "An Old Story" points this conversation toward future possibilities for compassionate change. The "swollen" hate and "ravaged" land build upon each other until they are countered with people taking "new stock" of each other and the land (lines 3-4, 14). "An Old Story" thus outlines the coming problems society will face if oppressive systems are not replaced by systems of justice and compassion. In this way, the poem reflects Lynes' argument that African American reclamation ecopoetics take responsibility for the future, "demand[ing] stewardship of nature... and, in a manner of speaking, of other humans" (55). "An Old Story," while condemning the injustices of the past, is also forward-looking, seeking to rectify past problems of environmental degradation and racial injustice in order to build a more equitable future for all. Scholar Keeanga-Yamahtta Taylor similarly notes that racism in the United States is not only about Black people but is a symptom of a broader unjust system, writing, "When Black people get free, everyone gets free, [and] Black people in America cannot 'get free' alone. In that sense, Black liberation is bound up with the project of human liberation and social transformation" (194). Reading Smith in this light, her poems seek to enact "human liberation and social transformation" that will create compassionate societal structures.

Compassion in Tracy K. Smith's Ecopoetics

Wade in the Water contends that neither racial nor environmental injustices can be defeated without compassion. Indeed, the book underscores compassion as a force for liberation, justice, and healing, therein also offering a new way of envisioning the focus on the future of African American reclamation ecopoetics. In so doing, Smith echoes what other Black women theorists of liberation, including bell hooks, Brittney Cooper, and Charlene Carruthers, have said as they center compassion as the foundation of any movement of restorative justice. They, like Smith, assert that compassion leads to community, allowing effective resistance movements because it disavows hierarchy and acknowledges the problems people face, creating mutual respect in which all members of movements are supported in their differences.

"Watershed," "Wade in the Water," and "An Old Story" in particular emphasize compassion as a weapon in the battle for human dignity and justice. These poems do not suggest that one should ignore the reality of injustice or rely on trite calls to "just love everyone" as the solution to systemic problems; rather, they pair compassion with an acknowledgement of ecological disaster and racist violence, because compassion requires that one acknowledges the injustice of the past and present to find healing in the future. Nor are calls for compassion a way to avoid concrete action, because "feeling with" requires both individual and collective work. bell hooks's two books on compassion argue that compassion does not mean ignoring difficult realities but instead "allows us to confront these negative realities in a manner that is life-affirming and life-enhancing" (*All About Love* 139). Thus, compassion, in the sense Smith and other Black theorists use it, motivates care and community to combat injustice and thus create a more equitable future.

For instance, "Watershed" demonstrates the way compassion creates recognition of and care for others in its use of quotations from near-death experiences juxtaposed with the story of DuPont's pollution. These quotes articulate the speakers' realization of the importance of compassion; near the end of the poem, the speakers say, "Viewing the myriad human faces with an incredible, intimate, and profound love. ... All that was made, said, done, or even thought without love was undone. ... It was experiencing the luminous warm water that I felt the most connection with the eternal" (lines 147, 154, 158-59). In "Watershed," it is not the story of DuPont that inspires the love the poem's speakers feel. Rather, their epiphanies of compassion provide a counterpoint to DuPont's actions, arguing that seeing "the myriad human faces" with compassion leads to a revolution in the way humans treat each other. One speaker's inclusion of "the luminous warm water" extends this care to

all of nature. In "Watershed," compassion allows people to recognize and work to end wrongdoing. Systems of oppression like extractive capitalism and white supremacy thrive on an absence of care for others (hooks, *Salvation* 9-10), whereas compassion brings "clarity" that "tells us what kind of world we want to see" (Cooper 93-97, 273). Compassion, then, is a foundational component to combating systems of oppression, because it creates care for others and turns such care into action toward concrete change.

Furthermore, the multitude of unidentified voices in "Watershed" create a communal chorus that invites compassion. The poem pulls lines from many different people affected by the DuPont crisis and places them alongside thoughts from those who have had near-death experiences quoted above to form this chorus. Smith does not assign the characteristics of race, class, gender, or sexuality to the plurality of voices she includes, instead leaving them anonymous. This plurality suggests a need for solidarity across the traditional boundaries of race, class, gender, and sexuality, or, in other words, true compassion for the self and the other-a "concern for the collective good" (hooks, All About Love 97-98). This call resonates with other contemporary calls, revealing Smith's collection to be part of a larger national conversant about the role of compassionate community in social movements. For example, the Black Lives Matter mission statement declares their ultimate goal of "cocreating alongside comrades, allies, and family a culture where each person feels seen, heard, and supported" ("What We Believe"). Social movements must combat the multiplicity of oppression under the combination of white supremacy, patriarchy, and extractive capitalism with a tool equally able to connect "the myriad human faces" across race, class, gender, and sexuality. Compassion is that tool, for it moves people toward solidarity and community while addressing the reality of past harms. In the same way systems of domination create a complex web that links racial violence with sexism, homophobia, and environmental degradation, "Watershed" illustrates that compassion can create structures in which every person as well as the land on which they live is supported and respected.

In "Wade in the Water," the repetition of the phrase "I love you" works to underscore compassionate community and elevate compassion as a liberatory force. Smith describes one of the Geechee Gullah Ring Shouters greeting her by saying, "I love you" (line 2). The woman repeats "I love you" again and again "as she continued / Down the hall past other strangers" (lines 7-9). In the poem, although the group does not know one another, they are "pierced suddenly / By pillars of heavy light" (lines 10-11). This declaration of love to a group of strangers, like the multiplicity of voices in "Watershed," demonstrates the way

compassion can create community, connecting people despite their differences. Carruthers argues that "liberation is a collective effort" (25) and therefore, "eradicating oppression requires us to identify connections" (32) and "[value] people enough to believe we can be transformed" (56). The performers' insistence on love embodies Carruthers's appeal for collective support.

The repeated refrain of "I love you" underscores compassion's creation of community but also demonstrates the way compassion also promotes care for the self, which is key to any revolutionary activity. The repetition of "I love you" among the Geechee Gullah descendant performers as they dance together voices their love for their community and thus implies their love of themselves as part of that community. They embody hooks's emphasis that marginalized groups must shake off the self-hatred dominant power structures have instilled in them to find liberation, performing a compassion that identifies the self and other as worthy of love (*Salvation* 7-8, 41-66). Compassion makes resistance possible by providing support systems.³ Because of this repetition of "I love you" to both strangers and Geechee Gullah descendants, every other action in the poem is inflected by diverse community created through compassion.

"Wade in the Water" personifies compassion, arguing that compassion itself has the power to temper injustice and loose chains. Compassion is infused "throughout / The performance," manifesting itself "in every / Handclap, every stomp," in "rusted iron / Chains," and "in the water" (lines 12-16, 20). As compassion pierces the scene with light, the "rusted iron / Chains" of racial injustice and environmental degradation are "unclasped and left empty" (lines 16-18). This image clearly communicates the immense power compassion has to combat injustice; it is compassion itself, not any individual, that breaks the chains. hooks notes that compassion roots out "obsession with power and domination" and instead cultivates the idea that "everyone has the right to be free, to live fully and well" (All About Love 87), and "Wade in the Water" echoes this sentiment. Further, in "Wade in the Water," compassion "drag[s] us to those banks / And cast[s] us in" as well as pushes itself into each audience member, "scraping at / Each throat" (lines 23-25). "Wade in the Water" mimics a baptism and confirmation by the hand of compassion. That compassion itself performs these actions again illustrates its potency in resisting oppression. Compassion is not merely the motivator of liberation, it is the liberator itself.

³ For more on compassion's ability to create support systems, see Black Lives Matter cofounder Patrisse Khan-Cullors's memoir *When They Call You A Terrorist*, especially pages 5, 35-42, 67, 99, 106, 129, 138, and 164-66.

The book's final poem, "An Old Story," invokes a creation myth of sorts to offer a vision of healing through compassion and argue that the structures of the world must be reimagined. "An Old Story" begins with a storm, "ravaged" land, and "swollen" hate-a picture of what the world might become if these twin oppressions of racial and environmental injustice are left unchecked. Eventually, however, "something / Large and old awoke" (lines 2-3, 4, 10-11). This force causes the people in the story to "[take] new stock of one another," begin to sing together, and "[weep] to be reminded of such color" (lines 11, 14-15). Compassion can be read as the "large and old" force coming back to life after being suppressed by hatred and destruction, reminding people of the brilliant and varied "colors" of the world. This awakening of compassion also brings healing to the ravaged world, replacing the storms with "a different manner of weather" and coaxing "animals long believed gone... down / From trees" (12-14). Of "An Old Story," Smith has written, "I wrote this poem thinking it might be nice to take a stab at creating a new myth" that takes "the failings of the twenty-first century... and fashion[s] them into a story that culminates in humankind finding its way to a compassionate existence" (Gioia 181). The healing of relationships between humans themselves as well as between humans and the natural world that takes place in the poem comes from a reassessment of how the world functions and who those functions serve. This reassessment facilitates a creation of a society based on compassionate structures. Because "An Old Story" depicts a new society, it demonstrates compassion's ability to incite expansive structural change, not merely individual transformation and community support.

In addition, this closing poem illustrates that compassion can transform resistance movements, making them inclusive and expansive and thus more effective at fighting the underlying systems of oppression that create myriad forms of injustice. In "An Old Story," compassion guides people toward imperative structural change, and thus, the poem argues that compassion is essential to truly remove systems of domination at their roots, rather than focusing only on singular instances of oppression. As Akiba Solomon and Kenrya Rankin note in their book *How We Fight White Supremacy: A Field Guide to Black Resistance*, compassion is not a magical quick-fix, but instead is a guiding force that creates "an enduring form of resistance that is radical, expansive, and transformative at its core" (183). The theorists discussed in this paper agree that to be successful, social movements must promote structural rather than individual change and must do so by addressing injustice in all its forms. "An Old Story" depicts the way in which compassion gives

social movements the power and scope to dismantle oppression at its roots.

Conclusion

Near the beginning of Wade in the Water, we read, "For our own good we have to answer / For all that has happened" (23 lines 9-10). The collection as a whole offers up compassion as a way to answer for the injustices found therein. Compassion is undoubtedly good for communities and landscapes threatened by systems of injustice; however, healing the injustices caused by white supremacist extractive capitalism benefits all members of society. A society that functions through the exploitation and harm of others, including Black people and the land as well as other marginalized groups, such as the LGBTQ+ community, people of color, and women of all races, is a society that degrades all of its members, even the most powerful. Members of dominant groups, although not affected to the same extent, are nonetheless negatively affected by systems built on extractive capitalism, because those systems restrict individuality and creativity while requiring indifference to destruction and injustice. Such a society cannot remain stable for long. Compassion, on the other hand, prioritizes justice and dignity for all, ending environmental degradation and racial violence, as well as the personal restriction and moral apathy that spreads across unjust societies.

Tracy K. Smith's book joins works by other contemporary Black women theorists in offering up a vision of a compassionate society that recognizes the value in all humanity and the earth and is committed to comprehensive structural change. In her touchstone essay "Poetry is Not a Luxury," Audre Lorde asserts that poetry "forms the quality of light within which we predicate our hopes and dreams toward survival and change," thus laying "the foundations for a future of change" (224). Compassion makes the necessity of such change clear, but it is also the tool by which change is accomplished. Poetry gives us a place "to hint at possibility made real" (Lorde 225). In this vein, *Wade in the Water* creates a world in which to explore the radical revolution that compassion can enact if we let it guide our actions and institutions. *Wade in the Water* urges us to start cultivating such compassionate revolution.

Works Cited

Carruthers, Charlene A. Unapologetic: A Black, Queer, and Feminist Mandate for Radical Movements. Boston: Beacon Press, 2018.

226 Humanities, Philosophy, and Foreign Language

Cole, Luke W. and Sheila R. Foster. From the Ground Up: Environmental Racism and the Rise of the Environmental Justice Movement. New York: New York University Press, 2001.

Cooper, Brittney. Eloquent Rage. New York: St. Martin's Press, 2018.

Davis, Angela. "Women and Capitalism: Dialectics of Oppression and Liberation." The Angela Y. Davis Reader. Edited by Joy James. Malden, MA: Blackwell Publishers, 1998, pp. 161-93.

Dungy, Camille T. "On Black Nature: African American Poets Reflect." Callaloo, vol. 34, no. 3, Summer 2011, pp. 760-62.

Gioia, Dana, editor. "Contributors' Notes and Comments." Best American Poetry 2018. Series edited by David Lehman. New York: Scribner Poetry, 2018, pp. 181.

Gómez-Barris, Macarena. "Preface." The Extractive Zone: Social Ecologies and Decolonial Perspectives. Durham, NC: Duke University Press, 2017, pp. xiii-xx.

Hansberry, Lorraine. "The Negro Writer and His Roots: Toward a New Romanticism." The Black Scholar, vol 12, no. 2, March/April 1981, pp. 2-12.

hooks, bell. All About Love: New Visions. New York: William Morrow, 2000.

hooks, bell. Salvation: Black People and Love. New York: William Morrow, 2001.

Hume, Angela. "Toward an Antiracist Ecopoetics: Waste and Wasting in the Poetry of Claudia Rankine." Contemporary Literature, vol. 57, no. 1, 2016, pp. 79-110.

Lorde, Audre. "Poetry Is Not a Luxury." Feminist Literary Theory and Criticism: A Norton Reader. Edited by Sandra M. Gilbert and Susan Gubar. New York: W. W. Norton & Company, 2007, pp. 223-225.

Lynes, Katherine R. "'a responsibility to something besides people': African American Reclamation Ecopoetics." African American Review, vol. 48, nos. 1-2, Spring/Summer 2015, pp. 49-66.

Rampersad, Arnold. "Introduction." The Oxford Anthology of African-American Poetry. Edited by Arnold Rampersad and Hilary Herbold. New York: Oxford University Press, 2006, pp. xix-xxix.

Smith, Tracy K. "An Old Story." Wade in the Water. Minneapolis: Graywolf Press, 2018, p. 75.

——. "Unwritten." Wade in the Water. Minneapolis: Graywolf Press, 2018, p. 23.

———. "Wade in the Water." Wade in the Water. Minneapolis: Graywolf Press, 2018, p. 15.

———. "Watershed." Wade in the Water. Minneapolis: Graywolf Press, 2018, p. 47.

Solomon, Akiba and Kenrya Rankin et al. "Love Me or Leave Me Alone." How We Fight White Supremacy: A Field Guide to Black Resistance. Edited by Akiba Solomon and Kenrya Rankin. New York: Bold Type Books, 2019, pp. 183-210.

Taylor, Keeanga-Yamahtta. "From #BlackLivesMatter to Black Liberation." From #BlackLivesMatter to Black Liberation. Chicago: Haymarket Books, 2016, pp. 191-219.

"The Gullah Geechee." Gullah Geechee Cultural Heritage Corridor Commission. Retrieved October 2, 2020, from https:// gullahgeecheecorridor.org/thegullahgeechee/.

"What We Believe." Black Lives Matter, Retrieved September 9, 2020, from https://blacklivesmatter.com/what-we-believe/.

Drinking Pattern Differences between Men and Women during the COVID-19 Pandemic: A Review of the Literature

Linnette Wong

Weber State University

Abstract

The purpose of this literature review was to summarize differences in the drinking patterns of men and women during the COVID-19 pandemic. A search was conducted for the keywords "drinking," "pattern," "gender," and "COVID-19" to help identify important articles pertinent to the topic, using the following databases: Academic Search Premier, ERIC, CINAHL Complete, PsycINFO, and MEDLINE. Articles published from 2020 to 2021 were included. Four articles were selected as the basis for this literature review. One study found no differences between male and female participants in mean number of days having consumed alcohol, total drinks consumed, and percentages reporting having engaged in binge drinking or extreme binge drinking at least once. Another study showed no differences between male and female participants in changes to substance use patterns, whether involving electronic vaping, marijuana, tobacco, or alcohol. A different study suggested that females who had children and those who had moderate to

severe depression symptoms were more likely to report increased participation in negative health behaviors, including alcohol consumption, potentially as a result of increases in available time during the outbreak or additional stressors arising from competing responsibilities associated with family and work. Another study indicated that COVID-19–related psychological distress was associated with increased drinking in women only. These results raise concerns from individual as well as public health perspectives. Future studies should assess the long-term effects of COVID-19 isolation on drinking behaviors, comparing men and women.

Introduction

COVID-19 is caused by severe acute respiratory syndrome coronavirus 2 (SARS CoV-2; Lai et al., 2020). On March 11, 2020, the World Health Organization announced that COVID-19 had caused a significant health crisis around the world and classified it as an international pandemic (Cucinotta and Vanelli, 2020). The COVID-19 pandemic has significantly affected the physical, mental, and social wellbeing of individuals generally. "Stay-at-home" orders were issued by the governments of various U.S. states during the pandemic to slow the spread of the virus, with residents advised to stay home, avoid large gatherings, and limit nonessential outdoor activities (Gostin and Wiley, 2020). These attempts to control COVID-19 caused extended periods of self-isolation for millions of people in the United States (Sallie et al., 2020), with an attendant rise in alcohol consumption, among other consequences. Nielsen research found that alcohol sales had increased by 55% from one year earlier, and a survey of 35- to 54-year-olds found that 25% had increased their alcohol consumption during the pandemic (NANOS, 2020). So significant an increase in alcohol consumption is worth investigating, especially differences in drinking pattern by gender. To date, however, there has been no synthesis of the existing research on this topic. The purpose of this literature review was thus to summarize differences in the drinking patterns of men and women during the COVID-19 pandemic.

Methods

A search was conducted for the keywords "drinking," "pattern," "gender," and "COVID-19" to help identify important articles pertinent to the topic, using the following databases: Academic Search Premier, ERIC, CINAHL Complete, PsycINFO, and MEDLINE. Articles published from January 2020 to December 2021 were included. The initial search captured 288 unique articles. The titles and abstracts were then screened according to the following exclusion criteria: (1) sample not drawn from the United States; (2) unrelated to the issue; and (3) lack of a validated data-based research design. Ultimately, four studies were included in this review.

Findings

The results of our review are presented in Table 1. Grossman et al. (2020) surveyed 832 participants, aged 26–49, 84% female and 16% male, and found no differences between male and female participants, respectively, in mean number of days having consumed alcohol (12.1 vs. 11.8 days, p=0.810), total drinks consumed (29.6 vs. 26.1 drinks, p=0.246), or percentages reporting having engaged in binge drinking (36.9% vs. 33.1%, p=0.491) or extreme binge drinking (9.5% vs. 6.5%, p=0.320) at least once. Sharma et al. (2020) surveyed a sample of 542 young adults aged 18–25, 80.4% female and 19.6% male, and found no difference between males and females in changes to substance use patterns, including those relating to electronic vaping, marijuana, tobacco, and alcohol (p=0.291).

Table 1: Summary of reviewed articles				
Paper (N); study type	Aims/objectives of study	Major findings		
Grossman et al., 2020 (N=832); cross- sectional study	This study assessed: (1) whether drinking behaviors changed during the pandemic; and, (2) how those changes were impacted by COVID-19-related stress.	There were no differences between male and female participants in mean number of days consuming alcohol (12.1 vs. 11.8 days, p=0.810), total drinks consumed (29.6 vs. 26.1 drinks, $p=0.246$), or percentages reporting binge drinking at least once (36.9% vs. 33.1%, $p=0.491$) or extreme binge drinking (9.5% vs. 6.5%, $p=0.320$).		
Sharma et al., 2020 (N=1018); cross- sectional	This study assessed the self- reported changes in substance use among a young adult population during the COVID-19	There were no differences between male and female participants in the change in substance use patterns including electronic vaping		

study	pandemic with imposed social distancing. The study assessed differences in demographic characteristics, self-reported anxiety, depression, loneliness, and substance use and direction of change between individuals who reported changes in substance use and those who did not.	marijuana, tobacco product, and alcohol (<i>p</i> =0.291).
Knell et al., 2020 (N=1809); cross- sectional study	The purpose of this study was to investigate how these health behaviors changed (increased/ improved or decreased/ worsened) at the early stages of the pandemic, what participant characteristics were associated with health behavior changes, and why these behavioral changes may have occurred.	Females with children (OR=1.58, 95% CI=1.19– 2.09) or with moderate-to- severe depression symptom severity (OR=2.24, 95% CI=2.41–4.64) were more likely to report increased engagement in negative health behaviors including alcohol consumption potentially due to increases in available time or additional stressors due to competing responsibilities between family and work.
Rodriguez et al., 2020 (N=754); cross- sectional study	This study explored how perceived threat and psychological distress related to the COVID-19 pandemic are associated with drinking behavior among an American sample of adults. The study also evaluated whether links between COVID-19-related perceived threat and psychological distress with drinking behavior are different for men and women.	COVID-19 psychological distress was only associated with greater drinking for women (peak drinks $RR=1.13$, $Z=4.82$, $p<.001$; typical drinks $RR=1.16$, $Z=5.59$, $p<.001$), whereas COVID-19 psychological distress was unrelated to drinking for men (peak drinks $RR=1.02$, $Z=0.58$, $p=.562$; typical drinks $RR=1.01$, $Z=0.32$, $p=.746$).

Knell et al. (2020) surveyed a convenience sample of 1,809 adults aged 18–50, 67.4% female and 32.6% male, and found that females who had children (OR=1.58, 95% CI=1.19–2.09) or moderate-to-severe depression symptoms (OR=2.24, 95% CI=2.41–4.64) were more likely to report increased participation in negative health behaviors. These behaviors included alcohol consumption and may have reflected increases in available time during the outbreak or additional stressors arising from competing responsibilities associated with family and work.

Rodriguez et al. (2020) studied 754 participants, 50% women, and found that COVID-19–related psychological distress was associated with more drinking in women (peak drinks RR=1.13, Z=4.82, p<.001; typical drinks RR=1.16, Z=5.59, p<.001) but not men (peak drinks RR=1.02, Z=0.58, p=.562; typical drinks RR=1.01, Z=0.32, p=.746).

Discussions and Future Directions

The evidence this study has reviewed points, variously, to no difference in drinking patterns among men and women but also to increased drinking behavior among women. Given the small sample of articles that have been published relating to this topic, information was lacking on numerous issues. The sample articles used in this study had many limitations, including those relating to demographic differences and the reliability of participants' reports, particularly when reporting use and psychological indicators. The self-reporting alcohol methodology used in these studies is not sufficiently comprehensive or reliable to allow accurate assessment of drinking behavior or determine the needs of a population. Future research should use valid data collection methods and apply interdisciplinary approaches to better understand the mechanisms that underlie the details of drinking behavior in men and women. Gaining a clearer understanding of whether differences in drinking patterns exist between men and women, as well as of which aspects of life experience contribute to such a difference, would offer further insights into how to help both men and women reduce alcohol consumption during the COVID-19 pandemic.

Reference

Cucinotta, D., & Vanelli, M. (2020). WHO declares COVID-19 a pandemic. *Acta Biomed*, 91(1), 157-160.

Gostin, L.O., & Wiley, L.F. (2020). Governmental public health powers during the COVID-19 pandemic: Stay-at-home orders, business closures, and travel restrictions. *JAMA*, 323(21), 2137-2138.

Grossman, E.R., Benjamin-Neelon, S.E., Sonnenschein, S. (2020). Alcohol consumption during the COVID-19 pandemic: a cross-sectional survey of US adults. *Int J Environ Res Public Health*, 17(24), 9198.

Knell, G., Robertson, M. C., Dooley, E.E., Burford, K., Mendez, K.S. (2020). Health behavior changes during COVID-19 pandemic and subsequent "stay-at-home" orders. *Int J Environ Res Public Health*, 17(7), 6268.

Lai, C.C., Shih, T.P., Ko, W.C., et al. (2019). Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): the epidemic and the challenges. *Int J Antimicrob Agents*, 55(3), 105924.

NANOS Research. (2020). COVID-19 and Increased Alcohol Consumption: NANOS Poll Summary Report. Retrieved March 20, 2021, from https://www.ccsa.ca/covid-19-and-increased-alcoholconsumption-nanos-poll-summary-report.

Rodriguez, L.M., Litt, D.M., Stewart, S.H. (2020). Drinking to cope with the pandemic: the unique associations of COVID-19-related perceived threat and psychological distress to drinking behaviors in American men and women. *Addictive Behav*, 110, 106532.

Sallie, S.N., Ritou, V., Bowden-Jones, H., Voon, V. (2020). Assessing international alcohol consumption patterns during isolation from the COVID-19 pandemic using an online survey: highlighting negative emotionality mechanisms. *BMJ Open*, 10(11), e044276.

Sharma, P., Ebbert, J.O., Rosedahl, J.K., Philpot, L.M. (2020). Changes in substance use among young adults during a respiratory disease pandemic. *SAGE Open Medicine*, 8(9), 2050312120965321.

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

Abstract

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 in the databases PsychInfo, Medline, and CINAHL Complete. **Study Inclusion and Exclusion Criteria:** Inclusion criteria: tested for the relationship between physical activity and smokeless tobacco use; adult samples in the US. Exclusion criteria: used 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.

Introduction

Physical activity is an important area in health promotion (Frantz and Ngambare, 2013). Despite the benefits of physical activity on health outcomes including reduced risks of obesity, coronary heart disease, and type 2 diabetes (Reiner et al., 2013), recent published works imply that higher rates of regular physical activity may be associated with greater smokeless tobacco use among the general population (Walker et al., 2015; Spangler et al., 2014). This is problematic because smokeless tobacco use becomes a major public health concern. For example, a report conducted in 2017 shows that 8.7 million Americans used smokeless tobacco in the past month (Substance Abuse and Mental Health Services Administration, 2017). Longer-term health consequences of smokeless tobacco use include increased risk of conditions like oral disease, heart disease, stroke, and certain forms of cancer (Centers for Disease Control and Prevention, 2016).

Objective

Given the considerable health benefits associated with regular physical activity and the problems associated with smokeless tobacco use, it is important to gain a better understanding of the relationship between the two. To date, however, there has been no synthesis of the existing research on this topic. The purpose of this systematic literature review was to address this gap by identifying: 1) the direction of the relationship between physical activity and smokeless tobacco use reported in the published research, and 2) which variable—physical activity or smokeless tobacco use—is characterized most frequently as the predictor.

These two objectives have important implications for the development of health promotion and intervention programs. For example, a positive relationship between physical activity and smokeless tobacco use whereby physical activity is the predictor variable would imply that there is something about physical activity that might lead to smokeless tobacco use. As such, programs designed to increase physical activity would want to identify ways of promoting physical activity that do not simultaneously increase smokeless tobacco use.

Methods

Data Sources

The electronic databases PsychInfo, Medline, and CINAHL Complete were searched from January 1, 2007, to December 31, 2017. Restricting the review to the previous 10 years reflects current climates surrounding physical activity and smokeless tobacco use that have emerged in the US. Database searches were conducted simultaneously and were limited to peer-reviewed empirical studies published in English with human and adult subjects. Three steps were used to search. In the first step, the term 'smokeless tobacco' was entered as a subject term. Next, 'physical activity' was entered as subject terms. The final step combined the two searches using the operator "and."

Inclusion and Exclusion Criteria

Inclusion criteria were samples drawn from the US of adults that reported results of analyses testing the relationship between physical activity and smokeless tobacco use. Studies were excluded if the sample was heavy smokers (i.e., those who smoke ≥ 25 cigarettes/day (Wilson et al., 1992) because a sample of individuals who are heavy smokers is likely to differ in a variety of ways from a sample of individuals who are not, and integrating findings of studies that sampled from such different populations would be inappropriate.

Data Extraction

The titles and abstracts captured by the searches were prescreened by the author. Studies deemed potentially relevant were independently reviewed and compared against inclusion/exclusion criteria. Articles that did not meet the inclusion criteria were removed, and articles that met inclusion criteria were then evaluated to ensure methodological quality.

Results

The initial searches captured 81 unique articles, of which 38 were excluded on the basis of abstract and title screening, leaving 43 articles for full-text review. Following full-text review, 6 studies met inclusion criteria and were included in this review (Table 1).

Table 1: Summary of reviewed articles			
Paper (N); study type	Aims/objectives of study	Major findings	
Walker et al., 2015 (N=34,208); quantitative study	To determine whether there are relationships among physical activity and health risk behaviors.	Smokeless tobacco use had a positive relationship with meeting physical activity guidelines ($\chi^2(7)$ = 185.03, P<.001).	
Spangler et al., 2014 (N= 29,536); quantitative study	To examine the correlates of smokeless tobacco use among first-year college students.	Students who participated in \geq 5 days/week of physical activity were 1.5× more likely to have used smokeless tobacco during the past 30 days (OR=1.5, 95% CI=1.07– 2.01).	
Hanson et al., 2011 (N= 9,954); quantitative study	To investigate the relationship between the use of smokeless tobacco, weight gain, and the incidence of obesity.	Regular physical activity during leisure time was more common in smokeless tobacco users than never users of tobacco (19.4% vs 18.8%).	
Noonan & Duffy, 2012 (N= 498); quantitative study	To understand various factors that predict smokeless tobacco use in operating engineers.	There is no significant correlation between physical activity and smokeless tobacco use (p=.416)	
Terry- McElrath, et al., 2011 (N=45,000); quantitative study	To examine the relationship between substance use and exercise in school athletic team over time.	Exercise was associated with lower levels of smokeless tobacco use. (p=.0109)	
Friesen, 2010 (N=333); mixed method study	To examine the effectiveness of an initiative to promote physical activity, improve nutrition, and implement other healthy lifestyle changes.	The percentage of smokeless tobacco users among those who reporting exercising 3–4 days/week declined from 11.2% to 10.0%.	

Type of relationship

Three of the six studies (50%) documented a positive relationship between physical activity and smokeless tobacco use (Walker et al., 2015: Spangler et al., 2014; Hanson et al., 2011). Walker et al. (2015) indicated that smokeless tobacco use had a positive relationship with meeting physical activity guidelines ($\chi^2(7)=185.03$, P<.001). Spangler et al. (2014) suggested that students who participated in \geq 5 days/week of physical activity were 1.5× more likely to have used smokeless tobacco use during the past 30 days (OR=1.5, 95% CI=1.07-2.01). Hanson et al. (2011) also mentioned that regular physical activity during leisure time was more common in smokeless tobacco users compared with never users of tobacco (19.4% vs 18.8%). Two studies (33%) documented a negative relationship between physical activity and smokeless tobacco use (Terry-McElrath et al., 2011; Friesen, 2010). Terry-McElrath et al. (2011) found that exercise was associated with lower levels of smokeless tobacco use (p=.0109). Friesen (2010) also reported that the percentage of smokeless tobacco among those who reported exercising 3-4 days/week declined from 11.2% to 10.0%. One study (17%) revealed there was no significant correlation between physical activity and smokeless tobacco use (p=.416) (Noonan and Duffy, 2012).

Predictor variable

Four studies (67%) conceptualized physical activity as the predictor variable (Walker et al., 2015; Hanson et al., 2011; Terry-McElrath et al., 2011; Friesen, 2010) and two (33%) conceptualized smokeless tobacco use as the predictor variable (Spangler et al., 2014; Noonan and Duffy, 2012).

Discussion

To our knowledge this is the first systematic review of the published literature that reports on the relationship between physical activity and smokeless tobacco use. Results revealed a positive relationship between physical activity and smokeless tobacco use, but a less clear picture emerged with respect to which variable was considered the predictor. Of the 6 studies, four (67%) conceptualized physical activity as the predictor, whereas two (33%) conceptualized smokeless tobacco use as the predictor. Taken together, the results of this systematic review indicate that higher rates of smokeless tobacco use are associated with higher levels of physical activity, but there is no clear evidence in the published literature of which variable is driving this relationship.

Implications for Health Promotion Programs

Findings from this systematic review have implications for health promotion programs that have the goal of increasing physical activity. Although it is unclear whether physical activity drives increases in smokeless tobacco use, developing strategies to protect against this possibility may be worthwhile. Therefore, when designing programs to increase physical activity, it may be useful to highlight some health consequences of smokeless tobacco use to help prevent unintended increases in smokeless tobacco use that may accompany increases in physical activity.

Results of this systematic review also have implications for health promotion programs that aim to limit or reduce smokeless tobacco use. One recent recommendation for limiting or reducing smokeless tobacco use is to highlight the negative consequence of weight gain (Hanson et al., 2011). The idea is that stable current smokeless tobacco users, compared with individuals who have never used any kind of tobacco, seemed to be associated with both weight gain (OR=1.31, 95% CI=1.04-1.65) and incident obesity (OR=1.93, 95% CI=1.13-3.30). However, this may be an ineffective approach, particularly if individuals who are using smokeless tobacco increase physical activity as a weight management technique as has been suggested in the literature (Hanson et al., 2011). Again, although it is unclear whether smokeless tobacco use drives increases in physical activity, it might be advantageous for smokeless tobacco use prevention messages to determine whether relying on information about weight gain will really be effective.

Future Research

Results of this systematic review identified several gaps in the published literature that, when addressed, will significantly advance our understanding of the relationship between physical activity and smokeless tobacco use. One gap that should be addressed is to elucidate the temporal or causal relationships between physical activity and smokeless tobacco use. Future studies should adopt research designs that allow for formal tests of temporal and causal links between the two. Furthermore, this work should control for personality characteristics that could potentially serve as confounders of the relationship between physical activity and smokeless tobacco use. Although the studies included in this review used a wide range of demographic covariates, very few controlled for personality characteristics. This will be an important avenue for future research as it will rule out the possibility that the positive relationships reported in the literature are due to personality traits common to physical activity and smokeless tobacco use. Another avenue for future research is to identify mechanisms that link physical activity and smokeless tobacco use. That is, why would physical activity lead to increases in smokeless tobacco use? Or, why would smokeless tobacco use lead to increases in physical activity? Regarding the former, Chagué et al (2015) speculated that smokeless tobacco is widely used by young athletes to enhance performance because nicotine improves some aspects of physiology. With respect to the latter, Van Duser and Raven (1992) have suggested that smokeless tobacco use increases oxygen uptake, cardiac output, and heart rate, which may lead to more physical activity participations. Although these studies have offered explanations for different mechanisms that could explain why physical activity and smokeless tobacco use are related, very few studies have directly tested these or other mechanisms.

The measures of physical activity varied considerably. The measures of physical activity included intensity, frequency, or duration, and some studies combined two or more characteristics into a single measure while others did not. There was no obvious consensus with respect to which characteristics should be included in measures, nor was there consensus about whether any one of the characteristics was any more important than another in the context of smokeless tobacco use. Future research might begin to explore whether these dimensions of physical activity make independent contributions or whether they combine in some particular interactions. More research in this area is needed to advance our understanding of the features of physical activity associated with smokeless tobacco use.

Although this review implies a positive relationship between physical activity and smokeless tobacco use, it is important to acknowledge that some work in the substance abuse treatment has reported the opposite. As an example, Collingwood and colleagues developed a 12-week physical activity training program as a substance abuse intervention for youth. The evaluation of the intervention found significant reductions in the percentage of youth who reported using cigarettes, smokeless tobacco, and alcohol. Reconciling these findings with results from this systematic review has the potential to open up new avenues of future research.

Limitations and Strengths

Although the results of this systematic review make a valuable contribution to the literature, there are a number of limitations of the studies upon which the review is based. All of the studies relied on selfreport measures, which are subject to biased recall and social desirability. None of the studies controlled for personality characteristics that may be related to both physical activity and smokeless tobacco use, which precludes ruling out these traits as a source of spuriousness.

Despite these limitations, the review has a number of strengths. One is the approach to the literature review whereby literature across disciplines was systematically gathered and synthesized. The measures of physical activity and smokeless use differed across the studies suggesting that the positive relationship is robust across different selfreport measures. Finally, there was considerable variability with respect to the samples increasing confidence that the findings herein are not tied to a specific group.

Conclusions

Results of this systematic review suggest a positive relationship between physical activity and smokeless tobacco use. There is less agreement regarding which variable serves as the predictor or whether the relationship is a reciprocal one. These findings have implications for the design of health promotion programs and highlight important gaps in the existing literature that should be addressed by future research.

References

Centers for Disease Control and Prevention (2016, December 1). *Smokeless Tobacco: Health Effects.* Retrieved January 20, 2021, from https://www.cdc.gov/tobacco/data_statistics/fact_sheets/smokeless/ health_effects/index.htm.

Chagué, F., Guenancia, C., Gudjoncik, A., Moreau, D., Cottin, Y., Zeller, M. (2015). Smokeless tobacco, sport and the heart. *Arch Cardiovasc Dis*, 108, 75-83.

Collingwood, T.R., Sunderlin, J., Reynolds, R., Kohl, H.W. (2000). Physical training as a substance abuse prevention intervention for youth. *J Drug Educ*, 30, 435-451.

Frantz, J.M., & Ngambare, R. (2013). Physical activity and health promotion strategies among physiotherapists in Rwanda. *Afr Health Sci*, 13, 17-23.

Friesen, C.A. (2010). Operation Wellness: a university/community collaboration to enhance adult wellness. *Fam. Consumer Sci. Res. J*, 39, 152-160.

Hanson, J., Galanti, M.R., Magnusson, C., Hergens, M-P. (2011). Weight gain and incident obesity among male snus users. *BMC Public Health*, 11, 371.

Noonan, D., & Duffy, S. A. (2012). Smokeless tobacco use among operating engineers. *J Addict Nurs*, 23, 132-136.

Reiner, M., Niermann, C., Jekauc, D., Woll, A. (2013). Long-term health benefits of physical activity—a systematic review of longitudinal studies. *BMC Public Health*, 13, 813.

Spangler, J., Song, E., Pockey, J., Sutfin, E.L., Reboussin, B.A., Wagoner, K., Wolfson, M. (2014). Correlates of smokeless tobacco use among first year college students. *Health Educ. J*, 73, 693-701.

Substance Abuse and Mental Health Services Administration. (2017, May 31). *Report shows that 8.7 million Americans used smokeless tobacco in the past month*. Retrieved January 18, 2021, from https://www.samhsa.gov/newsroom/press-announcements/201705311030

Terry-McElrath, Y.M., O'Malley, P.M., Johnston, L.D. (2011). Exercise and substance use among American youth, 1991–2009. *Am J Prev Med*, 40, 530-540.

Van Duser, B.L., & Raven, P.B. (1992). The effects of oral smokeless tobacco on the cardiorespiratory response to exercise. *Med. Sci. Sports Exerc*, 24, 389–395.

Walker, A., Langdon, J., Johnson, K. (2015). Relationships among meeting physical-activity guidelines and health risk behaviors. *J Phys Act Health*, 12, 776-781.

Wilson, D., Wakefield, M., Owen, N., Roberts, L. (1992). Characteristics of heavy smokers. *Prev Med*, 21, 311-319.

Selections from Death Kindly Stopped

Chanel Earl

Brigham Young University

Summary

At the 2021 UASAL Annual Conference, the Languages and Literature section sponsored its first creative writing sessions. Instead of delivering traditional papers growing out of literary or linguistic analysis and accompanying research, all presenters were graduate creative writing students who read from their creative works-in-progress. This work, which was presented at the conference, is an excerpt from a longer work by the author.

1 // Amie

Amie is my daughter. But she doesn't know me.

When she was born, I was all hers. It was just the two of us alone with a delegation of nameless doctors and medical students. I screamed as she came into the world, a great guttural scream born of pain and exhaustion, and then—this is my earliest memory of her—she screamed too, for the first time, as if in solidarity. Like she knew what I was going through and was going through it too, like she had never been more upset in her entire life.

Well, I suppose she hadn't.

We loved each other instantly. She was beautiful and healthy, whole and perfect. She was ready for the world. I was tired and tired, broken and used up, not ready to be a mother.

Twenty-three years later, when Amie was in her accident, she screamed again. I wasn't there, but a paper bird told me that it was much like Amie's birth. Everything was loud. There was pain, rushing and confusion as her body crashed through the windshield and then against the asphalt, as the sirens and lights blared, as the doctors and nurses opened her, instead of me, as they put her back together.

Amie was dying. Amie will die in this story, and very soon. I will explain it. After all, I am her mother, and her story is about to intersect with my story, and she is about to be my daughter again.

2 // How Amie's Whole Life Flashed Before Her Eyes

It didn't.

But later, when I asked her about it, she said that instead of a flash, she saw a single memory, crisp and clear.

She was a scant seven years old, a gangly beanpole of a girl with hair she had cut herself (grounded for a week after that) and overalls she wore at every opportunity, swinging, pumping herself, higher and higher and higher. Her best friend, Oliver, was swinging next to her. Then without warning, and having never done it before, he jumped from his swing, right as it reached its zenith, flew into the air like a bird, like a baseball that was just struck, and landed on his knees on the grass before her.

Determined not to be outdone, she followed suit. She wanted to follow suit. Nine, ten, eleven, she counted, fifteen, sixteen swings, later, and later, she kept counting, and waiting and wanting to jump and fly like Oliver had, but she never had the courage. He stood up on his one given leg and his prosthesis, determined to cheer her on, but she didn't jump, just kept swinging and imagining she was flying, wishing she really could.

3 // Amie in the Hospital

Dying is never quiet, never easy. It wasn't for me, and it wasn't for Amie.

After the accident, but before she died, Amie filled a bed in the hospital—the same hospital she was born in—and breathed and listened.

When she first arrived, she couldn't move. She was on her back. She tried to open her eyes, but her eyelids were weighed down like a gold blanket. She tried to sit up. Nothing. She couldn't speak or vary her breathing. She didn't have control of her hands or feet, or bladder. She could hear, feel, smell.

She heard the doctors cyclone around her, calling to each other, using words in combinations she didn't understand. She heard her shirt as it was ripped open. Omnipresent pain: in her head, chest, stomach, her skin. One wheel on the bottom of her gurney squeaked with every rotation as they ran her through the hospital. She heard the beeping of alarms going off, each one causing a flurry of activity.

As she travelled, she felt each bump of her bed, each crack she was rolled over. She felt it in her chest, in her head. Broken ribs, broken collarbone, internal bleeding, blood loss, traumatic brain injury. Needles entered the bend of her arm. She was stitched and blotted and wrapped and so cold.

She smelled antiseptic, iodine, lemon, bad breath, blood, sweat.

She tasted salt and blood, and she couldn't move her tongue to escape it.

Things began to quiet down, and then Amie was wheeled into another room, where her family was waiting for her.

She heard Kurt, Nicole, and Jonathan stand up when they wheeled her into the room. Heard their collective intake of breath when they saw her. Heard Nicole start crying, "My baby, my baby," and then heard the cries muffle. Amie imagined her leaning into Jonathan's shoulder as he reached his arms up to hold her.

She said she felt the doctors, or nurses, or someone lift her into a new bed and lay a warm blanket over her. She heard the doctor tell her family that she was brain dead, breaking the news softly and simply, with no hint of emotion. Then Amie heard all three of them cry.

Jonathan asked what could be done. Nicole sobbed. Kurt sat down. Amie could hear his voice sink closer to the ground as he said her name a few times.

Amie heard every excruciating minute of her family's mourning. She heard the doctor leave. She heard the stillness in the room as the crying stopped. She heard them plan her immediate future: who would stay, who would go. She heard them refuse to plan any further.

I was alone when I died. My family didn't have a chance to cry for me until after I was already gone, but Amie had weeks with them. And after a few days she went from merely recognizing the voices of her family to recognizing their movements. She heard Nicole smile when Jonathan cracked a pun. She heard Kurt zone out as he played a game on his cell phone—his hands brushing against the screen, which was silent but for soft vibrations as he clicked. Jonathan usually visited in the evenings, and had no trouble sitting in silence, in fact, that was his main desire, and Amie would often forget he was there until she heard him clear his throat or turn the pages of a book. He would stay for hours though.

She could recognize the energy of her niece and Kurt's daughter, Willa, in the room, even if she wasn't talking. Her heart and lungs worked faster than the others. Willa couldn't sit still, but talked more and touched more; she opened the windows, then closed them, then opened them again before running out of the room. She never stayed long.

Mostly it was Nicole who stayed with her during the day. Amie came to expect the reassuring feel of Nicole's hand in hers; it was warm, and wrinkled, and strong. She learned to anticipate Nicole's fits of crying, which were usually preceded by some frantic breathing and maybe foot tapping.

And Nicole talked to her, a lot. She talked about their family and extended family. She talked about her days, and nights, what she ate, how she filled her time. How she felt. How much she loved Amie. She talked about when Amie was born, and how Amie grew up. She reminded Amie of how happy their lives had been together.

And Amie listened, it was all she could do. She still couldn't move, even to close her eyes or close her mouth or tap her fingers.

People seemed very interested in whether she could tap her fingers. And she did try. She tried for hours to send a message down to her right index finger: tap, tap, tap. It wouldn't comply.

As the days went on Amie began to catalogue the sounds. She heard the nurses and doctors walk or shuffle by, their footsteps becoming more and more familiar as the days went on. She learned to tell the difference between the brisk-paced morning nurse and the smooth glide of the night nurse. After a few days they were both replaced with another set of nurses, one who hummed, one who smelled of Indian curry. Sometimes she heard shoes squeaking outside her room, but that person never came in to see her.

Amie was soon familiar with the sounds of people using her bathroom, washing their hands.

The fluorescent lights in her room made a sort of humming sound whenever they were turned on.

The heater came on occasionally with an echoing roar that was much louder than Amie felt was necessary.

When everything else was quiet, she could hear the traffic outside. It sounded the same as when she was home.

When there was nothing to listen to, Amie perused her memories of other times, other sounds.

She tried to remember visiting Oliver here in the hospital when she was only twelve years old. She remembered realizing that he was going to die, and laughed that now it was her turn, laughed that even though she was dying, she didn't know any more about it than she had when she was twelve. All she knew was that with each successive day she couldn't tap her fingers, she was getting closer to it.

She was dying, but was she doing it right? She wondered if there were better ways to die than others. If she had the right thoughts, the right attitude. Oliver had admitted to Amie that he was afraid, and she told him not to be. She told him that he was going to a "better place" because that's what she had heard Nicole say once. She told him that he was going to be fine and it was the people who were going to continue living—Oliver's parents, his brother, his friends, her—that were going to be the sad ones.

Now her perspective was different. She found herself trying to calculate the grief she felt about dying, and the grief she guessed that her family felt, and she couldn't tell who was sadder. She thought that maybe she was, but knew that it was an impossible calculation.

She heard laughing in the halls and added it to her list of sounds.

The breathing machine she was hooked up to seemed to be getting louder every day.

Outside, rain fell. She could hear each drop hit the window, slowly at first, then violently as the drops increased.

A fly buzzed.

And then one day, after a time that felt much too long, her family was all together again, Nicole, Jonathan, and Kurt all came on the same day; only Willa was missing.

The doctor came in and explained that this was it. The chances of Amie improving at this point were practically zero, and they had made the right decision. It was time to say goodbye. Kurt and Jonathan gave Amie awkward hugs over the hospital bed.

"Bye, little sis," was all Kurt said.

And Jonathan said nothing.

Nicole requested that she say goodbye alone.

4 // Nicole's Confession

Here is what Nicole said to Amie:

I don't know if you can hear me. Can you think of a way to signal if you can hear me? Maybe you could flutter your eyelids or tap your fingers? No?

They say you are probably not, that you might not, oh, God, I don't even want to think about it.

I always thought I would be the one in the bed and you would be the one sitting here begging me to live. Isn't that the way it's supposed to be?

I have to tell you something, and I have to tell you now because we might not have much time. And I hope you can hear me, I wish I knew you would hear me. I wanted to tell you on a birthday or graduation day, maybe make a big deal out of it, but the time never seemed right. And then I thought I would just sit back and wait for the right time, like someday you would ask me if I had any secrets you didn't know about, and then I would say yes, and you would ask what, and it would all come out. Or maybe we would be sitting in the park sometime.

Well, that fantasy never happened.

I guess I was scared that if you found out I had kept this from you, you would be mad at me. But now you have to know. I have to tell you because if you, if you ... If you die without knowing, then you will meet her and not even know who she is.

Amie, I'm not your mom. I know you think of me as your mom, and I think of you as my daughter, but I'm really your grandma. Your Grandpa and I raised you after your mom died when you were less than a year old. He never liked the deception, don't be mad at him, but I thought it would be easier on you to just raise you thinking we were your parents, so you would never have to be an orphan or wonder about what happened to your mom, or miss her.

And it wasn't like it was a big change for you. You and your mom were already living with us when she died. You already knew us, really you spent more time with us than with her when you were a baby.

She had a lot of problems.

Now you will see her before I will, and when you do, tell her I love her. Tell her—her name is Willa, just like your niece—tell her that we all loved her, and we loved you for her. Tell her I am so sorry for everything. I am so sorry that she's gone, and now you, too.

5 // Amie's Final Moments

Amie's weeks in the hospital were over.

After Nicole's confession, Amie's family came back into the room. The doctor removed the breathing tube. And in a long moment, like watching curls of steam dissolve into a cold, clear sky, Amie died. I wasn't ready, she wasn't either, but what choice did we have.
Synthesis of Merocyanine Compounds

Jacob Newey, Kyler White, Mackay B. Steffensen Southern Utah University

Abstract

Brooker's merocyanine (MOED) is one of the more common compounds known to exhibit solvatochromism. Solvatochromic molecules exhibit a color shift based on the polarity of the solvent in which they are dissolved. This phenomenon arises from a variety of complex interactions and dynamical processes among the solvent, solute, and light. Molecules that display this property can be used to identify the polarity of solutions or in biological studies to characterize local polarity. In our attempts to synthesize novel solvatochromic compounds, we have developed a method to expedite the synthesis of MOED. This method was also applied to the synthesis of both a known and a novel merocyanine-based molecule.

Introduction

Functional dyes are a class of molecules that are valued for their color and chemical properties, which can be exploited for various applications. Merocyanine dyes have the common polymethine (C–H),

or polyene, structural feature. Many merocyanine dyes are known to exhibit solvatochromism, and this class of molecules is typified by Brooker's merocyanine, 1-methyl-4-[(oxocyclohexadienylidene) ethylidene]-1,4-dihydropyridine, or MOED. Solvatochromism occurs in some molecules containing an extended conjugated pi bond system where electron density may localize in opposing regions of the molecule. Redistribution of electrons within the molecule occurs with changes in the polarity of the solvent environment around the molecule. There are two major resonance forms that can be drawn for MOED; one is represented as a zwitterion, while the other is electronically neutral (Fig. 1).¹



Figure 1. Resonance structures of Brooker's merocyanine (MOED).

In polar solvents, the electronic distribution of MOED is better represented by the zwitterion form, with the neutral form a more accurate depiction of MOED in nonpolar solvents.² Altering the molecular electronic distribution leads to solutions of MOED exhibiting a red color in polar solvents, with blue solutions forming in less polar and aprotic solvents. In addition to solvent polarity, hydrogen bonding affects the distribution of electrons, where protic solvents favor the zwitterion form, and thus result in red solutions. The distribution of electrons not only alters the wavelengths of light the molecule absorbs, but MOED exhibits strong fluorescence in most solvents.³ Solutions of MOED dissolved in a variety of solvents ranging from polar protic to aprotic or nonpolar gives a spectrum of colors (Fig. 2).



Figure 2. MOED in different solvents. From left to right, the solvents are water, methanol, ethanol, *n*-propanol, isopropanol, *n*-butanol, *sec*-butanol, isobutanol, *tert*-butanol, acetonitrile, acetone, dimethyl sulfoxide (DMSO), dimethylformamide (DMF), cyclohexanol, and cyclohexanone.

The color-shifting properties of solvatochromic dyes has led to their use as a tool to investigate many phenomena. These dyes have found use as probes in biological systems to analyze cellular structure features, such as lipid domains, and biological processes like apoptosis and endocytosis.⁴ MOED has been used to functionalize molecules including cellulose to develop a sensor for various compounds including cyanide.⁵ A recent application of solvatochromism involved investigating the ability to differentiate between solutions of organic compounds having similar structures, such as constitutional isomers or proteins with or without their cofactors bound.⁶

The most utilized literature method for the synthesis of MOED (VI) 1,4-dimethylpyridinium iodide (III) and 4starts with hydroxybenzaldehyde (IV) employing piperidine (V) as a catalytic base⁷ with a reflux period of 24 hours.⁸ Although the methods described in the literature are relatively simple, they can require a great deal of time. A recent advance using sonication increases the reaction rate, with the syntheses of merocyanine dyes occurring in 15 minutes with yields of 90%.9 The goal of our work was to develop a more efficient synthesis of merocyanine-based compounds, with the focus on identifying novel solvatochromic compounds. The use of 1,8-diazabicyclo[5.4.0]undec-7ene (DBU) is known to catalyze the condensation of aromatic aldehydes and N-methyl pyridines in a solvent-free environment. However, these efforts were not focused on the synthesis of solvatochromic compounds and in most cases suffered from yields in the 70% range or lower.¹⁰

To initiate the condensation reaction with an aromatic aldehyde (Knoevenagel Condensation), the reaction requires the deprotonation of the active hydrogen at the 4-methyl position of 1,4-dimethylpyridinium iodide (III). We investigated the use of DBU (VII) as the catalytic base instead of the typical piperidine. We optimized this reaction using various solvents and developed a method to expeditiously synthesize and isolate MOED. We looked to test the scope of the reaction and were able to synthesize a novel merocyanine using 5-hydroxy-2-furaldehyde (VII). However, upon testing the product's solvatochromic properties we saw no visible change of color when the compound was dissolved in various solvents.

The method developed using DBU and a high-boiling-point solvent, *p*-xylene, employs traditional organic methods. This avoids specialized equipment and methods, such as sonication. The standard literature procedure was published as an undergraduate organic laboratory experiment; however, the expected 24-hour reflux is not conducive to a standard schedule where students meet to complete and experiment once a week. The method we developed could easily be adapted to a typical 3-hour undergraduate organic laboratory because of the shortened reaction time and ease of product isolation. The 1,4dimethylpyridinium iodide (III) required for the reaction could be synthesized in an earlier laboratory or may be purchased commercially.

Once we had obtained MOED through a known route, we compared the yield and product using our method that employs DBU as the catalytic base and *p*-xylenes as the high-boiling-point solvent. The product obtained was identical in all characteristics. We demonstrate the utility of this method in synthesizing a novel molecule in hopes of identifying a novel solvatochromic dye.

Methods

The synthesis of the target molecules was carried out in a two-step fashion. The synthesis of the 1,4-dimethylpyridinium iodide (III) was conducted on a large scale to provide enough material for all the planned syntheses. The second fragments required to complete the syntheses of the target molecules consisted of commercially available aromatic aldehydes. The synthesis of MOED utilized 4-hydroxybenzaldehyde (IV) as the second fragment. The synthesis of the novel target molecule utilized 5-hydroxy-2-furaldehyde (VII). The solvatochromic properties of all products were qualitatively tested by dissolving the synthesized molecules in a variety of solvents of differing polarity and observing the color of the resulting solutions. Other chemicals utilized were purchased from commercial suppliers and used without further purification. Melting points are uncorrected and determined on a Stuart SMP Automatic Melting Point apparatus. ¹H-Nuclear magnetic resonance (¹H-NMR) spectra were recorded on a Bruker Ascend 400, with chemical shifts given relative to the solvent. Mass spectra were recorded on an Advion expression Compact Mass Spectrometry (CMS) system.

Experimental Procedures

Synthesis of 1,4-dimethylpyridinium iodide (III)



The desired compound was synthesized with slight modifications to a literature procedure.¹¹ To a 200-mL round-bottom flask was added \sim 80 mL of acetonitrile with a stir bar. 4-methylpyridine (I) (10.5 mL,

107.4 mmol) was added to the solvent by syringe, followed by slow addition of methyl iodide (II) (8.0 mL, 128.9 mmol) (over 2 min). The reaction mixture was heated at reflux for 18 hours, after which the heat was removed, and the reaction was allowed to cool. The solution was then placed in a fridge at 4°C overnight. The following day no crystals were present until agitation of the solution. Once the solution was agitated, large feathery white crystals formed. The crystals were isolated by vacuum filtration and washed with diethyl ether. Upon washing with ether, a large mass of crystals formed in the mother liquor. This second crop of crystals was also isolated by filtration and washed with ether to give off-white crystals. The total yield was 23.97 g (95%).

Data for 1,4-dimethylpyridinium iodide (III)

<u>mp:</u> 152-154 °C (lit. 152 °C)¹²

¹<u>H NMR:</u> (400 MHz, CD₃OD) δ 8.77-8.73 (d, 2 H), 7.96-7.91 (d, 2 H), 4.38-4.36 (s, 3 H), 2.71-2.67 (s, 3 H)

<u>MS:</u> APCI-MS (m/z) [M]⁺ calculated for C₇H₁₀N⁺, 108.2; found 108.1

Synthesis of 1-methyl-4-[(oxocyclohexadienylidene) ethylidene]-1,4-dihydropyridine (MOED) (VI)



The target molecule was prepared according to a laboratory procedure.⁷ The procedure utilizes dry ethanol as the solvent, 83 mole% of piperidine (V) catalyst, and a reflux period of 24 hours. The solid isolated from the reaction is further reacted with boiling 0.2 M KOH for 30 minutes. Isolation of the crude product is followed by recrystallization three times using hot water. The isolated yield from out attempt was 83.5%, while the literature reported a yield of 86.3%. The characterization of the product matched literature values.

The novel method employed for the synthesis of 1-methyl-4-[(oxocyclohexadienylidene)ethylidene]-1,4-dihydropyridine (MOED) (VI)



To a 50-mL round-bottom flask with a stir bar was added 1,4dimethylpyridinium iodide (III) (1.17 g, 5.0 mmol) and 4hydroxybenzaldehyde (IV) (1.83 g, 15 mmol) and mixed with ~17 mL of p-xylene. To a round-bottom flask, DBU (VII) (0.70 mL, 5.7 mmol) was added by syringe while stirring. The solution was heated to boiling, then refluxed for 15 minutes. A dark red tar-like precipitate formed and stuck to the bottom of the flask. The reaction vessel was removed from heat and cooled to room temperature. The solvent was then decanted, leaving the tar-like precipitate in the flask. To the flask was added 14 mL of deionized water, and the tar was broken up with a spatula. This mixture was then vacuum-filtered, leaving a dark red solid. The crude solid was dissolved in ~40 mL of 0.2 M KOH solution and heated until the solid dissolved. The vessel was cooled to room temperature then placed on ice. Dark red crystals formed and were isolated using vacuum filtration. The material was recrystallized a second time using the same procedure and upon filtration gave shiny maroon crystals that were dried thoroughly in a desiccator to a constant mass. The yield was 0.934 g (88%).

Data for 1-methyl-4-[(oxocyclohexadienylidene) ethylidene]-1,4-dihydropyridine (MOED) (VI)

<u>mp:</u>	212 °C (decomposition) (lit. 208 °C, decomposition) ¹³				
¹ <u>H NMR:</u>	(400 MHz, DMSO-d6) δ 8.13-8.09 (d, 2 H), 7.68-7.62 (d, 1 H), 7.51-7.46 (d, 2 H), 7.32-7.22 (s, 2 H), 6.47-6.41 (d, 1 H), 6.08-6.03 (d, 2 H), 3.92-3.88 (s, 3 H)				
<u>MS:</u>	APCI-MS (m/z) $[M - CH_3 + H]^+$ calculated for $C_{13}H_{12}NO^+$, 198.1; found 198.1				

Synthesis of the novel compound (E)-4-(2-(5-(hydroxyme-thyl)furan-2-yl)vinyl)-1-methylpyridin-1-ium Iodide (IX)



To a 20-mL vial with a stir bar was added 1,4-dimethylpyridinium iodide (I) (164 mg, 0.7 mmol) and 5-hydroxy-2-furaldehyde (VII) (265 mg, 2.1 mmol) with ~4 mL of p-xylenes. DBU (VII) (0.1 mL, 0.8 mmol) was added to the vial by syringe while stirring. The solution was heated to ~110°C for 15 minutes. A black and green solid formed and stuck to the bottom of the vial. The vial was cooled to room temperature, and the solvent was decanted. Approximately 2 mL of water was then added. The sticky solid was released from the surface of the vial using a spatula, and the suspension was thoroughly mixed with the water, resulting in a yellow/green powder falling out of solution. The product was isolated by vacuum filtration and dried to provide a yellow/green powder. The yield was 0.143 g (59%).

Data for (E)-4-(2-(5-(hydroxymethyl)furan-2-yl)vinyl)-1methylpyridin-1-ium iodide (IX)

<u>mp:</u> 217 °C (decomposition)

¹ H NMR:	(400 MHz, CD ₃ OD)					
	δ 8.68-8.65 (d, 2 H), 8.10-8.07 (d, 2 H), 7.77-7.72 (d, 1 H), 7.21-7.16 (d, 1 H), 6.87-6.85 (d, 1 H), 6.54-6.52 (d, 1 H), 4.63-4.61 (s, 2 H), 4.32-4.29 (s, 3 H)					
<u>MS:</u>	APCI-MS (m/z) [M - CH ₂ OH] ⁺ calculated for C ₁₂ H ₁₂ NO ⁺ 185 1; found 185 9					

Conclusions

Our efforts have culminated in an expedited synthesis and purification of merocyanine-based molecules. The method utilizes the nonnucleophilic but strongly basic DBU to catalyze the condensation of an aromatic aldehyde with an *N*-methyl 4-methyl pyridine through a Knoevenagel condensation. The method reduced the reflux time from a literature procedure of 24 hours to 15 minutes, with both methods producing similar yields. Upon optimization of the method, it was utilized to synthesize the novel (E)-4-(2-(5-(hydroxymethyl)furan-2-yl)vinyl)-1-methylpyridin-1-ium iodide (IX). In qualitative testing of this previously unreported molecule, no color change occurred in different polarity solvents, indicating the molecule was not solvatochromic. We anticipate this method to be broadly suitable for the synthesis of many known and yet undiscovered merocyanine dyes.

Acknowledgments

We acknowledge the generous support of the L. S. and Aline W. Skaggs Research Endowment and the Walter Maxwell Gibson Research Endowment for proving financial support for this project.

References

¹Morley, J.O.; Morley, R.M.; Docherty, R.; Charlton, M.H. Fundamental Studies on Brooker's Merocyanine. *J. Am. Chem. Soc.* 1997, *119* (42), 10192–10202. DOI: 10.1021/ja971477m

²Murugan, N.A.; Kongsted, J.; Rinkevicius, Z.; Agren, H. Demystifying the Solvatochromic Reversal in Brooker's Merocyanine Dye. *Phys. Chem. Chem. Phys.* 2011, *13* (4), 1290–1292. DOI: 10.1039/c0cp01014f

³Hoche, J.; Schulz, A.; Dietrich, L.M.; Humeniuk, A.; Stolte, M.; Schmidt, D.; Brixner, T.; Würthner, F.; Mitric, R. The Origin of the Solvent Dependence of Fluorescence Quantum Yields in Dipolar Merocyanine Dyes. *Chem. Sci.* 2019, *10* (48), 11013–11022. DOI: 10.1039/c9sc05012d

⁴Klymchenko, A.S. Solvatochromic and Fluorogenic Dyes as Environment-Sensitive Probes: Design and Biological Applications. *Acc. Chem. Res.* 2017, *50* (2), 366–375. DOI: 10.1021/acs.accounts. 6b00517

⁵Nandi, L.G.; Nicoleti, C.R.; Bellettini, I.C.; Machado, V.G. Optical Chemosensor for the Detection of Cyanide in Water Based on Ethyl(Hydroxyethyl)Cellulose Functionalized with Brooker's Merocyanine. *Anal. Chem.* 2014, *86* (10), 4653–4656. DOI: 10.1021/ac501233x

⁶Madeira, P.P.; Loureiro, J.A.; Freire, M.G.; Coutinho, J.A.P. Solvatochromism as a New Tool to Distinguish Structurally Similar Compounds. *J. Mol. Liq.* 2019, *274*, 740–745. DOI: 10.1016/j.molliq. 2018.11.050

⁷Brooker, L.G.S.; Keyes, G.H.; Heseltine, D.W. Color and Constitution. XI.1 Anhydronium Bases of p-Hydroxystyryl Dyes as Solvent Polarity Indicators. *J. Am. Chem. Soc.* 1951, *73* (11), 5350–5356. DOI: 10.1021/ ja01155a097

⁸Minch, M.J.; Shah, S.S. Merocyanin Dye Preparation for the Introductory Organic Laboratory. *J. Chem. Educ.* 1977, *54* (11), 709. DOI: 10.1021/ed054p709

⁹Saady, A.; Sudhakar, P.; Nassir, M.; Gedanken, A. Ultrasonic Assisted Synthesis of Styrylpyridinium Dyes: Optical Properties and DFT Calculations. *Ultrason. Sonochem*.2020, *67* (105182), 105182. DOI: 10.1016/j.ultsonch.2020.105182

¹⁰Seiad, L.L.; Villemin, D.; Bar, N.; Hachemi, M. Solvent-Free Condensation of Methyl Pyridinium and Quinolinium Salts with Aldehydes Catalyzed by DBU. *Synth. Commun.*2012, *42* (5), 650–657. DOI: 10.1080/00397911.2010.528573

¹¹Niu, W.; Guo, L.; Li, Y.; Shuang, S.; Dong, C.; Wong, M.S. Highly Selective Two-Photon Fluorescent Probe for Ratiometric Sensing and Imaging Cysteine in Mitochondria. *Anal. Chem.* 2016, *88* (3), 1908–1914. DOI: 10.1021/acs.analchem.5b04329

¹²Coulson, E.A.; Jones, J.I. Studies in Coal Tar Bases. I. Separation of βand γ Picolines and 2:6-Lutidine. *J. Soc. Chem. Ind.* 1946, *65* (6), 169– 175. DOI: 10.1002/jctb.5000650605

¹³Hünig, S.; Rosenthal, O. Farbe und Konstitution II: Phenolbetainfarbstoffe. *Justus Liebigs Ann. Chem.* 1955, *592* (3), 161– 179. DOI: 10.1002/jlac.19555920302

Phosphatidylserine in Supported Lipid Bilayers Binds His-Tagged Proteins

Ryan S. Koch, Christopher M. Reynolds, Sydney J. Williams, Dylan J. Keiser, Christopher F. Monson Southern Utah University

ABSTRACT

Phosphatidylserine is a phospholipid that has previously been shown to bind copper ions. Here, phosphatidylserine is used as a method for separating His-tagged proteins from non-His-tagged proteins. The phosphatidylserine is incorporated into a supported lipid bilayer inside a microfluidic device. Under basic conditions, copper ions bind to the phosphatidylserine and His-tagged proteins then bind to the copper ions, fixing the His-tagged proteins to the supported lipid bilayer and allowing non-copper-binding proteins to be rinsed away. This system was demonstrated using a fluorescently labeled hexahistidine-tagged protein and bovine serum albumin with a different fluorescent label as a model non-His-tagged protein.

INTRODUCTION

Lipids are one of the four major macromolecules that make up life on earth. A subsection of lipids is amphiphilic in nature as the molecules contain both hydrophilic and hydrophobic regions.¹ These amphiphilic lipids organize into micelles (clumps of lipids), bilayers (flat layers of lipids), or vesicles (hollow balls of lipids) in a polar solvent such as water. This property is what creates lipid bilayers that form cellular membranes.² When lipid vesicles are exposed to clean, flat glass, the vesicles flatten, burst, and merge into a supported lipid bilayer (SLB) in what is known as vesicle fusion.²⁻⁵ SLBs have been used to study many different membrane properties, including lipid domain formation,⁶ protein–lipid interactions,^{7,8} and sensing.⁹ Proteins are usually thought of as responsible for the more complex features of lipid bilayers, but some lipids have specific functions as well, such as phosphatidylserine.

Phosphatidylserine (PS) is a phospholipid and an important component of many cell membranes, particularly in eukaryotes.¹⁰ PS is found on the inner leaflet of the plasma membrane, until the cell undergoes apoptosis (regulated cell death) and the PS is flipped to the outer leaflet as an "eat me" signal to phagocytes.¹⁰⁻¹³ PS has been shown to bind copper (II) ions from solution, and under neutral to basic conditions, copper binds to PS with high affinity.^{11,14,15} This affinity is greatly reduced in acidic conditions, leading to the release of the copper ions.^{14,15}

Copper is an essential component of many enzymes but is toxic at high concentrations.¹⁶⁻¹⁸ As a result, the human body contains many copper-binding proteins with a variety of functions that maintain homeostasis of copper levels.^{16,19-21} The malfunction of these copper-binding proteins may be linked to diseases such as Alzheimer and Parkinson diseases.^{18,22}

When working with biomolecules and particularly proteins, Ni-His columns are a common purification method.^{23,24} Most commonly, expressed proteins are tagged with a hexahistidine tag, allowing the desired proteins to be separated from other proteins, DNA, lipids, and cellular debris.^{23,24} The materials run through the column in basic buffer to facilitate attachment of His tags to Ni ions. The pH is then lowered to release the proteins.^{23,24} We have developed a copper protein filter analogous to the Ni-His column, using PS to hold copper. This also takes advantage of the relatively inert nature of lipid bilayers compared with many other solid surfaces.

PROCEDURE

Device Fabrication

Microfluidic devices were fabricated by stepwise а polydimethylsiloxane (PDMS) addition method. First, a glass box was constructed in the final dimension of the microfluidic device with an open top. Glass pieces approximately 100 µm thick were superglued to the bottom glass piece to form the landing pads where solution junctions were made, and an additional thin piece of glass was placed between the front and rear landing pads (but not glued) held off the bottom glass piece by the landing pads. PDMS was then poured into the device to just cover the landing pads and hold the piece between the landing pads in place, and the device was baked for 10 minutes at 110°C to harden the PDMS. Holes were cut in the PDMS over the landing pads, and pieces of 0.8mm-diameter steel wire were placed in the holes, enough PDMS was added to just hold the steel wire in place, and the device was again baked at 110°C for 10 minutes. Glass supports were then added to the device using 1-mm-thick glass. First, a support over the central area of the device was added, and enough PDMS was added to cover it. The device was again baked at 110°C for 10 minutes. Then, longer, thinner 1-mmthick glass supports were added to each side of the center of the device, PDMS was added to cover the final supports with a few millimeters of PDMS, and the device was baked overnight. Following this final bake, the glass box and the steel wires were removed. Two Exacto knife blades taped together were used to cut out channels 200- to 500-µm thick from the landing pads, and the PDMS in the channels was removed with tweezers. Before each baking step discussed previously, the device was vacuumed to around 3 Torr to remove any bubbles in the PDMS.

Lipid Vesicle Preparation and Glass Cleaning

Lipid vesicles were prepared following a modified version of the freeze-thaw extrusion method, and glass was cleaned using 7X detergent and annealing at 540°C. Both of these methods have been discussed in previous work.²⁵

Protein Labeling

His-tagged proteins (5 Prime PerfectPro 6×His-tagged Protein Ladder, Fisher) and bovine serum albumin (BSA, Sigma-Aldrich) were purchased and used as received. The His-tagged proteins were labeled with Texas Red sulfonyl chloride (Thermo Fisher Scientific), and the BSA was labeled with Alexafluor 350 (Invitrogen). In either case, a few

mg of protein were mixed in a phosphate buffer (0.01 M, pH 8) with 0.5– 1.0 mg of labeling reagent and allowed to react for 1 hour. The labeled protein was separated from unreacted labels by passing it through a size exclusion column (G-Biosciences) that was preloaded with Tris buffer (0.1 M NaCl, 0.01 M Tris, pH 8), and the elution was performed with additional Tris buffer.

Device Operation

The device was first assembled as shown in Figure 1. Binder clamps were used to ensure the clean glass slide stayed sealed to the microfluidic device. Water was then introduced to the device through the supply tubes. The device was then submerged in an evaporation dish of deionized water, and 30 µL of lipid vesicles containing 10% 1,2dioleoyl-sn-glycero-3-phospho-L-serine (DOPS, Avanti Polar Lipids), 1,2-dioleoyl-sn-glycero-3-phosphoethanolamine-N-fluorescein 1% (Fluorescein DOPE, Fischer), and the balance 1-palmitoyl-2-oleoylglycero-3-phosphocholine (POPC, Avanti Polar Lipids) was introduced into the device and allowed to sit for around 30 minutes. The device was then rinsed with Tris buffer (0.1 M NaCl, 0.01 M Tris, pH 7.5) using a gravity-driven flow with a flow rate of a few microliters a minute and imaged using a fluorescence microscope (Nikon Eclipse, HQ F filter cube 460-500 nm excitation, 510-560 nm emission) to verify bilaver formation. Copper was then bound to the device using a Tris buffer solution containing 0.2 mM CuSO₄. This flow (and all subsequent flows) was also gravity-driven with a flow rate of a few microliters a minute. The copper solution was flowed over the device for approximately 3 minutes and resulted in a decrease in the observed fluorescence due to copper quenching the fluorophores.¹⁴ The device was prepared by rinsing with Tris buffer containing no copper for approximately 2 minutes, and then 10 µL of protein solution was added. Often, a mixture of Texas Red-labeled His-tagged proteins, which should bind to copper, and Alexafluor 350-labeled BSA, which should not bind to the bilayer, was used.^{26,27} The device was monitored in a fluorescence microscope while alternating between a filter cube tuned to Texas Red (530-560 nm excitation, 620-660 emission) and one tuned to the Alexafluor (340-380 excitation, 435–485 emission) until the protein was observed in the channel, at which point the protein was allowed to sit for approximately 5 minutes to facilitate binding. Unbound protein was then rinsed from the channel using Tris buffer. The rinsing was continued until a stable protein fluorescence signal was obtained. This often required more than an hour.

Phosphatidylserine in Supported Lipid Bilayers 267



Figure 1. Device schematic. At left are shown side and top views of the device. The inlets are at the right of the device and the outlet is on the left. The position of the SLB, which attaches to a thin glass slide at the bottom of the device, is illustrated at right. Glass within the PDMS serves as internal stiffeners.

When the protein fluorescence signal was stable, the solution was made acidic (usually a citric acid solution with a pH of approximately 4 was used), releasing the copper from the bilayer. This allowed us to verify that the observed fluorescence was due to specific protein–copper binding. Finally, the device was rinsed with basic Tris buffer to verify that observed fluorescence loss was not due to pH-dependent fluorescence.

RESULTS/DISCUSSION

The device is made primarily of PDMS, with glass serving as the background for fluorescence measurements to reduce nonspecific protein absorption to PDMS and also as stiffeners to prevent the device from leaking. The device is adhered to a cleaned and annealed glass coverslip. The glass coverslip has a SLB formed on it when lipid vesicles are added to the device. A partial bilayer may also form on the top glass layer, but that glass is not clean enough to support a complete SLB. Because the SLB includes DOPS, when copper ions are flowed through the device as illustrated in Figure 2 (top left panel) the DOPS binds to the copper ions and holds them on the surface. Any free copper ions are rinsed away with buffer, and then a mixture of proteins including Histagged proteins (represented by pink shapes in Figure 2, top right panel) and non-His-tagged proteins (represented by yellow and blue shapes in Figure 2, top right panel) are added to the device. The His-tagged proteins attach to the device, and the non-His-tagged proteins are rinsed away by flowing buffer through the device (Figure 2, bottom left panel). Finally, acidic solution is flowed through the device. This causes the DOPS to release the copper and thus frees the proteins to be collected at the outlet.



Figure 2. Illustration of device operation. Top left, a bilayer containing DOPS is prepared, copper is added to the device, and excess copper is rinsed away. Top right, a mixture of His-tagged proteins (pink) and non-His-tagged proteins is added to the device. Bottom left, when the protein mix is rinsed away, the His-tagged proteins remain attached to the bilayer while the non-His-tagged proteins are rinsed away. Bottom right, finally acid is added to the device, which causes the DOPS to release the copper and thus frees the His-tagged proteins to be collected.

The proteins were labeled with fluorophores to enable their visualization with a fluorescence microscope. A section of the device was selected, and this section was tracked throughout the run. The vesicles used to form the SLB contained a small amount (approximately 1%) of lipids labeled with fluorescein. This allowed the initial bilayer formation to be visualized. Copper addition could be verified by the quenching it induced. Thus, the initial stages of bilayer formation were verified visually to ensure the device was ready for subsequent steps.

When the device was prepared with a SLB and bound copper ions, a mixture of fluorescently labeled proteins resulted in an increase in the fluorescence of the observed region. This increase occurred in the colors with which the proteins were labeled—typically red and blue (the Histagged protein was labeled with Texas Red and the non-His-tagged protein was labeled with Alexafluor 350). This jump is illustrated in Figure 3. Fluorescence quickly goes from approximately 550 counts (noise) to approximately 16000 counts. The protein is allowed to sit in the channel for a time to allow the protein to diffuse to the edge of the channel and bind to the copper (and thus the bilayer). After the binding period, unbound protein is rinsed away by flowing buffer through the device. As the vast majority of the protein is not bound to the device but floating freely in the middle of the channel, the observed fluorescence decreases dramatically, as can be seen in Figure 3.



Figure 3. Fluorescence measurements during two runs. At left is shown a simple run in which the copper-binding protein plateaus during basic rinsing and then releases in acidic solution. At right is shown a more complex run in which the copper-binding protein fluorescence rises during the initial acid rinse and then gradually falls. Labeled arrows indicate times when protein is added to the bilayer, the basic rinse begins, and the acidic rinse begins.

Two separate runs are shown in Figure 3, which illustrate the types of behavior observed during the runs. A "simple" run is shown at left (top and bottom). As the protein is rinsed away, the fluorescence falls until it plateaus. In the run shown, the plateau happens at approximately 630 counts. After the plateau is reached, acid is added to the solution and the His-tagged protein is quickly released, causing the observed fluorescence to fall to baseline levels. In this type of run, the sequence of events is easily understood—some of an initial injection of protein is bound to the copper on the bilayer until the solution is made acidic, at which point the protein is released. In other words, the device functions exactly as hoped and anticipated.

In other cases, the behavior was as shown in the right half of Figure 3. This begins as before—protein is added (in this case, the fluorescence signal for His-tagged and non-His-tagged proteins are shown in red and green, respectively) and allowed to bind, and then unbound protein is rinsed away. In this case, the injected protein is a mixture of the His-

tagged and non-His-tagged protein. As expected, upon rinsing the Histagged protein and non-His-tagged protein fluorescences both fall, the His-tagged protein to a non-zero plateau and the non-His-tagged to near its initial value (what could be considered zero, or no protein binding). However, at this stage, the behavior of the His-tagged protein becomes slightly more complicated. Rather than plateauing and remaining stable, the fluorescence plateaus and then begins a gradual rise.

Although we do not fully understand the reasons for the second type of behavior, it is likely due to a combination of proteins from upstream in the device being dislodged by flow and then binding to free sites in the observation window and some nonspecific binding, likely because of imperfect bilayer formation. Additionally, because this behavior is almost only seen in runs in which a non-His-tagged protein has been added, it is also possible that BSA (the non-His-tagged protein used) is interfering either with protein binding to the bilayer or with acid transport to the bilayer, both of which are feasible given BSA's function as a nonspecific binder and its many protonatable groups.

CONCLUSIONS

We have demonstrated that copper binding to PS can be used to bind aqueous His-tagged proteins to a surface and have used this to develop a protein filtration method analogous to a metal chelation column. This was demonstrated in a microfluidic device that was created using inexpensive and readily available methods and materials and thus could be an important model for other low-cost devices.

ACKNOWLEDGMENTS

We thank Susan Harris for fabricating the ceramic annealing rack. We thank the SUU faculty scholarly support fund and C.M.R. thanks the Walter Maxwell Gibson research foundation for funding.

REFERENCES

1. Zheng, L.; Fleith, M.; Giuffrida, F.; O'Neill, B. V., Schneider, N. Dietary polar lipids and cognitive development: a narrative review. *Adv Nutr.* **2019**, *10*, 1163–1176.

2. Richter, R. P.; Bérat, R.; Brisson, A. R. Formation of solid-supported lipid bilayers: an integrated view. *Langmuir*. **2006**, *22*, 3497-3505.

3. Castellana, E. T.; Cremer, P. S. Solid supported lipid bilayers: from biophysical studies to sensor design. *Surf Sci Rep.* **2006**, 61, 429–444.

4. Yoshina-Ishii, C.; Boxer, S. G. Arrays of mobile tethered vesicles on supported lipid bilayers. *J Am Chem Soc.* **2003**, *125* (13), 3696-7.

5. Kung, L. A.; Kam, L.; Hovis, J. S.; Boxer, S. G. Patterning hybrid surfaces of proteins and supported lipid bilayers. *Langmuir.* **2000**, *16*, 6773-6776.

6. Stottrup, B. L.; Veatch, S. L.; Keller, S. L. Nonequilibrium behavior in supported lipid membranes containing cholesterol. *Biophys J.* **2004**, *86*, 2942-2950.

7. Neumann, J.; Hennig, M.; Wixforth, A.; Manus, S.; Radler, J.O.; Schneider, M.F. Transport, separation, and accumulation of proteins on supported lipid bilayers. *Nano Lett.* **2010**, *10*, 2903-2908.

8. Groves, J.T.; Wulfing, C.; Boxer, S.G. Electrical manipulation of glycan-phosphatidyl inositol-tethered proteins in planar supported bilayers. *Biophys J.* **1996**, *71*, 2716-2723.

9. Yang, W.; He, Y.; Xu, L.J.; Chen, D.; Li, M.; Zhang, H.; Fu, F.F. A Novel phosphatidylserine-functionalized AuNP for the visual detection of free copper ions with high sensitivity and specifity. *J Mater Chem B*. **2014**, *2*, 7765-7770.

10. Leventis, P. A.; Grinstein, S. The distribution and function of phosphatidylserine in cellular membranes. *Annu Rev Biophys.* **2010**, *39*, 407-427.

11. Cong, X.; Poyton, M. F.; Baxter, A. J.; Pullanchery, S.; Cremer, P. S. Unquenchable surface potential dramatically enhances Cu²⁺ binding to phosphatidylserine lipids. *J Am Chem Soc.* **2015**, *137* (24), 7785–7792.

12. Gordesky, S. E.; Marinetti, G.V. The asymmetric arrangement of phospholipids in the human erythrocyte membrane. *Biochem Biophys Res Com.* **1973**, *50* (4), 1027-1031.

13. Huang, B. X.; Akbar, M.; Kevala, K.; Kim, H. Y. Phosphatidylserine is a critical modulator for Akt activation. *J Cell Biol.* **2011**, *192* (6): 979–992.

14. Monson, C. F.; Cong, X.; Robison, A. D.; Pace, H. P.; Liu, C.; Poyton, M. F.; Cremer, P. S. Phosphatidylserine reversibly binds Cu^{2+} with extremely high affinity. *J Am Chem Soc.* **2012**, *134* (18), 7773–7779.

15. Jiang, X.; Zhang, J.; Zhou, B.; Li, P.; Hu, X.; Zhu, Z.; Tan, Y.; Chang, C.; Lü, J.; Song, B. Anomalous behavior of membrane fluidity caused by copper-copper bond coupled phospholipids. *Sci Rep.* **2018**, *8*, 14093.

16. Inesi, G. Molecular features of copper binding proteins involved in copper homeostasis. *IUBMB Life*. **2017**, *69* (4), 211-217.

17. Nishito, Y.; Kambe, T. Absorption mechanisms of iron, copper, and zinc: an overview. *J Nutr Sci Vitaminol (Tokyo)*. **2018**, *64* (1), 1-7.

18. Hsu, H. W.; Bondy, S. C.; Kitazawa, M. Environmental and dietary exposure to copper and its cellular mechanisms linking to Alzheimer's disease. *Toxicol Sci.* **2018**, *163* (2), 338–345.

19. Horng, Y. C.; Leary, S. C.; Cobine, P. A.; Young, F. B. J.; George, G. N.; Shoubridge, E. A.; Winge, D. R. Human Sco1 and Sco2 function as copper-binding proteins. *J Biol Chem.* **2005**, *280* (40), 34113–34122.

20. Xiao, Z.; Donnelly, P. S.; Zimmermann, M.; Wedd, A. G. Transfer of copper between bis(thiosemicarbazone) ligands and intracellular copper-binding proteins. Insights into mechanisms of copper uptake and hypoxia selectivity. *Inorg Chem.* **2008**, *47*, 4338-4347.

21. Davies, P.; Wang, X.; Sarell, C. J.; Drewett, A.; Marken, F.; Viles, J. H.; Brown, D. R. The synucleins are a family of redox-active copper binding proteins. *Biochem.* **2011**, *50*, 37–47.

22. Montes, S.; Rivera-Mancia, S.; Diaz-Ruiz, A.; Tristan-Lopez, L.; Rios, C. Copper and copper proteins in Parkinson's disease. *Oxid Med Cell Longev.* **2014**, 147251.

23. Bornhorst, J. A.; Falke, J. J. Purification of proteins using polyhistidine affinity tags. *Methods Enzymol.* **2000**, *326*, 245–254.

24. Hoffmann, A.; Roeder, R. G. Purification of his-tagged proteins in non-denaturing conditions suggests a convenient method for protein interaction studies. *Nucleic Acids Res.* **1991**, *19* (22), 6337.

25. Trujillo, M. J.; Scholes, D. T.; Reynolds, C. M.; Winegar, C.; Monson, C. F. Phosphatidylserine-copper (II) binding can lead to fast through-membrane copper transport. *J Utah Acad Sci Arts Lett.* **2015**, *92*, 257-271.

26. Watly, J.; Simonovsky, E.; Wieczorek, R.; Barbosa, N.; Miller, Y.; Kozlowski, H. Insight into the coordination and the binding sites of Cu^{2+} by the histidyl-6-tag using experimental and computational tools. *Inorg Chem.* **2014**, *53*, 6675-6683.

27. Cornell, D. G.; Patterson, D. L.; Hoban, N. The interaction of phospholipids in monolayers with bovine serum albumin and α -lactalbumin adsorbed from solution. *J Coll Interface Sci.* **1990**, *140*, 428-435.

Evaluation of Superfund Removal Action at the King Edward Mine

J. Andreas Lippert,¹ Charles F. Davidson,¹ Robert A. Davidson,² Tori L. Schaffer¹

¹Weber State University; ²Utah Valley University

Abstract

Thousands of abandoned uranium mines are located in the Four Corners Area from mining occurring between the 1940s and 1970s. The abandoned King Edward Mine, located on Manti-La Sal National Forest land, was the object of a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Removal Action in 2009 because of both environmental and safety issues, which included discharge of water contaminated with radionuclides and metals, eroding waste rock piles, and open adits. This study evaluated the effectiveness of the Superfund removal action at the King Edward Mine. Water samples from the remediated site were analyzed for arsenic, cadmium, lead, selenium, and uranium using inductively coupled plasma-mass spectrometry (ICP-MS). Samples from the mine adits substantially exceeded the elemental concentration limits for drinking water set by the Environmental Protection Agency (EPA). Samples taken from the stream above and below the mine had concentrations lower than the EPA drinking water regulations for four of the elements studied. Uranium concentrations from the samples taken upstream and downstream were

higher than EPA drinking water regulations, but they were not statistically different. Therefore, there was no evidence of additional seepage coming from the mine into the stream at the time of this study.

Introduction

Thousands of abandoned uranium mines are located in the Four Corners Area from mining during the 1940s through the 1970s. According to the U.S. Bureau of Land Management website, there are over 52,200 sites and 97,600 features that are considered abandoned mine lands as of January 2017 [1]. Even though mining in these areas ended decades ago, uranium and other toxic elements may still appear in the surroundings of abandoned mines and/or inadequately remediated mine workings long after they were closed. There has been significant research on the environmental contamination of uranium and other heavy metals from these abandoned uranium mines [2-5].

The U.S. Department of Agriculture Forest Service oversees the remediation of abandoned mines on their public lands. The abandoned King Edward Mine complex, located on Manti-La Sal National Forest land, was placed on the Environmental Protection Agency (EPA)'s National Liability List, which resulted in a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Removal Action in 2009 because of both environmental and safety issues. These issues included discharge of water contaminated with radionuclides and heavy metals, eroding waste rock piles, and open adits. The King Edward complex occupies 18 acres along the west bank of South Cottonwood Creek, which is used for irrigation on Ute Mountain Ute allotments. Wells in the alluvium of South Cottonwood Creek are used as drinking water sources for the town of Bluff, Utah. Eventually, South Cottonwood Creek flows into the San Juan River and then the Colorado River. The location of the King Edward complex is shown in Figure 1.

Removal actions are common at CERCLA Superfund sites when the contamination poses an immediate threat to human health and the environment. Removals are classified as either emergency, time-critical, or non-time-critical, depending on the extent and type of contamination.

Superfund Removal Action at King Edward Mine 277



Figure 1. Location of the King Edward uranium mine complex.

The King Edward abandoned uranium mine site was classified as an EPA Superfund Site where a non-time-critical CERCLA removal action was implemented. The removal action for the King Edward Mine consolidated and isolated the contaminated waste rock on site in an onsite repository, using a geotechnical nonpermeable liner and then covering the contaminated waste rock with three feet of clean soil taken from the surrounding area. The soil was allowed to vegetate using remediation techniques, surface roughening, seeding, and mulching. The mine adits were closed. The adit closures were engineered to allow mine adit water to drain and exit the mine adits while containing existing radon gas. The adit water was allowed to flow out across the ground and seep into the native soils as per EPA guidelines and instructions. The removal action was designed to isolate any seepage from the mine site to the stream below, minimize erosion, and minimize human and animal contact to uranium, radon gas, and heavy metals. This project studied the effectiveness of these non-time-critical CERCLA removal actions at the King Edward Mine site.

Removal Action History

An initial evaluation and cost analysis for the King Edward mine site was prepared for the Forest Service in 2005 [6]. Subsequently, a CERCLA Non-Time-Critical Removal Action King Edward Mine was implemented in the summer of 2009 [7-9]. The planned CERCLA action met all the requirements of 40 CFR § 1910.120. The project tasks to meet these requirements included:

- 1. Protection of archaeological resource areas
- 2. Adit closure
- 3. Mine adit surface water discharge diversion infiltration channels
- 4. Consolidating, recontouring and capping waste rock
- 5. Soil borrow source area development and reclamation
- 6. Access road improvement, abandonment and reclamation

Current Status

Satellite imagery shown in Figure 2 of the King Edward complex shows the result of the 2009 CERCLA action. The north, central, and south waste rock piles are clearly seen in the 2008 photo. The waste rock piles were consolidated into a north and central waste rock repository. These repositories can be seen in the 2020 satellite photo. Each repository had a geo-textile underlayment to prevent water seepage into the Cottonwood Creek and groundwater and a cap made from surrounding natural soil to prevent water and wind erosion of the waste rock. The CERCLA action also required recontouring and vegetation for erosion control, adit closure, and drainage infiltration channels to isolate the radon gas and soluble metals and radionuclides.



Figure 2. Satellite photos of King Edward mine complex showing before and after remediation.

The closure of adits was a critical part of the CERCLA action. Open mine adits present several safety and environmental hazards, including release of radon gas, public access, and surface water drainage discharge and seepage to South Cottonwood Creek. Comparison of the before and after photos in Figure 3 of the remediated north adit shows significant vegetation growth. The slope contours are improved, resulting in less erosion.



Figure 3. Before and after photos of the north adit closure and remediation.

The north and south adits had significant mine drainage. Figure 4 shows the remediated infiltration channel used to isolate and contain the mine drainage. The before and after photos show improvement on vegetation and erosion control surrounding the drainage areas. The infiltration channels were designed to divert the contaminated mine waters away from Cottonwood Creek to prevent increased creek and groundwater contamination. Notice the motorcycle tracks in the 2008 photo. Recreational use of the nonremediated site exposed the public to high concentrations of radionuclides in the resulting mud and dust contamination.

280 Physical Sciences



Figure 4. North adit before and after remediation showing infiltration channel for mine water.

Figure 5 shows the recontouring and vegetation of the north waste rock pile. Mine waste rock piles have little or no soil that can support vegetation. Without proper vegetation, significant erosion will occur. Remediation consisted of consolidating the waste rock piles, recontouring to reduce the slope, soil cover, and seeding. The 2020 photo shows successful vegetation cover and erosion control of the consolidated waste rock pile. The CERCLA removal action left the mining structures to preserve the historical significance of the area.



Figure 5. North waste rock pile and north waste rock repository after remediation.

The central waste rock pile was also consolidated into a repository and covered with a three-foot layer of soil. Figure 6 shows the effect of recontouring and remediation. The foreground shown in the 2020 photo is the soil borrow area where soil was taken to cover the waste rock repositories. Both the repository and borrow areas show good vegetation cover and no significant erosion.



Figure 6. Central waste rock pile and repository showing effect of remediation. Soil borrow area is in the foreground of the 2020 photo.

The south waste rock pile was removed and consolidated into the central waste rock repository. Figure 7 shows the result of waste rock removal from the site. The 2008 photo shows significant erosion and rilling of the waste rock that resulted in contaminated sediment being washed into the creek drainage. The site one year after remediation, in the 2010 photo, shows little erosion and good vegetation cover beginning to form. As of late 2020, there is still no evidence of significant erosion from the remediated south waste rock pile area (personal site visits; 10/2019, 11/2020).



Figure 7 Comparison of south waste rock pile showing erosion before and vegetation growth after remediation.

Experimental Procedure

Apparatus

A Thermo Fisher Scientific iCAP RQ ICP-MS instrument (Waltham, MA, USA) running Qtegra software version 2.10.3324.62 and equipped with an ESI SC-2DX autosampler (Omaha, NE, USA) was used for the analysis.

Chemicals

Trace metal nitric acid was obtained from Fisher Chemical (Waltham, MA, USA). A Thermo Fisher Scientific Barnstead Genpure water purification system (Waltham, MA, USA) was used to generate 18+ M Ω water in house. ICP multi-element standard solutions were purchased from SPEX Claritas PPT (New Brunswick, NJ, USA).

Samples

Environmental water samples from various areas surrounding the mine, including mine adit seepage water and stream-water samples from above and below the removal action site (Figure 8), were collected in October 2019.



Figure 8. Sample locations.

The samples were acidified on-site to 2% (v/v) with nitric acid and stored in polypropylene bottles at 4°C afterwards. All samples were prepared for analysis by filtering the water samples using a 0.22-µm polyethersulfone (PES) filter. The analysis of each sample was based on an eight-point standard addition calibration curve. Calibrant solutions were prepared gravimetrically by accurately weighing about 5 g of filtered sample water into a clean centrifuge tube. Varying amounts of a 10-ppm multielement standard solution were gravimetrically added to each centrifuge tube to produce a calibration curve range from 0 to about 0.7 ppm. Each calibrant was gravimetrically diluted to approximately 15 g with 2% (v/v) nitric acid. The samples were analyzed for trace levels of uranium and other heavy metals commonly found near mine sites (arsenic, cadmium, lead and selenium) by inductively coupled plasmamass spectrometry (ICP-MS). Each sample was analyzed in triplicate.

Results and Discussion

Water samples from the north and south adits were analyzed and compared to Cottonwood Creek water samples taken from above and below the mine complex. These samples were taken to determine if the CERCLA removal action was effective at isolating uranium and other metals to prevent contamination of the Cottonwood Creek drainage. Results of these analyses are given in Table 1. Locations are shown in Figure 8.

Table 1. King Edward Mine Water Analysis. WSU—10/18/2019							
Element (nuclide)	North Adit	South Adit	Up Cottonwood	Down Cottonwood	EPA Limits		
As (75)	0.0653	0.0020	<0.0001	0.0005	0.01		
Cd (111)	0.370	N.A.	<0.0001	0.0001	0.005		
Pb (208)	0.0039	0.0016	0.0012	0.0002	0.015		
Se (77)	1.61	0.0015	0.0032	0.0008	0.05		
U (238)	30.0	10.0	0.0482*	0.0491	0.03		

*UDWQ 0.0342 ppm (3/31/1998)

Water samples taken from the north adit contained arsenic, cadmium, selenium, and uranium above EPA drinking water regulation guidelines [10]. However, only uranium in the south adit water sample

was above the EPA drinking water regulation. Cadmium in this sample was lower than the detection limit of the instrument and was not reported. The differences in the metal concentrations between the north and south adit water are most likely due to the mineralogy of the ore deposits. The north ore body contains sulfide minerals, and the south ore body is oxide based. Sulfide minerals oxidize to produce acidic solutions that dissolve the metals better than the water from the oxide ores [11].

The samples taken up- and downstream in Cottonwood Creek show uranium as the only element above EPA drinking water regulations. Results for the up- and downstream samples are shown in Table 1. The standard deviations (n=3) for the analysis of uranium from up- and downstream samples were respectively ± 0.0014 and ± 0.0016 . This gives a range for the upstream sample of 0.0468–0.0496 and the downstream sample of 0.0475–0.0507. The overlap of the analysis shows there is no statistical difference between the up- and downstream Cottonwood Creek samples. Thus, the creek water is not being affected by the mine adit waters or from soil erosion causing elevated concentrations of uranium or other metals. The uranium concentration in creek samples is similar to the analysis performed by the Utah Division of Water Quality (UDWQ) on 3/31/1998 on pre-CERCLA upstream creek water. Analysis of pre-CERCLA downstream water was not performed. Therefore, uranium contamination of the Cottonwood Creek water from adit drainage could not be concluded. However, contamination from erosion of the south waste rock pile was occurring before remediation as documented in the 2008 photo in Figure 7. The lower uranium analysis in the UDWO sample is expected because of high water runoff during the spring as compared with the low water runoff during fall when this study samples were taken. These results show that the CERLA remediation action is still working after more than 12 years.

For comparison, a study by Kayzar et al. on the Juniper Uranium Mine in California, which is similar to the King Edward mine, found that the uranium contamination occurred in creek water downstream from the mine site [12]. The creek in this study was found to have uranium concentrations higher than the EPA drinking water regulation downstream from the mine site but clean levels located in the upstream. Therefore, there is contamination from the Juniper Uranium Mine into the groundwater that is seeping into the nearby creek. However, the Juniper mine had not been through a removal or containment process like the King Edward Mine.

Conclusion

This study concludes that the CERCLA removal action of the King Edward mine is working effectively. Because the uranium concentrations in up- and downstream Cottonwood Creek water show no statistical difference, there is no indication that uranium contamination from the post-reclaimed mine site is reaching the creek. The adit discharge water diversion containment is working effectively. Also, recontouring and reclamation of the waste rock piles have minimized surface erosion. The adit closure, recontouring, consolidation, and capping of waste rock piles have minimized human, animal, and plant exposure to uranium, radon gas, and other heavy metals.

Further sampling and analyses should be performed on the waters of Cottonwood Creek at different distances from the mine to account for any possible contamination from the other mining sites or natural uranium ore outcroppings in the vicinity. Also, more analyses should be performed on samples collected during different seasons to account for possible runoff differences.

Acknowledgments

The authors wish to express appreciation to the Department of Chemistry and Biochemistry, Weber State University, for the support of this project; the Office of Undergraduate Research, Weber State University, for the funding of the analytical work; and Dale Harber, retired Geologist, US Forest Service, for his contribution to understanding the geology of the King Edward Mine complex site.

References

[1] Bureau of Land Management. AML Inventory. Retrieved May 17, 2021 from https://www.blm.gov/programs/public-safety-and-fire/abandoned-mine-lands/blm-aml-inventory.

[2] Blake, J.; Avasarala, S.; Artyushkova, K.; et al. *Elevated Concentrations of U and Co-occurring Metals in Abandoned Mine Wastes in a Northeastern Arizona Native American Community.* Environ. Sci. Technol. 2015, 49, 14, 8506–8514.

[3] Avasarala, S.; Lichtner, P.; Ali, A.; et al. *Reactive Transport of U and V from Abandoned Uranium Mine Wastes*. Environ. Sci. Technol. 2017, 51, 21, 12385-12393.

[4] Blake, J.; Avasarala, S.; Ali, A.; et al. *Reactivity of As and U co-occurring in Mine Wastes in northeastern Arizona*. Chem. Geol. 2019, 522, 26-37.

[5] Hoover, J.; Gonzales, M.; Shuey, C.; et al. *Elevated Arsenic and Uranium Concentrations in Unregulated Water Sources on the Navajo Nation, USA*. Expos. Health 2017, 9, 113-124.

[6] MSE (Millennium Science & Engineering Inc.). Engineering Evaluation/Cost Analysis for the King Edward Mine, U.S.D.A. Forest Service Manti-La Sal National Forest, prepared by Millennium Science & Engineering Inc., Salt Lake City, Utah, January 2005.

[7] Davidson, R.; Sargent, H.; Forsgren, H. Non-Time Critical Removal Action Memorandum King Edward Mine Site; United States Department of Agriculture Forest Service Intermountain Region: Ogden, UT, 2008.

[8] Contractor Scope of Work - King Edward Mine Removal Action, Manti-La Sal National Forest, Utah May 11, 2009. Principal Author: Don Tibbets, E.I.T.

[9] Defense-Related Uranium Mines Assessment of Radiological Risk to Human Health and the Environment, U.S. Department of Energy Doc. No. S11072, Page 15, June 2014.

[10] United States Environmental Protection Agency. National Primary Drinking Water Regulations. Retrieved September 16, 2020, from https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.

[11] Personal communication with author. Dale Harber, retired Geologist, US Forest Service. April 2021.

[12] Kayzar, T.; Villa, A.; Lobaugh, M.; et al. *Investigating uranium distribution in surface sediments and waters: A case study of contamination from the Juniper Uranium Mine, Stanislaus National Forest, CA. J. Environ. Radioact.* 2014, 136, 85-97.

A Homebuilt Laser Light Scatter Particle Sizer for Use with Microfluidic Devices

Stephen K. Smith, Christopher F. Monson, Matthew B. Rowley

Southern Utah University

Abstract

The design, construction, and performance characterization of an inexpensive home-built laser light scatter particle sizer is presented. Light scatters off small particles with greater or lesser efficiency depending on the ratio of particle size to wavelength of light. The instrument collects and measures the scattered light from two lasers of different colors. The ratio of scatter intensities can give the size of the particles scattering the light. This instrument is purpose-built to determine the size of particles passing through the channel of a microfluidic device. The performance of the particle sizer was characterized by collecting data on a set of particle size standards passing through a simple microfluidic device.

Introduction

A static laser light scatter particle sizer is an instrument that relies on the phenomenon of light scattering to determine the size of small particles in the sub-micron size range. No single particle sizing instrument can be optimal for all use-cases, and any given commercial instrument is usually best-suited for particles of a particular size, carrying medium, and even shape.^{1,2} This paper describes the construction and performance characterization of an inexpensive homebuilt particle sizer instrument based on this phenomenon of light scattering. Although laser scatter particle sizing instruments have been described before,³⁻⁵ the instrument presented here is unique in its particulars and purpose-built to work with nanoparticles travelling through a microfluidic device. The sample stage is large and able to accommodate prototype microfluidic devices.

The way that light scatters off particles can be determined by solving Maxwell's equations for electromagnetic radiation. The scatter intensity depends on several factors, including the scatter angle, the particle index of refraction, the wavelength of light, and the particle size. The ratio of particle size to the wavelength of light falls into three different regimes, including Rayleigh scattering, Mie scattering, and the optical limit. Each of these regions shows its own relationship between scatter efficiency and particle size.

Rayleigh scattering is observed when the particle is much smaller than the wavelength of light. In this limit, the equation for scattering cross-section can be simplified and shows sixth-order power relationship between scattering efficiency and particle size. The Rayleigh-scattering cross-section is given in equation 1, where r is the particle radius, n_{med} is the index of refraction for the surrounding medium, and n_{part} is the index of refraction for the particles.⁶

$$\sigma_{Ray} = \frac{8\pi}{3} \left(\frac{2\pi n_{med}}{\lambda}\right)^4 r^6 \left(\frac{m^2 - 1}{m^2 + 2}\right)^2 \qquad m$$
$$= \frac{n_{part}}{n_{med}}$$

In the optical limit, when particles are much larger than the wavelength of light, particle size is no longer a factor and scattering efficiency becomes constant. Mie scattering is observed at the transition between these two regimes, where the particle size and wavelength are of comparable size. Mie scattering is more complex than the other two scattering regimes. The formula for the Mie-scattering cross-section involves rather complex infinite sums over spherical Bessel and Hankel functions, and will not be given here.⁶ Mie scatter exhibits oscillations
in the scattering efficiency as a function of particle size, which reduce in magnitude at larger particle sizes and settle into the optical limit. Scatter intensity in all three of these regimes are illustrated in Figure 1.



Figure 1. Plot of scatter intensity vs. relative particle size (circumference/ wavelength). The dashed line represents the Rayleigh scatter limit, and the dotted line represents the optical limit. Scatter intensity is sketched approximately, rather than calculated, in the Mie scatter region where scatter deviates from both limits.

In our laser light scatter particle sizer instrument, two lasers with different wavelengths are used to determine the particle size, sometimes called the Dual Beam method.² The scattered light from a single light source would vary based on both the particle size and the particle concentration. Instruments using a single beam must rely on measurements of scatter at different angles, necessitating either an array detector or moving parts.² In a microfluidic device, the concentration of particles could be both unknown and variable over time, further complicating matters. A second laser makes it possible to determine the size of particles in real time, independent of their concentration, as long as the particles are monodisperse in their size. A calibration curve can be constructed by recording the ratio of scattered light from both lasers for each of a series of size standard samples. As shown below, our instrument only worked reliably with samples of constant concentration.

Instrument Construction

The laser light scatter particle sizer instrument was designed and home-built by the authors. The aluminum base plate and the lumber for the light-tight enclosure were constructed from scrap, which could have been purchased inexpensively from a material wholesaler. Additionally, several mounting brackets were either milled from scrap aluminum in the university machine shop or 3D-printed using a university printer. The rest of the components, with their source and cost, are listed in Table 1. Although the cost of commercial devices varies depending on particular features, these instruments cost many tens of thousands of dollars at a minimum.

Table 1: Material, source, and cost (at time of purchase) of all materials nurchased for the particle sizer			
Item	Source	Quantity	Price/unit (USD)
450 nm laser	Thorlabs (CPS450)	1	221.34
532 nm laser	Thorlabs (CPS532)	1	172.06
Laser power supply	Thorlabs (LDS5)	2	86.96
Lens	Thorlabs (LB1761-A)	1	39.23
Lens mount	Thorlabs (LMR1)	1	15.69
Ruled diffraction	Thorlabs (GR25-	1	116.86
grating	1205)		
Grating mount	Thorlabs (KM100S)	1	85.49
Al-coated mirror	Thorlabs (CM254- 075-G01)	2	60.34
Kinematic mirror mount	Thorlabs (KS1)	2	92.52
Si photodiode	Thorlabs (FDS100)	2	14.94
Photodiode socket	Thorlabs (STO5S)	2	3.77
MSP432	Mouser (595-MSP-	1	12.99
microcontroller	EXP432P401R)		
10 MΩ resistor	Mouser (594-	2	0.19
	5043DM10M00J)		
0.1 µF capacitor	Mouser (581-	2	0.31
	CK06BX104K-TR)		
Precision amplifier	Mouser (584-	2	7.60
	AD820ANZ)		
Total cost			1196.92

Figure 2 shows the optical design and a top-down photograph of the instrument. All optical elements are mounted on an aluminum base plate. First, the two lasers are held mounted in a custom-machined bracket. This bracket holds the lasers at 90° and 50° degrees from the optical path. The lasers output 4.5 mW each with 450-nm (blue) and 532-

nm (green) light. The unfocused laser beams are directed toward a 3Dprinted sample stage. This stage holds a microfluidic device at the crossing point of the two laser beam paths. The microfluidic device was fabricated from polydimethylsiloxane (PDMS) using a method developed previously.⁷ First, a ribbon of Mg metal was cut and bent to form a template of the microfluidic channel. Liquid PDMS was then poured over the template, two nails were used to anchor the device to the sample stage, and the device was baked to set the PDMS. The Mg ribbon was then dissolved though sonication in a solution of hydrochloric acid, leaving behind a channel 200 μ m thick and 4 mm wide, with a length of approximately 4 cm.



Figure 2. Schematic design of the instrument's optical pathway (top), with a top-down photograph of the final built instrument (bottom). The original CAD design file in the supplementary information contains all dimensions. An adhoc sample stage and microfluidic device can be mounted at the "Sample" location.

Figure 3 shows a close-up view of the microfluidic device, held at the crossing point of the laser beams. A 25-mm focal length biconvex lens collects scattered light and focuses it through a slit. The slit is made by two razor blades mounted on another custom-machined bracket. The divergent light is then collimated with a 75-mm focal length mirror and directed toward a 1200-lines/mm ruled grating. Another 75-mm focal length mirror focuses the blue and green light to different points on a focal plane. These two mirrors and the grating make up a polychromator, separating the blue and green light spatially for independent detection. Two silicon photodiodes are held at the proper points in the focal plane by a 3D-printed bracket. The sample stage, polychromator, and detector electronics are all separated by removable light-blocking baffles constructed from plywood, and the entire instrument is enclosed in a wooden light-tight enclosure.



Figure 3. Close-up photo of the microfluidic device and the laser bracket. Note that the laser beams point directly at the channel in the device.

Figure 4 shows two photographs of the finished instrument from different views, and more photographs are included in the supplementary information.



Figure 4. Views of the sample stage (left) and polychromator stage (right) of the instrument

The photodiodes are configured in current mode with identical transimpedance amplifier circuits, each utilizing an AD820AN precision operational amplifier. This circuit converts the photocurrent produced by the diode into a voltage. A schematic of the amplification circuit is shown in Figure 5. The amplified output is connected to analog inputs pins of a Texas Instruments (TI) MSP432 launchpad microcontroller board. This microcontroller has an integrated 14-bit analog-to-digital converter and is able to output the measured voltages to a computer over USB. The microcontroller firmware was written and flashed to the hardware using the Energia programming language and development platform. Energia is a third-party development platform designed to work with TI microcontrollers in a simple and intuitive way and is based on the popular Arduino platform. The raw code firmware can be accessed in the supplementary information under the filename "LightLevel.ino." The firmware is quite simple, reading the output voltage from both amplifiers and passing them along to the computer over USB.



Figure 5. Schematic of the transimpedance amplifier circuit

The user interface software was written using the Processing programming language. The raw code for the user application can be accessed in the supplementary information under the filename "SerialGraph.pde." This application receives, processes, and stores the raw voltage values that are transmitted from the instrument over USB. The user can collect and subtract a background light level for both the blue and green channels before particles are passed through the microfluidic system. Background-corrected light levels are displayed on a graph and saved in a file for later analysis. The user interface program is portable and can be run on any modern computer from a USB flash storage drive.

Instrument Performance Characterization

The instrument was characterized using commercially purchased microspheres. Initially, three sizes of polystyrene microspheres were used: 0.027-µm, 0.22-µm, and 0.57-µm diameter. All were purchased from Bangs Labs and came at approximately 10% solids by mass. The solutions were diluted to the desired concentrations using deionized water and were run either by syringe injection or by a gravity-driven flow. Both methods used 24-gauge Teflon tubing to convey the solutions to the device. Two other types of microspheres were also used: a magnetic microsphere with an average size of 5.8 µm (Compel Magnetic Microsphere, Bangs Labs) and a fluorescent microsphere with an average size of 2.2 µm (Sphero Nile Red Fluorescent Particles, BD Biosciences). In all cases, pure deionized water was forced through the

device before and after the microsphere solutions to obtain scattering measurements without microspheres for comparison.

As mentioned previously, two injection methods were tested: syringe and gravity-driven flow. For syringe injections, after rinsing the device with deionized water from a syringe and measuring the light scattering with no particles present, a 0.5- to 1-mL sample of microspheres was injected using a second syringe. Using this technique, it was observed that the total amount of scattering observed was highly dependent on sample size—larger sample sizes resulted in more scattering. This resulted from uneven filling of the microfluidic, as edge effects reduce flow velocity and thus solution exchange near walls. Because of this and the intended future use of the device being in a continuous flow situation, the gravity-driven flow procedure discussed below was generally preferred.

In the gravity-driven flow procedure, a height difference between the inlet and the outlet tube provided the force that led to fluid flow. Before and after each measurement, deionized water was run through the device and the scattering with no particles was measured. Measurements were performed when the inlet tube was moved from a beaker of deionized water to a sample bottle containing microspheres at a desired concentration. Microsphere solution was flowed into the tubing for 30 seconds, and then the inlet was switched back to deionized water to minimize sample consumption.

Discussion

As can be seen in Figures 6 and 7, light scattering was observed when particles were introduced into the sampling microfluidic device. Figure 6 shows the results of a series of tests of 0.22-µm polystyrene microspheres with different concentrations. The data from a run is shown on the left, and there are a few interesting features to note. First, 0.00078% solids is at or near the detection limit of the instrument, as shown in the first peak of Figure 6. Second, a little less than a minute before each run, two negative deviations are seen in the green fluorescence signal. At the same time, two smaller positive deviations are seen in the blue laser signal in Figure 7. A variation such as these was observed every time a syringe injection was performed or a beaker providing the gravity-driven flow was raised or lowered. Thus, these dips are attributed to the sampling chamber flexing and slightly changing the angle at which the laser encounters the wall of the chamber, resulting in less scattering from the wall toward the detector for the green laser. For the blue laser, a flexing of the chamber results in a decrease of the angle at which the laser impacts the wall, and thus an increase of the scattering signal.



Figure 6. Particle sizer response to different concentrations. Normalized intensity data (left) and ratio of blue to green fluorescence responses (right). The arrows on the figure at the left correspond to 0.22-µm polystyrene particle injections of 0.00078%, 0.0026%, and 0.013%, respectively. The final two peaks are injections of silver nanoparticles of unknown size and concentration, and thus they are not shown in the curve on the right.



Figure 7. Response of instrument to particle size. At left is shown the normalized intensity data from polystyrene particles at constant concentration. At right is shown the response when microsphere concentrations are controlled (top) and when microsphere concentrations are not controlled (bottom).

The feature of Figure 7 that was the most surprising is the dependence of the scattering on concentration, shown in the right side of the figure. As the concentration increases, the ratio of the scattering signal from the blue and green lasers changes dramatically, from approximately 3.6 to greater than 5. Although some dependence on

concentration might be expected because of particle aggregation at higher concentrations, the observed behavior implies that aggregation is significant at essentially all concentrations above the detection limit.

Despite these limitations, the instrument is able to detect particle sizes when the concentrations of the particles are controlled (as can be seen in the top right graph in Fig. 7). Indeed, when the concentrations of the particles are constant for all samples, the detection of particle size is remarkably linear. However, when the concentrations of particles vary, the particle size and concentration effects are convoluted and the graph is no longer linear. This is illustrated in the lower right graph of Figure 7, which was obtained by running particles of known size but random concentrations through the particle sizer.

The particle sizer was designed to be used to detect and size lipid vesicles in a flow-through configuration.⁸ Accordingly, it was tested with lipid vesicles and was able to detect them (data not shown). However, when the concentration dependence of the size was observed, this work was discontinued, as the concentration of the vesicles was unknown and therefore the size of the vesicles could not be determined. Similarly, silver nanoparticles were also measured (e.g., the last two peaks on the left graph in Fig. 6), but their concentrations were also unknown and thus they could not be sized. However, in these situations the instrument did clearly indicate the presence of particles, even if their size remained unknown.

The particle sizer performed well enough for our use now and in the future, but there are several simple ways its design might be improved. The first issue has to do with the beam angle for the two lasers. This angle must be chosen to maximize the scattered light signal-to-noise ratio. Just like in fluorescence spectroscopy, a right angle between the excitation beam and the collected light optical axis will minimize the amount of stray light from the original laser beam or reflections off of macroscopic components of the sample stage. The angular dependence of Rayleigh and Mie scattering, however, has angular dependence and much more scattered light is produced at small angles. In our instrument, the green laser was placed at 90°, while the blue laser was placed at a shallower 50° angle. The blue light channel had much better signal to noise, as can be seen in Figure 7. Positioning both lasers at 50°, or an even shallower angle of perhaps 20°, would improve the signal to noise for both channels.

Another avenue for improvement lies in the positioning and product choice for the photodiodes. Photodiodes with a large active area were chosen so that focusing the light onto them would be easy. However, noise is increased for these large-area diodes compared with similar ones with smaller active areas. Although it would take more care to focus the light onto the diodes, stronger and cleaner signals could be obtained with smaller active area diodes.

Finally, introduction of an optical beam chopper and lock-in amplification could dramatically reduce the noise in both channels. Although this would be the most difficult change to implement, it also offers the greatest promise. It is hoped that with these changes the detection limit could be reduced low enough to work in concentrations where aggregation and concentration effects are not an issue, thus realizing the original goal of concentration-independent sizing of particles.

Supplemental Information

Supplemental information, including design notes and program code, can be accessed at https://rowleylab.github.io/Particle-Sizer/.

Acknowledgments

This research was funded in part by a Walter Maxwell Gibson Fellowship Award. We are also grateful to Southern Utah University machinist Roger Greener for his expertise and his labor in machining the aluminum parts for our instrument.

References

(1) Seville, J. P. K.; Coury, J. R.; Ghadiri, M.; Clift, R. Comparison of techniques for measuring the size of fine non-spherical particles. *Part. Part. Syst. Charact.* **1984**, *1* (1–4), 45–52. https://doi.org/10.1002/ppsc.19840010108.

(2) Lee Black, D.; McQuay, M. Q.; Bonin, M. P. Laser-based techniques for particle-size measurement: a review of sizing methods and their industrial applications. *Prog. Energy Combust. Sci.* **1996**, 22 (3), 267–306. https://doi.org/10.1016/S0360-1285(96)00008-1.

(3) Card, J. B. A.; Jones, A. R.; Zhao, H. A light scattering instrument for sizing mixtures of small and large particles. *Part. Part. Syst. Charact.* **1996**, *13* (2), 137–142. https://doi.org/10.1002/ppsc.19960130212.

(4) Blum, K.; Fissan, H. Determination of particle size distribution parameters using a laser-scattered light spectrometer. *Part. Part. Syst. Charact.* **1988**, *5* (4), 165–169. https://doi.org/10.1002/ppsc. 19880050402.

(5) Agrawal, Y. C.; Pottsmith, H. C. Laser diffraction particle sizing in STRESS. *Cont. Shelf Res.* **1994**, *14* (10–11), 1101–1121. https://doi.org/10.1016/0278-4343(94)90030-2.

(6) Cox, A. J.; DeWeerd, A. J.; Linden, J. An experiment to measure Mie and Rayleigh total scattering cross sections. *Am. J. Phys.* **2002**, *70* (6), 620–625. https://doi.org/10.1119/1.1466815.

(7) Barney, J.; Torgerson, T.; Monson, C. F. A diffusion limited titration using microfluidics. *J. Utah Acad. Sci. Arts Letts.* **2018**, *95*, 235–249.

(8) Ornstead, M.; Hunter, R.; Valentine, M.; Cooper, C.; Smith, S.; Monson, C. Stripping material from a supported lipid bilayer with high speed buffer flow. *Am. J. Undergrad. Res.* **2020**, *17* (3), 51–59. https://doi.org/10.33697/ajur.2020.027.

3D-Printed Cell Phone Spectrophotometer and Spectroscope

Brittany Christensen, Saselah Goulding, Carrigan Holt, Christopher F. Monson

Southern Utah University

Abstract

Spectroscopy, or the study of light and its interaction with matter, is an important topic in many different fields, but its educational introduction is often hampered by cost and the opaque nature of the operation of many commercially available instruments. A three-channel spectrophotometer and a spectroscope were designed, 3D-printed, and tested. Both proved to be functional as simple scientific instruments and were relatively easy for nonscientists to use. These two facts make them effective teaching devices, as demonstrated by increased student understanding upon completing labs designed to use the devices.

Introduction

Spectroscopy is a family of techniques with many different scientific, commercial, and educational applications, ranging from compound identification and quantification to high-speed communications. A strong understanding of the properties and uses of light and spectroscopy would be beneficial for many students, including those that are not interested in science. Thus, there is a motivation for high school–level students to engage with spectroscopy. However, spectroscopic instruments are generally expensive, with costs ranging from several hundred up to tens of thousands of dollars. Additionally, many spectroscopic instruments function as a "black box" in which students perform operations and get graphical or numerical outputs but do not develop much of an understanding of the means by which their results are obtained.¹ This becomes problematic when a deeper understanding is called for, such as when instruments have problems or instrumental limitations are encountered.²

Many different scientists have recognized these limitations, and several inexpensive spectroscopic instruments have been created, particularly in the past few years as 3D printing has made such work much more reproducible³ and smart phones have made optical sensors ubiquitous. Previous work includes several examples of instruments to measure fluorescence,^{4,5} various examples of spectrophotometers,^{1,2,6,7} and other examples such as physical demonstrations of diffraction⁸ and colorimetry.⁹ Although the spectrophotometers are well designed and functional, in our discussions we realized there was a need for a fully integrated (light source and light path) spectrophotometer capable of interfacing with any smart phone. During the design and testing of our device, we also realized that there were opportunities to use a similar design to create a 3D-printed spectroscope. We report the results of our effort in this paper.

Device Design and Testing

As stated previously, the spectrophotometer was designed to be a fully integrated device, with a light source, a cuvette holder, and diffraction grating all in one device to facilitate use by high school students. Additionally, in discussion with teachers and inspired by a 3D-printable dual-beam device,⁷ the device was designed as a triple-beam device (three separate light paths allow three simultaneous measurements) to allow students to see the differences in absorbance among three different solutions at the same time, as shown in Figure 1.



Figure 1: Cell phone spectrophotometer design. At left is shown a top view (top) and a top/side view (bottom) of the model used to print the device. At right is shown the actual device with printed covers and LED light source (top) and the optical paths in the device (bottom).

It should be noted that the difference in path length between the middle and two side positions means that using all three positions for quantitative measurements is difficult, as the intensity varies between the middle and side positions. Thus, for quantitative measurements the device functions best using one cuvette at a time.

The device was designed in OpenSCAD and printed on an Ender3 printer (Creality) using black PETG filament (Overture). Mirrors (Juvale square mirrors), diffraction grating (NewItem, 1000 lines/mm, purchased as a 1-foot \times 6-inch sheet and cut), LED bulbs (Chanzon 8-mm straw hat white LED, 3 V, 250 mA), and battery packs (LampVPath 2AA packs with switch) were purchased online, and the total cost for fabricating a device was under \$5.

The spectrophotometer went through several optimization rounds to ensure that the mirrors were aligned correctly and the device was stable and to decrease printing time. Additionally, versions with changeable slits (0.2 to 3 mm) and fixed slit widths (2 mm) were created. As high school teachers generally told us they preferred the fixed slit widths, because of the potential for the changeable slits to be lost, these were the devices used in testing.

The spectroscope (Figure 2) was also designed in OpenSCAD and printed on the Ender3 with black PETG filament. The spectroscope is a much simpler design, with a pair of 0.5-mm slits leading to an angled mirror that reflects the incoming light onto a pass-through diffraction grating. The mirror was angled to allow a cell phone to sit flat on the surface of the spectroscope and still be able to image the spectrum produced by the grating. In the spectrophotometer, this problem was solved by printing the cell phone support piece such that it sloped up from the spectrophotometer, placing the cell phone at an angle to the diffraction grating and allowing the spectra to be seen. The overall cost of materials for a spectroscope was around \$1.



Figure 2: Cell phone spectroscope. At left is shown the model of the top section of device looking from below (top) and the bottom section of the device looking from the top front (bottom), and at right is shown an image of the actual device (top) and the optical path in the device (bottom).

Both devices were first tested in a University laboratory and then tested as the central part of labs for high school students. The spectrophotometry lab and the spectroscope lab were tested at Cedar High School in Cedar City, Utah. The spectrophotometry lab was also tested at Lone Peak High School in Highland, Utah. The labs and files to 3D print the devices can be found on the SUU STEM center website (www.suu.edu/stem/) or by contacting the authors (christophermonson1@suu.edu).

App Development

An app for Android phones, "spectro," was developed to allow the quantitative use of the devices. Before using the app, a picture must be obtained by the smart phone and then cropped to just the spectrum and rotated so the blue/purple portion of the spectrum is at top. The app then imports the prepared image, and the pixel intensity is averaged horizontally across the spectrum (getting one number for each RGB pixel in that wavelength) and then the RGB values of each horizontal line are summed. This allows the app to produce a graph of the observed light intensity of each color. Additionally, when the graph is touched the light intensity at the wavelength touched is displayed. Finally, a list of the intensity values can be displayed by pressing a "list" button.

The graphing feature allows students to quickly and easily visualize the pattern of light observed, while the numerical features allow for quantitative work. The app is available for free download on the SUU STEM center website. Two versions of the lab were developed in part so that students not using an Android could do the labs—one uses the spectro app and the other does not.

Spectrophotometer Performance

In qualitative and quantitative trials using the spectro app, the spectrophotometers performed fairly well. Figure 3 shows several features of the data generated by the setup. First, the spectrophotometer shows both the color of the solution as seen by the eye (top of the image) and the spectral composition of that color (bottom of the image). This allows students to directly compare the color with the light going through the solution and thus the light absorbed by the solution.



Figure 3. Spectrophotometer performance. At left is shown the cropped image obtained by the camera when blue, pink, and yellow solutions were examined. In the center of the figure are the spectra generated by the spectro app for the three solutions. On the right is shown a calibration curve obtained using blue solutions of known concentration ratios.

In the central section of Figure 3, the ability of the spectro app to calculate and display light intensity curves is demonstrated. For each of the graphs, the section of the image obtained by the cell phone camera corresponding to the spectrum of that solution was cropped from the rest of the image and aligned so the blue portion of the spectrum was at top, then imported into the app. It should be noted that the spectro app does not identify spectral features, so both the colors shown in the background and the wavelengths displayed at the bottom of the graph are approximate and dependent on user skill.

The right side of Figure 3 shows the setup's ability to perform quantitative work. For this, a solution of blue food coloring was gravimetrically diluted to two known concentrations (49.3% and 9.02% of the initial concentration). The solutions were measured in multiple setups—all at once in the different cuvette positions and sequentially in the same cuvette position. Sequential analysis produced better results. There were multiple causes for the observed poor linearities of measurements. First, significant changes in the scattering from adjacent solutions were observed and were particularly troublesome when attempting to measure multiple solutions at once. Second, the camera changed its exposure time depending on light intensity. Although this is a desirable feature to get good images in typical cell phone use, a longer exposure resulted in nonlinear results. It should be noted that this could be (and was in the more linear measurements) counteracted by consistently using a blank in one position, resulting in a similar light intensity maximum. This also had significant effects on background, as longer exposure times resulted in more observed noise. Third, the selection of the location and size of the area to analyze in the spectro app could result in significant changes to the light intensity (and thus absorbance). Although the use of a more advanced imaging program such as ImageJ could reduce these errors (particularly those associated with noise and inconsistent area selection),⁷ it was considered beyond the scope of an average high school student and thus not appropriate for use in this case. Overall, the performance of the spectrophotometer is definitely below that obtainable by commercial instruments but is sufficient for high school uses.

Spectroscope Performance

As mentioned previously, the spectroscope was simpler both in design and performance than the spectrophotometer, and it was also somewhat less powerful, with quantitative measurements being significantly less reproducible. As shown in Figure 4, the spectroscope was tested with several different light sources. Light from the sun and from fluorescent lights produced strikingly different patterns both in the camera (top left of Figure 4) and when using the spectro app (bottom left of Figure 4). These clearly illustrate the black body radiation from the sun versus the discrete wavelengths emitted by fluorophores in the coating of fluorescent lights.



Figure 4. Spectroscope performance. At left are shown camera images (top) and intensity graphs produced by the spectro app (bottom) for sunlight and fluorescent lights. In the middle are shown the spectra produced by a computer screen when white, red, blue, green, yellow, and pink colors are displayed. At right the results of a quantitative measurement of intensity versus distance are shown.

The middle section of Figure 4 shows the light spectra observed with the spectroscope when pointed at a computer screen displaying a white, red, blue, green, yellow, and pink boxes. The three-color (red, green, blue) nature of modern displays is clearly demonstrated. Additionally, the additive nature of colors is demonstrated, in which red, green, and blue together make white, red and green make yellow, and blue and red make pink.

The right section of Figure 4 displays the results of quantitative measurements with the spectroscope. In this experiment, the spectroscope was positioned at a varying distance from a light source (a flashlight shining at a piece of white paper). Although the mathematics of the situation are somewhat complicated by the light from the flashlight being focused, a linear increase in the diameter of the "spot" illuminated by the flashlight was observed. This should result in an intensity that is decreasing as a function of the distance to the second power (inversely to the increase in area). As can be seen, a generally decreasing trend was observed over the three attempts at getting a good distance versus intensity relationship, but the trend was not consistent. In addition to all the problems associated with using a cell phone camera as a detector

(particularly those involving camera integration time and noise), the spectroscope also has to be positioned pointing at the light source. There is an aiming hole to help with this, but it is still difficult to position the device reproducibly, and this is a major source of error.

Lab Performance

Because the two devices were designed as teaching tools, their ultimate utility comes from their ability to effectively teach principles of spectroscopy. Each device has labs designed to go with it, and each device has two versions of the lab designed for it—a qualitative version that did not use the spectro app and a quantitative version that did use the spectro app. Having two versions of the lab lets teachers more easily test the devices in their class with fewer requirements, as having students download an app to their phones can require school approval. In testing it was found that the devices work with most phones (although the app only works with Androids). The main limitation was that very large phones tended to be harder to keep in the correct position, as the supports had trouble holding them up. Additionally, phones with multiple cameras at times caused problems if the phone automatically switched between cameras.



Figure 5. Lab performance as evaluated by students and by final student understanding. The spectrophotometry lab is on the left and the spectroscope lab is on the right. In all graphs, red is a "1" (poor), gold is "2" (average), green is "3" (good), and, on "graded understanding" only, blue is "4" (excellent).

At the end of each lab, an evaluation sheet was used to determine student perception of the lab and whether the lab helped the students better understand spectroscopy. The questions asked were: Was the

device easy to use? Did it help you understand spectroscopy? and "Was the lab easy to follow? Each question had response options of "Yes" (reported as 3 in Fig. 5), "Kind of" (reported as 2 in Fig. 5), and "No" (reported as 1 in Fig. 5). There were also open response questions that asked "What is spectroscopy and how can it help identify substances?" and "What is the relationship between colors we see and the colors that are being absorbed?" for the spectroscopy lab. The spectroscope lab evaluation asked "What can be determined about light using a spectroscope?" and "What is the relationship between colors we see and what colors are being produced?" Student responses to these questions were graded on a scale of 1-4, with students earning a 1 for demonstrating almost no understanding, a 2 for showing some understanding but still some possibly significant errors, a 3 for showing good understanding with only minor errors, and a 4 for demonstrating excellent understanding with no errors. The results of these surveys are shown in Figure 5. For the spectrophotometry lab, the average graded score for understanding after the lab was a 2.3 and for the spectroscope lab the average score was a 2.5. Although these scores do make sensethe spectroscope lab is conceptually simpler than the spectrophotometry lab—the scores may also reflect the fact that the spectroscope lab was done with students who had previously done the spectrophotometry lab. Thus, the increase in student understanding in the spectroscope lab relative to the spectrophotometry lab may be because it was the second time thinking about light-related topics for the majority of the students. However, in discussions of light held before the spectroscope lab, the majority of students did not demonstrate much understanding of light, so in both cases it appears there were at least temporary learning gains.

As mentioned previously, students were also asked about the ease of using the instruments and how straightforward the lab instructions were. As expected, the spectrophotometer was ranked as much easier to use than the spectroscope. We believe this is largely because of the previously mentioned difficulties with aiming the spectroscope. Recognizing this difficulty ahead of time, significant effort was put into making the spectroscope lab easy to understand, which is reflected in the rankings compared with the spectrophotometry lab.

Conclusions

A spectrophotometer and a spectroscope were designed, 3Dprinted, and demonstrated to function. An app for use on Android smart phones was developed to facilitate the use of these devices. Using the devices, good qualitative data could be easily obtained. Using the devices and the app, additional qualitative data could be obtained and some quantitative data could be obtained, although the quality of the quantitative data was dependent on the skill of the user and was below that obtainable by commercial instruments. Labs were developed that used these devices and the app, although the versions of the lab with the app could not be classroom tested. In classroom tests, the labs and devices were shown to be easy to use and to increase student understanding of light and spectroscopic techniques.

Acknowledgments

We thank Travis Wood, Lisa Monson, and Rachel Wentz for letting us try out our labs on their classes. We thank the L.S. and Aline W. Skaggs foundation and the SUU STEM center for funding. We thank Kim Weaver and Cade Christensen for helpful discussions. We thank Riley Paul and Wyatt Whitman for testing the spectroscopy and spectroscope labs.

References

1. Grasse, E. K.; Torcasio, M. H.; Smith, A. W. Teaching UV-Vis spectroscopy with a 3D-printable smartphone spectrophotometer. *J. Chem. Ed.* **2016**, *93*, 146-151.

2. Wilson, M. V.; Wilson, E. Authentic performance in the instrumental analysis laboratory: building a visible spectrophotometer prototype. *J. Chem. Ed.* **2017**, *94*, 44-51.

3. Pinger, C. W.; Geiger, M. K.; Spence, D. M. Applications of 3Dprinting for improving chemistry education. *J. Chem. Ed.* **2020**, *97*, 112-117.

4. Yu, H.; Tan, Y.; Cunningham, B. T. Smart phone fluorescence spectroscopy. *Anal. Chem.* **2014**, *86*, 8805-8813.

5. Vidal, E.; Lorenzetti, A. S.; Aguirre, M. A.; Canals, A.; Domini, C. E. New, inexpensive and simple 3D printable device for nephelometric and fluorimetric determination based on smartphone sensing. *RSC Adv.* **2020**, *10*, 19713-19719.

6. Hosker, B. S. Demonstrating principles of spectrophotometry by constructing a simple, low-cost, functional spectrophotometer utilizing the light sensor on a smartphone. *J. Chem. Ed.* **2018**, *95*, 178-181.

7. Bogucki, R.; Greggila, M.; Mallory, P.; Feng, J.; Siman, K.; Khakipoor, B.; King, H.; Smith, A. W. A 3D-printable dual beam spectrophotometer with multiplatform smartphone adaptor. *J. Chem. Ed.* **2019**, *96*, 1527-1531.

8. Piunno, P. A. E. Teaching the operating principles of a diffraction grating using a 3D-printable demonstration kit. *J. Chem. Ed.* **2017**, *94*, 615-620.

9. Di Nonno, S.; Ulber, R. Smartphone-based optical analysis systems. *Analyst*, **2021**, *146*, 2749-2768.

Optimizing Theta Pinches for Outreach Demonstrations

Theodore S. Lane, Thayne Hansen, Shaun Cluff Southern Utah University

Abstract

Theta pinches are devices that are frequently used in science demonstrations. We have created a modular theta pinch that allows for different coils of wire to be attached to our capacitor. By varying the number of loops in the coil of wire and maximum voltage in the capacitor, different amounts of can deformation can be measured. These values are compared with theoretical values as a form of validation. An increase in the total number of loops in a coil is shown to lead to an increase in can deformation, as is an increase in voltage on the capacitor.

Background

A theta pinch gained its name because of the direction the current flows in, the azimuthal direction. The current flowing around in the theta direction will create a magnetic field in the z direction in cylindrical coordinates [1]. Theta pinches were first designed in the early 1950s as an attempt to achieve nuclear fusion for energy production [2]. The theta pinch would prove to be an important stepping stone towards more viable closed-field configurations in fusion research, such as spheromaks and field-reversed configurations [3], which apply similar principles but with a more stable field geometry.

The theta pinch has seen a resurgence as a scientific demonstration [4], because it can crush aluminum cans easily and reliably [5]. This allows students to actively see the effects of Maxwell's equations, specifically Faraday's law, in real time. Many current theta pinches use a coil of wire that consists of 3.5 loops [4]; we intend to determine whether this is the most effective setup for classroom demonstrations.

Theory

The theory behind how a theta pinch works is entirely from Faraday's law,

$$\frac{d\Phi_B}{dt} = -\Delta V \tag{1},$$

where $\frac{d\Phi_B}{dt}$ represents the change in magnetic flux with respect to time, and ΔV is a change in voltage around a closed loop. What this means is that if the amount of magnetic field lines through any given area changes with respect to time, a voltage will be created around the perimeter of the area. For the purposes of crushing cans, the time-varying magnetic flux is created by a loop of wire connected to a capacitor. As the capacitor discharges, the amount of charge left on the capacitor will go as

$$Q(t) = CV \, e^{-\frac{Rt}{2L}} \cos(\omega_d t) \tag{2},$$

because this would be an LRC circuit, with the loop of wire acting as an inductor. In this equation, Q(t) is the charge on the capacitor at any given time t after the capacitor has started to discharge, V is the initial voltage in the capacitor, R is the resistance of the circuit, C is the capacitance of the capacitor, L is the inductance of the loop, and ω_d is the characteristic frequency of an LRC circuit [6]. As the charge varies with time, a current is produced in the circuit, given by the time derivative of the charge

$$I_1(t) = CVe^{-\frac{Rt}{2L}} \left[-\frac{R}{2L} \cos(\omega_d t) - \omega_d \sin(\omega_d t) \right]$$
(3).

Here, I_1 is the current in the loop. This time-varying current will cause the magnetic flux within the wire loop to change as well, as the current is what creates the magnetic flux. Because the flux in the wire loop is changing, the flux in the can is also changing, and goes as,

$$\Phi_B = M I_1 \tag{4}.$$

Here M is the coefficient of mutual inductance between the wire loop and the can, and I_1 is the current in the loop.

A change in magnetic flux will create a change in voltage around the perimeter of the can, as seen by Faraday's law (Eq. 1). Because the can is a conducting material, it will feel the effects of an applied voltage, causing charges to move inside the can. This leads to a current based on Ohm's law,

$$I_2 = \frac{V_{can}}{R_{can}} \tag{5},$$

where I_2 is the current created in the can and R_{can} is the resistance of the can. This is seen in Figure 1A.



Figure 1. (A) The clockwise outer loop of current changes as a function of time, creating the inner, counter-clockwise current around the edge of the can. (B) The opposite currents repel each other, causing the wire loop to feel force outwards and the can to feel a force inwards. This is what crushes the can.

With two currents now in the system, one creating the time-varying magnetic field and the other created by the time-varying magnetic field, there will be a magnetic force interaction between them. The currents will be opposite in direction, which will create a repulsive force between them, leading to the can being crushed, as shown in Figure 1B.

The force felt by a current when it is placed inside a magnetic field is given by

$$F = I_2 LB \tag{6}$$

Here, F is the force felt along the length of the current, L and B is the magnetic field the current is in. Equation 7 can be modified to provide force per unit length,

$$f = \frac{F}{L} = I_2 B \tag{7}$$

Through this equation, we can determine the force acting on any part of the can by letting B be the magnetic field created by the loop of wire, which goes as

$$B = \mu_o I_1 \frac{N}{l} \tag{8},$$

with μ_o being the permeability of free space, N being the number of loops, and *l* being the spatial extent of the loops. Combining Equations 6, 8, and 9, the force per unit length becomes

$$f = -\frac{V_{\text{can}}}{R_{can}} \left(\mu_o I_1 \frac{N}{l} \right)$$
(9).

The voltage around the circumference of the can can also be written in terms of the current flowing through the loop, which yields

$$f = \frac{\mu_o NM}{l R_{can}} I_1 \frac{dI_1}{dt}$$
(10).

This is the force at any single moment in time, but how crushed the can will become depends on the total force felt on the can, which would be given by the impulse,

$$J = \int f dt \tag{11}.$$

The force the can will feel will start at t = 0 and go until the current stops. This is an important distinction to be made for our system. In a standard LRC circuit, the current will oscillate for some time. In the setup used in this experiment, the current can only make one pass through our circuit, as the trigger mechanism is a spark gap arranged to only allow a specific voltage to bridge the gap; any less and it cannot pass. This means we integrate to a time t_1 such that $I_1(t = t_1) = 0$.

Integrating our function for force (Eq. 11), we find

$$J = \frac{\mu_o NM}{l R_{can}} I_1^2 \big|_0^{t_1}$$
(12).

Inserting our expression for I_1 (Eq. 3) and evaluating it at t=0 and t = t_1 , the expression for the impulse becomes

$$J = \frac{\mu_o N M R^2}{4 l R_{can} L^2} C^2 V^2$$
(13).

This again shows that the total number of loops plays a direct role in how much the can will be crushed, as the larger J, the more total force has acted on the system. A larger initial voltage on the capacitor should also increase the amount the can is crushed.

Experiments

The experimental setup is comprised of two different circuits, a charging circuit and a discharging circuit, that are connected by the capacitor in the middle, as shown in Figure 2.



Figure 2. The circuit diagram for the experimental setup. While switch A is closed, the capacitor can change. Opening A and closing switch B allows for the rapid discharge of current through the loop of wire. Switch C is a safety switch.

The charging circuit consists of the 5000V, the $100-\mu$ F capacitor connected to our 5000V, a 0.1-mA power supply [7], and a switch. Because the power supply is current limited to 0.1 mA, a minimum resistance of 1 M Ω is required. In this setup, four 1 M Ω resistors were connected in series, as each resistor was rated to only 2W of power [8]. This setup also allows for a sensitive control of voltage placed on the capacitor, as the voltage on a charging capacitor is given by

$$V(t) = V_s \left(1 - e^{-\frac{t}{RC}} \right) \tag{14},$$

which is plotted in Figure 3 for this experimental setup.



Figure 3. The voltage on the capacitor as a function of charging time. Because of the large RC time constant, voltage can be controlled easily by monitoring charge time.

The discharging circuit consists of the charged capacitor, a spark gap switch, and the loop of wire, inside of which the can is placed.

For these experiments, three different loops of wire were used, so as to see which one had the largest coefficient of mutual inductance and thus would make the best loop for crushing cans. The details of the different loops can be found in Table 1.

Table 1. Experimental loop information				
Loop	Number of loops	Length (mm)	N/l (#/mm)	Resistance (Ω)
Loop 1	1.5	6.44	2.33	7.75
Loop 2	2.5	8.34	3.00	9.15
Loop 3	4	13.86	2.89	8.70

To see how much a can was deformed, its diameter was measured using a pair of digital Vernier calipers. As the deformation of the can was often asymmetric, two measurements were taken, that of the largest diameter of the can and the smallest diameter of the can. These two measurements were combined using a geometric mean to provide a single value for can deformation.

Methods and Results

Once data were collected, the first step in data analysis was determining the standard deviation associated with the voltage on the capacitor when it was discharged. This voltage, given by Eq. 9, has two variables with associated error, the voltage provided by our power supply, V_s , and how long the capacitor was charged, t. This requires propagating errors [9] using

$$\sigma_{V_o} = \sqrt{\frac{\partial V_o^2}{\partial V_s}} \sigma_{V_s}^2 + \frac{\partial V_o^2}{\partial t} \sigma_t^2$$
(15),

where σ_n is the standard deviation associated with quantity n and $\frac{\partial V_o}{\partial n}$ is the partial derivative of equation 9 with respect to the quantity n.

Tables 2–4 detail the experimental configurations and results for Coils 1, 2, and 3, respectively. As multiple shots were taken with the same voltage and coil setup, each individual shot has the same error, so the average for each experimental setup is just the geometric mean. The standard deviation for can deformation is then

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N}}$$
(16).

Here \bar{x} is the average of the can diameters, x_i is the individual can diameter from each experimental setup, and N is the number of individual measurements.

Table 2. Data from coil 1			
Voltage (V)	Maximum	Minimum	Average
	diameter (mm)	diameter (mm)	diameter (mm)
3800	58.62	50.46	54.54
3800	58.4	56.70	57.55
3800	59.8	54.00	56.90
3800	58.6	54.50	56.55
3800	58.4	53.40	55.90
4470	57.13	50.95	54.04
4470	57.10	51.10	54.10
4470	55.20	51.10	53.15
4470	55.08	50.13	52.61
4910	53.58	45.30	49.44
4910	56.70	47.20	51.95
4910	55.20	49.80	52.50
4910	53.70	46.60	50.15
4910	54.13	48.50	51.32

Table 3: Data from coil 2			
Voltage (V)	Maximum diameter (mm)	Minimum diameter (mm)	Average diameter (mm)
3800	54.41	50.63	52.52
3800	54.08	48.63	51.36
3800	54.06	51.80	52.93
3800	56.38	53.20	54.79
3800	57.65	53.90	55.78
4300	55.10	44.86	49.98
4470	51.46	47.26	49.36
4470	53.84	49.00	51.42
4470	53.82	47.20	50.51
4900	50.59	46.82	48.71
4910	49.37	46.73	48.05
4910	52.85	46.26	49.56
4910	53.4	47.50	50.45
4910	51.3	46.20	48.75

Table 4: Data from coil 3			
Voltage (V)	Maximum diameter (mm)	Minimum diameter (mm)	Average diameter (mm)
3800	52.50	48.23	50.37
3800	52.10	47.10	49.60
3800	51.40	48.20	49.80
3800	52.85	48.80	50.83

The final coil only has viable data for the lowest voltage, because at the higher voltages, the can was physically torn, which did not allow for an accurate measure of minimum diameter. In Figures 4 and 5, we see that both more voltage and more coils lead to the can being crushed more. The asymmetry in the crushing of the can stems from the nature of the coils, as coils 1 and 2 both have noninteger values for the number of loops, resulting in more deformation on the side with the extra halfloop.



Figure 4. Three of the same type of can all crushed using the same coil (coil 3) but with different voltages. Can A was crushed with 3800V, can B with 4470V, and can C with 4910V.



Figure 5. Three of the same type of can all crushed using the same voltage (3800V). Can A is with coil 1, can B is with coil 2, and can C is with coil 3.

The results for an increase in voltage for one coil setup is plotted in Figure 6. The can diameter decreases with an increase in voltage, which correlates with an increase in impulse acting on the can. This result agrees with theory, as Eq. 14 states. However, Eq. 14 shows a quadratic dependence on voltage, where these initial results show more of a linear dependence. This parameter space should be explored more before a conclusion is drawn.



Figure 6. As voltage is increased, the average can diameter decreases, showing that a higher voltage leads to a larger impulse acting on the can. The data shown here are for coil 1, which has 1.5 loops.

In line with theory is the result that an increase in the total number of loops will lead to a higher impulse and thus more can deformation. This can be seen in Figure 7, where voltage was held constant at 3800V and as the number of loops increases the diameter of the can decreases.



Figure 7. As the number of loops in the coil increases, the average can diameter decreases, showing that a higher voltage leads to a larger impulse acting on the can. The data shown here are for a voltage of 3800V.

The theory also predicts a dependence on loop density (# of loops/mm), which is plotted in Figure 8. This figure shows that the density of the loops was not correlated with can deformation based on

our current data, which disagrees with the theory. A possible explanation for this discrepancy is that the theory also involves the inductance of the loops as well as the mutual inductance between the loops and the can. Thus, it is important to take all of these factors into account. Unfortunately, the coefficient of mutual inductance is very hard to calculate for a continuous object, such as a can, as opposed to a series of loops. This should be investigated more using more loop configurations as well as different loop materials to isolate where the discrepancy may lie.



Figure 8. As the number of loops in the coil per unit length is changed, there is no correlation with can deformation. More data should be obtained to confirm this. The data shown here are for a voltage of 3800V.

Conclusions

Based on the acquired data, increasing the number of loops and increasing the voltage on the capacitor leads to a more crushed can. When presenting a theta pinch as an outreach tool, the most important factor is that the can is crushed after the demonstration. Therefore, the best design for outreach is one with more loops that can deliver a larger voltage to the pinch.

When comparing the experimental results with theory, there are inconsistencies that need to be investigated in more depth. The voltage parameter space needs to be investigated more, specifically with respect to voltage-squared. The current variations in voltage-squared are significantly large, and only three different points make it difficult to determine dependence.

Another action that must be taken in the future is varying wire gauge while maintaining the number of loops in the coil. This will allow for the resistance in the discharging loop to be varied and controlled, as different gauges of wire will have different resistances. This will allow for a better probe into the dependence on the number of loops, resistance, and length of the loops. In this same vein, loops should be constructed to have the same number of turns but with different overall lengths. This would allow for more probes into the dependence on number of loops, length, and self and mutual inductances, which could provide more insight into the theory.

Overall, we have developed an exciting platform to help test student understanding of Faraday's law. With this information, outreach programs can be designed to help show students which factors go into inducing a current and how that can affect materials. These types of demonstrations are not only informative, but also entertaining, which should increase class participation and retention.

Acknowledgments

We thank the L.S. and Aline W. Skaggs Research and Scholarship Fund for partially funding this research. We also thank Dr. Rhett Zollinger for allowing us to borrow some of his equipment during this experiment.

Citations

[1] Basu, Dipak. *Dictionary of Material Science and High Energy Physics*, CRC Press, Boca Raton, FL, 2001, p. 315.

[2] Phillips, James. "Magnetic Fusion." Los Alamos Science, 1983;7:64-67.

[3] Friedberg, Jeffrey P. *Plasma Physics and Fusion Energy*. Cambridge University Press, Cambridge, UK, 2010.

[4] Harvard Natural Sciences Lecture Demonstrations. "Can Crusher -Magnetic Implosion," November 15, 2020, from https://science demonstrations.fas.harvard.edu/presentations/can-crusher-magneticimplosion.

[5] Stewart, Tristan. "Electromagnetic Can Crusher," (7 September 2001). Retrieved November 15, 2020, from https://members.tripod. com/extreme_skier/cancrusher/.
[6] Ohanian, Hans C., and John T. Markert. *Physics for Engineers and Scientists*. 3rd ed., W.W. Norton and Company, New York, 2007

[7] Information Unlimited. "HV350CC / HV350REG / HV350SAFE Operating Instructions," (3 March 2021). March 30, 2021, from https://www.amazing1.com/content/download/HV350INS.pdf.

[8] Vishay Intertechnology. "Power Metal Film Leaded Resistors," (11 July 2018). Retrieved January 1, 2021, from https://www.vishay.com/ docs/28729/pr010203.pdf.

[9] Bevington, P., and D. Robinson. *Data Reduction and Error Analysis for the Physical Sciences*. McGraw-Hill, New York, 1969.

Making Silicon Places: Regional Entrepreneurialism and the Technology Economy on the Silicon Slopes

Jeremy Bryson, Melissa Jensen Weber State University

Abstract

Hoping to imitate the successes of California's Silicon Valley, metropolitan areas around the United States have tried to create similar high technology entrepreneurial regions in an effort to attract highpaying jobs and a skilled workforce. Although researchers have already begun to explore the environmental histories, landscape conflicts, and social impacts of Silicon Valley's development, we know relatively little about the second wave of these self-styled technology hubs. This paper explores one of these newer technology innovation hubs, known as Silicon Slopes in Utah, to understand the role of regional-scale entrepreneurialism in shaping contemporary metropolitan landscapes. Specifically, this paper examines the importance of rhetorics of place that are manifest on Silicon Slopes cultural landscapes.

In 1979, in Provo, Utah, Alan Ashton, a Brigham Young University (BYU) professor, and Bruce Bastian, a BYU graduate student, started WordPerfect, the software that dominated word processing in the 1980s. WordPerfect was eventually sold to Novell in 1994 for about a billion dollars. That sale netted enough money for the Ashton family to begin development of a mixed-use entertainment and office complex, Thanksgiving Point, in 1995. Thanksgiving Point, located in Lehi, Utah, at the Point of the Mountain about halfway between BYU and the University of Utah, would quickly become the locus for technology startup companies founded by graduates of these major universities. One of these startups, Omniture, a web analytics and online marketing company, was founded in 1996 by Josh James, a BYU graduate. Omniture grew quickly, but not as quickly as James would have liked. Despite demonstrated promise and success, James was not able to attract the attention of venture capital (VC) firms. In fact, he had to wait three years before gaining his first sniff of Silicon Valley VC-a veritable eternity in Silicon Valley life cycles. James's inability to attract VC stuck with him even as his company continued to grow. He realized that other startups like Qualtrics, a maker of custom analytics software founded in 2002 that had to wait nearly a decade before receiving any VC investment, were similarly growing but having a difficult time. Thus, to stimulate investment for a burgeoning tech startup culture, James established Silicon Slopes in 2007.

Silicon Slopes is a 501(c)(3) nonprofit organization that acts as the "voice, hub, and heart of Utah's startup and tech community." "Thanks to the Silicon Slopes community," the organization's About Us page states, "Utah is a vibrant, diverse, global innovation hub with some of the greatest entrepreneurs and companies in the world" (Silicon Slopes, n.d.). It continues that there are now "6,500 startup and tech companies in Utah that are full of entrepreneurs and leaders who have earned global recognition through hard work, a focus on building exceptional companies, and a willingness to give back and serve others." Indeed, Silicon Slopes was created to attract VC, and its plan seems to have worked. By 2014, Inc. Magazine said "Move over, Silicon Valley: Utah has arrived" (Mochari, 2014). While this was and is surely hyperbole, the accompanying graphics showed the strides the region had made with both the Provo-Orem and Salt Lake City-Ogden Metro areas listing in the top 12 in total value of VC funding. It was around this time that the tech media really began to see the promise that the tech startup region along Utah's Wasatch Front. As billion-dollar businesses including Domo, Qualtrics, Vivint, Ancestry, Pluralsight, Workday, and Instructure began to develop, the buzz continued to grow. Observers have noted several factors that have contributed to the region's early

success in attracting tech investment, including the Wasatch Front's geographic location at the "crossroads of the West," the state's young and highly educated workforce, and the relatively low business and housing costs (Howell, 2020). Yet, a fundamental geographic problem remained: There needs to be a more developed place for mobile capital to attract to. The strategic placemaking efforts of Silicon Slopes are aimed at resolving that fundamental problem. Silicon Slopes was created to present a place for VC, an important form of mobile capital, to land.

Placemaking

To more easily attract investment, the Silicon Slopes organization figured that it had to transform the Wasatch Front into a place that would attract VC firms. Decades of evidence had shown that there is no place that is more synonymous with innovation, entrepreneurship, and the accompanying VC funding than California's Silicon Valley. Silicon Slopes, then, intuited that the tech industry on the Wasatch Front needed to mimic that successful place. The Wasatch Front needed to become a Silicon Place. Economic geography scholar Richard Florida calls these places that "try hard to give themselves that certain 'silicon' branding" Siliconias. He continues that "the atmosphere and circumstances that the Silicon Valley area has created has and will continually be attempted in other parts of the world. ... There are numerous cities and regions that have made an effort to create their own Siliconia" (Florida, 2013). In effect, to adopt the language of cultural geographers and urban planners, to create their own Siliconia, Silicon Slopes needed to make a place. They needed to make a Silicon Place to thrive in the contemporary economy. Placemaking, generally, according to the Congress for New Urbanism, is "the process of creating quality places that people want to live, work, play, and learn in" (Steuteville, 2014). Although this is true of many types of places, to make a Silicon place, Silicon Slopes required a more specific approach. Strategic placemaking aims to "develop places that are uniquely attractive to talented workers, that attract businesses, and that catalyze substantial job creation and income growth" (Steuteville, 2014). Even more specifically, strategic placemaking is used by public, nonprofit, and private sectors to "target knowledge workers who, because of their skills, can choose to live anywhere and who tend to pick Quality Places offering certain amenities" (Steuteville, 2014).

In this project, we explore how Silicon Places—in this case Silicon Slopes—manage their strategic placemaking. We argue that rhetorics of place are a crucial element of this placemaking. A classic definition of rhetoric is that it is the process of producing that which is probably true. In the case of the Silicon Slopes, the universities, the business-friendly environment, the pioneer tech entrepreneurs—all the things you needed to have a technology industry were already in place—that is, a future tech hub was already "probably true." To produce that future truth in the material landscape, place promoters had to create a linguistic discourse about what was probably true about the technology region, which then would inform and be informed by the built landscape. More specifically: If placemaking involves creating both a rhetoric of place and landscapes, then what are the outcomes of these approaches? What types of place rhetorics are being created? How are these rhetorics then translated onto the landscape?

Rhetoric of Place

A combination of private, nonprofit, and public efforts have worked toward the creation of a rhetoric of place for Silicon Slopes. A quick search through the words of entrepreneurs, local and state economic development agencies, politicians, and the Silicon Slopes organization, reveals a Silicon Slopes that is simultaneously business and family, urban with a reasonable cost of living, a place of hard-working go-getters and also a place of abundant leisure pursuits. In many respects, Silicon Slopes seems to be an ideal place. Yet, for all of the words, one of the most illuminating ways to capture the place rhetoric strategies that Silicon Slopes employs is to look at the maps that are produced of Silicon Slopes. Several of the maps showcase the transportation networks that are central to the circulation of the region, the major universities that provide graduates that drive innovation, and the corporate headquarters of prominent tech companies. In addition to these features that are all expected inclusions for a map of a technology corridor, though, we also find deliberate inclusion of mountain recreation. The prominent placement of representations of prominent peaks along the Wasatch Front, ski resorts, and mountain biking trails suggests the importance of outdoor recreation to Silicon Slopes place branding efforts. Consider, for example, the tale reported in Silicon Slopes Magazine about how Ryan Smith, the founder of Qualtrics, promotes the region: "You don't think the [tech elite that attend conferences on the Slopes] will start to notice how amazing this place is? I sat in the audience today while Ryan Smith unabashedly pitched Utah to all of his customers and gave them all ski passes to Park City. We need more of this type of evangelism!" (McClary, 2018).

Indeed, the message that Utah is a place worth living and working in seems to have sunk in, at least for the people that are already working in the place. For example, the efforts by Qualtrics to attract young Silicon Valley talent begins with a page on its website titled "Why Live (and Work) in Utah?" "When we first opened our headquarters in Provo," the text begins, "hardly anyone thought of Utah as a startup hotbed. Today, we're proud to be part of the thriving 'Silicon Slopes' scene. And it's no surprise tech companies—and their employees—are flocking to the state. Utah offers stunning scenery, year-round outdoor adventures, and a lively nightlife (yes, really!) plus a cost of living that's a fraction of that 'other' Silicon city" (Qualtrics, n.d.). Another employee said: "When I came to Utah, I discovered something completely new-the outdoors and the magic in them... The best part is that I don't have to give up my love for the city. I am never more than an hour away from my next big adventure. It would be hard to take me away from this amazing state." Continuing this theme, another employee recalled: "The first thing I noticed after moving to Utah was that I didn't watch as much TV. I have two young boys and a wife and we're constantly on the go outdoors now. The scenery is just staggeringly beautiful. My drive to work feels like I'm in Switzerland. I also feel like Utah's summers are underappreciated. Everyone comes here in winter for the powder, but there's also mountain biking, and the fly fishing and boating are phenomenal" (Qualtrics, n.d.). The companies themselves may have been attracted to the skilled workforce, but employees are undoubtedly drawn to everything else Utah has to offer.

By promoting the outdoor and mountain recreation potential of the region, Silicon Slopes boosters are hoping to create a rhetoric of place that will attract investment. In creating this rhetoric of place, boosters are looking at their place characteristics and crafting a narrative that is probably true. Attempts to define the region as a place that young talent, and by extension, VC firms, will be interested in attaching themselves to seem largely successful.

Rhetoric of Place Manifest in the Landscape

All of this place rhetoric, though, has real implications on the ground. The physical landscape is changing dramatically in order for the Wasatch Front to become a Silicon Place. Michael Leavitt, Utah's governor during the 1990s while the technology industry was just beginning to take hold, regularly took recruiting trips to Silicon Valley and recognized the real challenges that can accompany technology growth. "It has become clear to me," he said, "that Silicon Valley has a challenge. They have reached natural boundaries geographically. Traffic has become a huge problem. Those have become significant inhibitors." On the other hand, he concluded, "We have workers, we have space, we have proximity" (Lee, 2001). Leavitt's words were surely true then, but

Silicon Valley's traffic problems in the 1990s have quickly become Silicon Slopes's traffic problems in the 2010–2020s.

These traffic problems contribute in visible ways to perhaps the biggest detractor of enjoyment of the outdoors in Utah: the notoriously poor air quality in the Salt Lake Valley. However, the culture of innovation that is drawing people to Silicon Slopes may be what is needed to find solutions for this long-term concern. Investing in infrastructure can ease traffic congestion and improve air quality-and a larger tax base can help Utah do that. In the 2020 Investor's Choice Capital Conference, businessman and former governor Jon Huntsman Jr. expressed concern over the potential downsides of rapid population growth. He stated, "What we can't let happen is for our livability to be affected by air quality that really becomes so bad that people don't want to come in and those here want to move out, and it becomes a health issue as a much as a quality-of-life issue" (Wallace, 2020). His overall outlook for Utah's economic future was overwhelmingly positive, yet he admonished the state to make the necessary investments to ensure that positive growth doesn't become negative. His view was that, "... When you lose control of growth, transportation, air quality, water resources... You lose talent-they look for the next big thing-you lose kids, you lose brainpower and ultimately you lose investment. You need both to make any economy successful: You need brainpower and you need investment" (Wallace, 2020).

Speaking of the future of the Silicon Slopes, an op-ed writer commented: "Another [challenge] is infrastructure. Anyone reading this story knows how much of a mess it is to get around Lehi during lunch time or how bad traffic on I-15 is during rush hour, both ways. We need to work with our legislative body to fund the right projects that will take care of our future infrastructure needs" (McClary 2018).

Indeed, this is already happening as the Interstate 15 landscape is transforming at the epicenter of Silicon Slopes to accommodate more vehicle traffic, and plans are underway to broaden public transportation access throughout the region. Other landscape changes are responding to the potential of Silicon Slopes. Central among these projects is the relocation of the Utah State Prison—which currently sits on a 700-acre site at the heart of Silicon Slopes. The new prison is currently being relocated away from the Wasatch Front. In preparation for the prison relocation, the planning for the redevelopment of the state-owned land has been in process for years already. The technology sector has been at the center of the planning process throughout the years' long effort. "By properly developing the [Prison] site," one economic development decision maker said in an op-ed, "the state has an opportunity to create a new economic engine that will positively impact Utah for decades by creating great jobs, new capital investment and strong revenues for state and local governments to fund schools, roads, open space and the other future needs of our state. It will also help us retain our graduates and attract the best and brightest from around the world. If we want to compete with Silicon Valley, we need to continue to develop an environment where companies have a large pool of educated workers, access to venture capital, and a network of related companies that help create a unique culture of innovation" (Edwards, 2015).

Conclusion

The creation of Silicon Slopes, like all Silicon Places, is still in progress. However, as we have explored in this paper, we can be confident that the making of a Silicon Place, as we have explored through the development of Silicon Slopes along the Wasatch Front, involves the creation of a rhetoric of place. Place rhetorics, like those used to create Silicon Slopes, can then have real impacts on the landscape—creating both opportunities and challenges.

References

Edwards, J. (2015, August 2). Moving the prison would present an economic opportunity for Utah. Deseret News. Retrieved March 12, 2019, from https://www.deseret.com/2015/8/2/20569375/moving-the-prison-would-present-economic-opportunity-for-utah.

Florida, R. (2013). The ubiquity of silicon (at least in name). Martin Prosperity Institute Insights. Retrieved February 19, 2019, from http://droplet01.heliosdesignlabs.com/mpi/insight-the-ubiquity-ofsilicon/

Howell, I. (2020, October 14). Bay Area companies are moving to Utah (here's why): Companies are starting satellite offices outside of Silicon Valley and Utah is one of their top choices. Utah Business, 34(10). Retrieved February 10, 2021, from https://www.utahbusiness.com/ satelite-offices-are-coming-to-utah/.

Lee, J. (2001, June 3). Way out west: There's silicon in them that hills, or will be soon. New York Times. Retrieved March 15, 2019, from https://www.nytimes.com/2001/06/13/business/way-out-west-there-s-silicon-in-them-thar-hills-or-will-be-soon.html?pagewanted=1

McClary, B. (2018). Future forward: What will Silicon Slopes look like in 10 years? Silicon Slopes Magazine 2(2):36-37. Retrieved February 12, 2019, from https://newsroom.siliconslopes.com/magazine/temp-slug-28/

Mochari, I (2014, November 10). Move over, Silicon Valley: Utah has arrived. Inc. Magazine. Retrieved February 12, 2019, from https://www.inc.com/ilan-mochari/silicon-valley-utah.html

Qualtrics. (n.d.). Why live (and work) in Utah? Qualtrics website. Retrieved February 20, 2019, from https://www.qualtrics.com/ about/why-utah/

Silicon Slopes. (n.d.). About. Silicon Slopes newsroom. Retrieved February 12, 2019, from https://newsroom.siliconslopes.com/about/.

Steuteville, R. (2014, October 10). Four types of placemaking. Public Square: a CNU Journal. Retrieved February 24, 2019, from https://www.cnu.org/publicsquare/four-types-placemaking

Wallace, B. (2020, March 2). Huntsman: Utah driven by 'a lot of natural zeal.' The Enterprise, 49(32), 1–2. Retrieved March 4, 2021, from https://slenterprise.com/index.php/news/latest-news/3506-huntsman-utah-driven-by-lot-of-natural-zeal.

From "My Guy" to "Inner City Blues": A Spectrum of Resistance in Motown Music

Theresa A. Martinez University of Utah

Abstract

In 1959, Berry Gordy Jr. founded Motown—a record company based in his hometown of Detroit, Michigan. Gordy designed this premier blackowned record company to create non-confrontational music that appealed to both white and black audiences. While Gordy established his vision and goals for the company, the intrepid Motown artists that he discovered created their own audacious sound and style that sometimes subtly and at times straightforwardly questioned racial, class, and gendered oppression in their day. This paper reflects on the sociohistorical context of Motown music and frames a lyrical and thematic analysis of selected Motown artists through the lens of oppositional culture and resistance theories as well as dramaturgical approach, a framework we will call oppositional performance or performance as resistance. In all things that are purely social we can be as separate as the fingers, yet one as the hand in all things essential to mutual progress... No race that has anything to contribute to the markets of the world is long in any degree ostracized.

(Washington 1901/1995: 107)

It is a peculiar sensation, this double-consciousness... One ever feels his two-ness,—an American, a Negro; two souls, two thoughts, two unreconciled strivings; two warring ideals in one dark body, whose dogged strength alone keeps it from being torn asunder... The history of the American Negro is the history of this strife—this longing to attain self-conscious manhood, to merge his double self into a better and truer self.

(Du Bois, 1903/1997: 38)

These quotes encapsulate threads of African American discourse in the late 19th and early 20th century that are still resonant down to our time. The standpoint of Booker T. Washington represents "the strategy of a compromiser," who presented the issues of inequity in his day "in a way that whites in the audience would find acceptable" as he advanced a "goal of racial uplift" for African Americans (Smock 2009: 50). In deliberate contrast, the standpoint of W.E.B. Du Bois (1903/1997: 92) represents the centrality of the "double-consciousness" among African Americans—the profound internal fracture of a freed people who are yet ultimately denied "freedom of opportunity". Du Bois underscores the need for protest to achieve a vision of equality and, in fact, "added the missing dimension" to Washington's thread of the discourse by insisting on "agitation for civil rights and standing up to Jim Crow, not bargaining with it" (Smock 2009: 159).

It seems fitting to reflect on two standpoints that, in turn, speak to contradictory strands of the Motown ethos. On the one hand, in a nod to Booker T. Washington, we have Berry Gordy Jr.—the founder of Detroit's black-owned Motown Record Company—who was "almost completely apolitical" and worked assiduously to create non-controversial music that would appeal to both white and black audiences (Posner 2002: 107). Gordy even went as far as creating a "finishing school" for Motown artists that taught deportment, table manners, hygiene, and posture as well as "the art of the inoffensive interview" (George 2007: 88). On the other hand, in a nod to W.E.B. Du Bois, we have Motown artists who would contradict Gordy's non-confrontational stance with music that subtly but also powerfully evokes the critical issues of their time, alluding to Dr. King's civil rights messages of racial harmony and black dignity—the struggle for racial justice fought on "the

high plane of dignity"—but also the grim realities of police brutality, urban immiseration, and a brutal war overseas (King 1963).

This paper explores the music of Motown within its particular sociohistorical context as a form of popular cultural resistance. Reflecting the standpoints of both Washington and Du Bois, Motown artists spoke both subtly and stridently to issues of racial, gendered, and class inequity in their day. The paper contributes to scholarship focused on the music of Motown as well as African American music in the 20th century by revealing a collection of oppositional performances in Motown music through a conceptual lens that blends elements from oppositional culture and resistance theories as well as dramaturgical approach—*performance as resistance* or *oppositional performance*.

THE MOTOWN CONTEXT

The Motown Record Company was the brainchild of Detroit native Gordy, who designed the black-owned company to create popular music that would not provoke either debate or division, but would simply deliver popular appeal to white and black audiences alike. As mentioned, Gordy was practically apolitical, an astonishing stance given the nature and intensity of the era's political upheavals. As Motown was reaching its zenith, the civil rights movement was coming into its own, uprisings were unfolding across the country bred of the glaring disenfranchisement of African Americans, and hundreds of thousands of American soldiers were being shipped overseas to fight in Vietnam.

Selma, the War in the Streets, and the War Overseas

As Motown was coming into its own, significant civil rights actions were taking place, particularly a series of marches and demonstrations for voting rights in Selma, Alabama, in 1965. The tipping point of all this activity took place on Sunday, March 7, when state troopers and local possemen, some riding on horseback, savagely attacked unarmed, peaceful civil rights marchers. The troopers and possemen assailed the marchers with billy clubs and tear gas as well as more grotesque instruments of torture, including "bullwhips, ropes, and lengths of rubber tubing wrapped with barbed wire" (Fager 2015: 100). An eyewitness wrote that the peaceful marchers were "knocked to the pavement, screaming in pain and terror, the wooden clubs thudding into their flesh" while "from the sidelines a shrill cheer went up from the watching whites" (Fager 2015: 100). This hideous scene, witnessed on television by the American public, focused the nation on the unrelenting denial of voting rights to African Americans (Fager 2015; Garrow 2015). In

August of that year, President Johnson would sign the Voting Rights Act, a follow-up to the Civil Rights Act of 1964 (Fager 2015: 227).

While major uprisings fanned out across the country in the 1960s, the Detroit uprising in 1967 underscores the Motown context (Darden and Thomas 2013). Detroit's uprising was sparked by an early morning police raid in "one of black Detroit's most prominent business districts" (Sugrue 2017: ix), reinforcing anger and outrage at the unrelenting police brutality toward African Americans in the city. In fact, Detroit's police enforced segregation as "the first line of white defense against the invading 'black hordes' that, if left unchecked, would overwhelm surrounding white neighborhoods" (Darden and Thomas 2013: 29). At the same time, Black Detroiters were forced into "[s]ubstandard housing and racially restricted living spaces" with a "shortage of jobs in the area where most blacks resided," contributing to high unemployment rates (Darden and Thomas 2013: 6, 82). These deplorable factors helped shape the vicious cycle-crime increases "largely as a result of the terrible living conditions produced and maintained by racial discrimination in housing and employment," which then justifies police presence (Darden and Thomas 2013: 29).

We then turn to the escalating war overseas in Vietnam in the mid-1960s, unfolding during some of Motown's most profitable years (George 2007). In unequivocally human terms, a historian describes the war's escalation.

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 and young men of color—"disproportionately they came from America's small towns, farms, and inner cities" (Farber 1994: 146). The "quagmire" overseas resulted in tens of thousands of casualties, though opposition to the war began to emerge with early opponents including "a number of civil rights activists" (Farber 1994: 155). Over time, "more and more prominent and mainstream participants" joined the growing antiwar movement (Farber 1994: 163).

Motown was clearly reaching its peak at a weighty moment in the nation's sociohistory, and we will find that the messages of resistance in Motown music reflected the era in unique ways. Motown artists spoke artfully and even openly to the chaotic upheavals in their time and to glaring inequities of race, gender, and class. Motown artists took up the mantle of speaking to these realities in their critical and performancebased brand of resistance.

Performance as Resistance

Bonnie Mitchell and Joe Feagin (1995: 73) suggest that "art and music" created by oppressed groups can be an empowering method of resistance to domination. In fact, they assert that oppressed groups can draw on art and music, along with other elements of a rich cultural heritage, to "preserve dignity and autonomy, 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" (1995: 73, 69). They describe these *oppositional cultures* or *cultures of resistance* as "a coherent set of values, beliefs, and practices which mitigates the effects of oppression and reaffirms that which is distinct from majority culture" (Mitchell and Feagin 1995: 68).

Like Mitchell and Feagin, James Scott (1985) speaks of forms of resistance to oppression. Scott suggests that dominant and oppressed groups follow given public transcripts or prescribed ways of acting within particular social settings that suggest oppressed groups submit to their lot in life. However, Scott asserts that *everyday forms of resistance* emerge even in the midst of the starkest forms of oppression, such as enslavement or peonage. Resistance in this regard, he suggests, takes the form of hidden transcripts that are capable of resisting the powerful by using imposed language and ways of behaving as a means of resistance. Scott (1985: 137) identifies forms of resistance such as "linguistic tricks, metaphors, euphemisms, folktales, ritual gestures, anonymity."

Erving Goffman (1959) introduces a performance element within this context, a dramaturgical approach to understanding the social world, suggesting that we as social actors are always performing to audiences, much like theater actors. Moreover, Goffman asserts that we all manage the impressions and therefore the responses of our audiences by crafting frontstage performances that please and even manipulate them. At the same time, when we drop the performance, Goffman suggests that we are existing in the backstage, the place where our genuine self emerges the self that audiences rarely see. More than that, Goffman's dramaturgical approach argues that this level of impression management can be especially useful to social actors who are capable of meticulously molding frontstage performances for their audiences.

It is the central argument of this paper that Motown artists, always negotiating the white sensibilities and the double-consciousness of their time, were shaping oppositional performances in response to the world they inhabited. These artists witnessed the passage of the Civil Rights and Voting Rights Acts, yet were also aware of glaring inequities facing African Americans in Motown's home city of Detroit and across the nation, inequities that spurred urban uprisings even close to home. They also watched the unfolding horror of the war in Vietnam and the growing anti-war movement. These artists found ways to address the over-whelming issues of racial, gendered, and class injustice in this era while hiding in plain sight as the vibrant sound of Motown. Their often subtle and sometimes daring lyrics articulated courageous hidden transcripts and brave critiques—intrepid acts of *oppositional performance* or *performance as resistance* for their time.

THE MOTOWN STORY

Studies that focus specifically on popular music include a range of scholarly interests (Marsh 2020; Morgan 2020; Mustamo 2020). The scholarly work that focuses on the Motown era describes the entrepreneurial significance of the record company as well as the sociohistorical context in which the music was created.

A Marketable Sound

Motown is featured principally as a community and business enterprise in several scholarly works. Motown is situated firmly in the Motor City—Detroit, Michigan—in the work of Suzanne E. Smith (1999). Smith asserts that a focus on the city "presents a sharper picture of Motown's cultural, political and historical contributions throughout the civil rights era" (1999: 8). Further, Smith emphasizes Motown's distinct role as a black-owned business enterprise as it reflected "the unique concerns of African Americans living in the urban North" (1999: 8). Brian Ward (1998: 165) describes the rise of Gordy and Motown within a sociohistorical timeframe marked by a distinctly "integrationist agenda" that enabled a black-owned record company to succeed in the "American mainstream."

Ellis Cashmore (1997: 2) focuses on the extraordinary extent to which "whites have intervened in black culture" by producing, packaging, and merchandising it "into any shape that will turn a profit." Cashmore notes the rise and commercial success of Gordy and Motown Record Company, but stresses that Gordy played "a bigger game" that demonstrated "the power of whites' images in affecting the ways or patterns in which blacks construct a culture that is, in a genuine sense, theirs" (1997: 81, 112). Mark Anthony Neal (1997: 117) suggests that the strategies that Gordy developed to market the Motown sound would ironically become the blueprint for "Corporate America's later annexation of the black popular music industry." These strategies, he

asserts, exploited "post-Civil Rights movement narratives that often implied the inclusion of African Americans," but "in reality rarely offered African Americans significant autonomy and agency in their commercial products" (1997: 118).

Nelson George (2007) documents the rise and decline of Motown as primarily a corporate interest. He interrogates a plethora of painful lows for the company—the complaints over low salaries, the alienation of artists like Martha Reeves and Florence Ballard, the departure of the songwriting and production team of Holland–Dozier–Holland, and the ultimate departure of Motown Record Company from the Motor City itself. George (2007: 202) sums up the fallout of this ultimate departure from Detroit—"since its move to Los Angeles, Motown has had moments of glory, but the magic of the production line has been lost, discarded, and buried."

A Gordy Legacy

Several scholars place a central focus on Gordy, detailing his background, influences, and shrewd business strategies, but also his shortsightedness and inflexibility. In Peter Benjaminson's history of Motown (2018, he explains the many and varied Gordy methods for creating the Motown Sound, which included playing "master recordings on the tinniest…phonographs around to approximate the sound heard in a car," implementing a quality control process to separate hit songs from "garbage," and of course crafting a "marketable soul" that both white and black audiences would find appealing (2018: 41, 42, 46). In all, Benjaminson asserts that Gordy and Motown "integrated the business of making rock 'n' roll and black music in America" (2018: 175).

Gerald Early (2004: 42) describes several distinctive foundational influences for Gordy's success with Motown, including three African American icons. Booker T. Washington is the first—values of "thrift, Yankee ingenuity, hard work, business acumen and ambition were instilled in" Gordy and his siblings from an early age. Champion boxer Joe Louis is the second—"Gordy's first and probably most impressive hero" (2004: 44). The third is perhaps an inadvertent icon for Early—W.E.B. Du Bois—who unveiled the "peculiar sensation" of the double-consciousness (Du Bois, 1903/1997: 38).

Gerald Posner (2002: 172) proffers perhaps the most critical history of Gordy and Motown. He asserts that while Gordy was moved by Dr. King's messages of racial harmony and nonviolence, Gordy "had little sense of social destiny or moral responsibility stemming from his remarkable success." Posner offers the notable example of Gordy insensitively entertaining "lavishly at his Detroit mansion" precisely "when black protests increased in the streets" of Motor City (2002: 174).

The scholarly work on Motown music uncovers a black-owned business enterprise shaped in urban Detroit in an integrationist era by an ambitious, shrewd, and at times tone-deaf founder, with far-reaching consequences for black popular culture in America. Scholarly works also reveal a record company that worked diligently to appeal to audiences— both black and white—in the midst of tremendous sociohistorical upheavals. This study will draw from a theoretical lens of *performance as resistance* or *oppositional performance* through which we will focus on a lyrical and thematic analysis of the music of Motown artists.

A Few Words on the Method

The current study is a content and thematic analysis of resistance themes in the songs of selected Motown artists. The artists that will be the focus of our analysis include Mary Wells, the Temptations, Martha and the Vandellas, Stevie Wonder, and Marvin Gaye. The analytical rubric for the current study "is conceived as an emergent product of a process of gradual induction...very much a creative act" (Lofland and Lofland 1995: 181-182). Shulamit Reinharz (1992: 159), in addition, notes that "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." In this regard, our theoretical lens will guide the analysis as we uncover oppositional performance or performance as resistance in the music of our selected Motown artists, who spoke through hidden transcripts as well as overt critiques to issues of race, gender, and class inequity in their time (Goffman 1959; Scott 1985; Mitchell and Feagin 1995).

MESSAGES OF DIGNITY, MESSAGES OF RESISTANCE

The Motown artists selected for this analysis played central roles in the company's successes both early on and in later years (Ritz 1985; Ward 1998; Smith 1999; Posner 2002; Early 2004; Ribowsky 2010a,b; Benjaminson 2018). Drawing on our theoretical lenses, we will find that the songs of each artist—popular cultural performances— express critiques of the status quo for white and black audiences alike, taking the form of hidden transcripts as well as blatant criticisms that also speak to themes of black dignity and racial harmony (Goffman 1959; Scott 1985; Mitchell and Feagin 1995).

Character Is Power

To appeal to white as well as black audiences, Gordy specifically trained his artists to be "nonthreatening to the white majority in voice and manner," packaging "the black music of Detroit in such a way as not to contribute to racist stereotypes of African Americans as uncouth or uncivilized" (Ribowsky 2010a: 59; Smith 1999: 120). Motown artists, then, presented their best, most promising faces to white audiences, communicating messages of black dignity and racial harmony. Such strategies hearken back to notions of racial uplift (Washington 1901/1995) but also endurance within the double-consciousness (Du Bois 1903/1997). More importantly, for some Motown artists, oppositional performance meant concealing critiques of the racial, gendered, and class inequity within hidden transcripts that served to uplift black audiences while not offending white audiences (Goffman 1959; Scott 1985; Mitchell and Feagin 1995).

A Lesson in Devotion

Although it was written by Smokey Robinson, Mary Wells performed the song "My Guy" (Posner 2002). The lyrics speak of a woman's relationship to the man in her life and include a consistent, plainly emphatic stress on the unwavering loyalty and devotion of the woman to the man she loves. Similes in the lyrics and an idiom express this fidelity—"stuck like glue," "like a stamp to a letter," "like birds of a feather." The song lyrics even suggest that the woman in the song cannot be bribed—"nothing you could buy"-to make her unfaithful-would "make me tell a lie." The lyrics also note that the woman has made a pledge to the man of her dreams—"her word of honor"—and the man is described as "tops," her "ideal," and "the cream of the crop." Other men are described as "muscle bound" and "handsome," but these qualities have no effect on the woman in the song. Although terms like "tear me away" or "torn apart" are briefly mentioned with regard to the relationship between the woman and the man in her life, they are negated as preposterous given the devotion of the woman to "my guy."

Both black women and black men are center stage in the song "My Guy." The faithful, true, and loyal woman in "My Guy" with her overt pledge of fidelity stands in unequivocal contrast to horrendous images of black women in American history and culture, as noted by Patricia Hill Collins (2000). Collins (124-125) asserts that "U.S. culture... routinely accuses Black women of being sexually immoral, promiscuous jezebels." In addition, the unfailingly positive, glowing allusions to "my guy" contrast sharply with horrific perceptions of black men in American culture, as Angela Davis asserts. Davis (1997: 69, 267-268) stresses that

black men have long been stigmatized in American culture as criminal and violent by nature within a "hidden logic of racism" that leads to criminalization. For Smokey Robinson to write, and for Mary Wells to sing, a song that upholds the worth and dignity of black women and men in this era, is a courageous hidden transcript—a performance as resistance for black and white audiences alike.

Surpassing Nature

"My Girl" was performed by The Temptations as Smokey Robinson's follow up to "My Guy." "My Girl" describes the power of a man's love for the woman in his life by evoking the laws of nature and the beauty of the natural world. The man in the song perceives "sunshine on a cloudy day," the warmth of May even in the midst of cold weather, a wealth of honey that the bees "envy," and a song so sweet it rivals those sung by "birds in the trees." The man in the song declares that he doesn't need "money, fortune, or fame," because being with the woman he loves showers him with "riches." The person who topples the natural and physical world in the song is "my girl"—the woman in the man's life.

Both black men and black women are the central focus of "My Girl." With regard to black women, thoughts of "my girl" are so powerful they upend the universe, her sweetness serves as a rival to nature's own, and being with her represents all the riches a man could desire. Again, this portrayal stands in opposition to images in American society, which "effectively treats Black women as potential prostitutes" (Collins 2000: 132). In addition, "My Girl" presents an implied vision of black men who value the beauty of nature, resist the purely venal desires of "fortune and fame," and express a profound capacity for love. This again stands in direct contrast to appalling perceptions of black men in American society—Davis (1997: 266, 268) describes America's criminal justice system as "an out of control punishment industry" that disproportionately incarcerates black men. Tellingly, Darden and Thomas describe a case of police abuse of a young black couple in Detroit in this time period that

revealed the pattern of white male police sexist and racist stereotypes of black women as prostitutes, but what was more revealing was the all too common beating ritual of black men by white police as a show of racial control. (2013: 35)

The performance of "My Girl" by the Temptations is a hidden transcript that speaks to the dignity and value of black men and women, a performance standing in frank opposition to horrendous and oppressive racial, gendered, and class images in their day.

An Invitation to the Nation

The song "Dancing in the Street" performed by Martha and the Vandellas begins with a call out to the "world," announcing "a brand new beat." The song suggests that "the time is right for dancing in the street"—evidently the time was not quite right before this. The song then mentions where "dancing" will take place-Chicago, New Orleans, and New York City. The song's hook enters next with a reminder that "all we need is music," which will be "everywhere"—a sound that will make people swing, sway, and dance. This is followed by the chorus, which encourages everyone to join the dance—"it doesn't matter what you wear, just as long as you are there." The next verse confirms this is an "invitation" and a "chance for folks to meet"-folks from all manner of backgrounds. Again, cities are mentioned where dancing is taking place-Philadelphia, Baltimore, Washington D.C., and Detroit, of course. The hook and the chorus are repeated followed by a last set of lines mentioning Los Angeles, but "also a big strong line" of dancers that can span "across the ocean."

"Dancing in the Street" is a song that calls for movement in the streets and the breaking down of barriers between people regardless of race, gender, or class-"a chance for folks to meet" and "it doesn't matter what you wear." The implication is that such movement has long been restricted, but the song's message is hopeful for integration across the country from New York City to Los Angeles. There is also a nod to Motown itself in the lyrics, as after all it is music that will offer the "chance for folks to meet" as it breaks down every barrier. It is no small coincidence that the song was released in July 1964, just a few months after President Johnson made his Great Society speech at the University of Michigan presaging what would become sweeping programs and measures to create "a more just and equal society" (Zeitz 2018: 2; see also Johnson 1964). Moreover, the song was released within the very month that the Civil Rights Act was passed (Kurlansky 2013). It is little wonder then that the song was embraced as an anthem by civil rights activists (Kurlansky 2013). H. Rap Brown, a noted activist and later chairman of the Student Non-Violent Coordinating Committee, "often spoke in urban black neighborhoods from the roof of a parked car. Sometimes the car had music playing, and often that music was Martha and the Vandellas singing 'Dancing in the Street'" (Kurlansky 2013: 181). It seems, then, that the song's timing was right, coincidental with sweeping changes in the nation, particularly with regard to race, gender, and class-civil rights and the Great Society. Martha and the Vandellas, in a song by Mickey Stevenson, Marvin Gaye, and Ivy Jo Hunter, were unveiling a hidden transcript in a pop song that offered a sidelong critique of the status quo, inviting white audiences to a dance of understanding and spurring black audiences to action, in a memorable oppositional performance.

A Better and Truer Self

The times were changing in significant and transformative ways at the time when Motown was reaching its peak. Hard won fights and tremendous sacrifices were coming to fruition with the passage of the Civil Rights and Voting Rights Acts (Garrow 2015). Bloody urban uprisings in Detroit and across the country reflected deep-seated anger and frustration among African Americans with police brutality, *de facto* segregation, housing discrimination, and high unemployment (Darden and Thomas 2013). In addition, the U.S. was embroiled in the war in Vietnam, costing tens of thousands of lives, particularly the lives of the disenfranchised (Farber 1994). Motown artists waded into what was a time of immense upheaval, often without their founder's approbation (Ritz 1985, Ribowsky 2010a). These audacious artists created music that presented "members of the dominant group an insightful critique of their own culture" in their own brand of Motown performances (Mitchell and Feagin 1995: 69).

A Vision and a Reckoning

The song "Higher Ground" launches full grown into the first verse, with references to war and a reckoning that appears in all four verses. The first verse juxtaposes earnest people who continue to learn and remain conscious with the specter of wars that continue to be waged-"soldiers keep on warring." The lyrics remind us that through it all, the sun will rise as our world continues to turn, but there will also be some settling of accounts, because "it won't be too long." In the second verse, the wars are explained by the recognition that "powers" consistently lie to the people who "keep on dying." Again, the verse reminds us that the world will continue to turn, but something is coming and it won't be long. The third verse, leaving aside the chorus, speaks to "teachers" and "preachers," who the song insists must keep going, keep hope alive, because as the world turns "it won't be too long." The fourth verse speaks to "lovers" and "believers" who are encouraged to continue to love and believe, but the verse gives no quarter to the "sleepers"-"just stop sleeping"-because there will be a tally of what is owed and it "won't be too long." Finally, the chorus is a message to God or some higher power, thankful of a second chance, because they "lived a whole world of sin" in some prior existence. Moreover, the chorus lyrics are thankful that they are more aware—"I know more than I knew then"—and will continue to strive, and love, and believe "til I reach my highest ground." The final chorus acknowledges God as the one to "show you higher ground" and "He's the only friend" you have, because the "world will bring you down."

The song "Higher Ground" conjures the war in Vietnam—"soldiers keep on warring"—as well as outright deceitfulness on the part of the U.S. government—"powers keep on lying." The song asserts that those in positions of power in the nation allow their citizens to die needlessly-"your people keep on dying"-perhaps in war but also from immiseration and poverty. Ribowsky (2010a: 230) notes that Stevie Wonder viewed Nixon as "reptilian," treasonous, and responsible for "body bags still coming back from Vietnam every day, escalating cuts in federal aid to inner-city schools and housing projects, and the slimy scab of Watergate beginning to break open." At the same time, the song includes messages of hope for those that continue to love, believe, and receives more condemnation than those who remain asleep in the face of this unfolding tragedy of societal neglect and war. Moreover, there is the oft-repeated reckoning---"it won't be too long." This could refer to the end of the world or the end of the Nixon presidency—Ribowsky (2010b: 176) notes that Wonder "would have loved to put Nixon on notice about Vietnam, poverty, race, and a million of other matters." In either case, the song exhorts the listener to stay aware and to seek the "highest ground"-perhaps a reference to heaven, or perhaps to what Du Bois (1903/1997: 38) described as our "better truer self." In all, the song is a critique of American leadership in the context of a war fought disproportionately by disenfranchised young men and in the midst of the immiseration of urban communities-an overt, straightforward critique of the powers that be in a funk-rock performance (Farber 1994; Darden and Thomas 2013). In addition, the song references seeking "the highest ground," reinforcing Dr. King's message that the struggle for racial justice must be fought on "the high plane of dignity" (1963).

The Truly Disadvantaged

"Inner City Blues (Make Me Wanna Holler)," written and performed by Marvin Gaye, is structured in four brief verses. The first verse describes "rockets" and "moonshots"—presumably the NASA program that sent men to the moon in 1969 (Smith 2019). But the verse suggests that the money spent on that feat should've gone to "the havenots." In addition, the verse notes that when the "have-nots" do make money, the government takes it—a reference to taxes. The second verse is about financial struggles with "inflation," with no chance to save money as "bills pile up sky high." There is also a reference to the brutality of war in the last line of that verse—"send that boy off to die." The third verse mentions "hang ups" and "let downs," seemingly part of financial "bad breaks" and "set backs." The final lines of that verse again reference taxes and the failure to pay them. The fourth verse contains a spiral, where crime increases, policing becomes "trigger happy," and panic spreads in the chaos and confusion—"God knows where we're heading." The chorus has two aspects, but both describe hopeless frustration—in one chorus the grim situation "make me wanna holler the way they do my life," and in the other "make me wanna holler" is followed by throwing "up both my hands."

"Inner City Blues (Make Me Wanna Holler)" is a palpably bleak description of "the plight of the poor," barely surviving within an immiserating urban setting, that references the horrors of war-the mood of the song lacks any resemblance to happy, lively Motown tunes (Ritz 1985: 151). The song's lyrics are a forecast of unemployment, low wages, and despair-"let downs," "bad breaks," and "set backs." Thomas A. Klug (2017: 93, 103) describes the decline of Detroit's central city in the 1960s into a landscape of "economic decay, abandonment, and concentrated poverty" where "the rates of joblessness for African Americans remained three times that of whites." In addition, Ritz asserts that Marvin Gaye was adamant and angry with regard to the "burden of taxes," the plight of the urban poor, and sending "that boy off to die," which raised questions for the artist-"Why pay taxes to buy moon rockets when we can't feed the poor? Why are we sending innocent sons off to die in wars that make no sense?" (Ritz 1985: 151). Moreover, into this setting "trigger happy" police enter, not to serve and protect, but to brutalize and mortally threaten—as Darden and Thomas (2013: 29) assert, "[w]hite police officers in the black ghettos in Detroit and throughout the country symbolized a form of unbridled racism." Finally, the lyrics evoke a sense of profound distress, weariness, and hands," "God knows where we're heading." These lyrics serve to underscore the blight of economic abandonment, unemployment, and poverty, as well as the brutal actions of police, but perhaps more. Perhaps they also represent a grave crossroads for the nation in that era in the wake of several horrendous blows, including the assassination of Dr. King, tens of thousands of deaths of young men in the war, and the pitiless aftermath of the Detroit uprising, which left 43 dead and close to 5,000 people "homeless-most of them black" (Darden and Thomas 2013: 40). Ritz (1985: 120) also suggests that Gave was facing his own personal crossroads at the time, in part a response to the chaos in the nation, in a "series of near-suicides" and "periods of abject depression." Clearly, "Inner City Blues" is an overt, searing critique of a world gone

wrong, decrying racial and class divisions, police brutality, and a brutal war overseas—all in a Motown song.

CONCLUSION

The current study helped to unpack the two contradictory threads of the Motown ethos within its sociohistorical milieu and included a thematic and lyrical analysis of a few songs by selected artists. These courageous Motown artists sometimes voiced subtle hidden transcripts being mindful of their white audiences, but also bold strident critiques that would resonate with the experiences of their black audiences, as they spoke to the issues of their day.

In all honesty, Motown created some of the most enduring music of the 20th century. In this respect, let us also note that the Motown songs framed in this analysis spoke blatantly to issues of political corruption, police brutality, and the senseless losses that occur in war. More than that, let us be emphatic in our recognition that the songs unpacked in this analysis spoke to the significance and meaning of black lives in an era when black people endured astounding levels of disenfranchisement and inequity. Motown artists raised their voices in resistance—voices needed then as they are today.

ACKNOWLEDGMENTS

Many thanks to Joe Feagin, Bonnie Mitchell, James Scott, and Erving Goffman for the wealth of their ideas. Thanks also to Brett Clark for his always thoughtful and substantive support of my research. Sincere thanks go to the many Motown artists who challenged barriers to social justice in their time.

REFERENCES

Benjaminson, Peter. 2018. *The Story of Motown*. Los Angeles: Rare Bird Books.

Cashmore, E. 1997. The Black Culture Industry. New York: Routledge.

Collins, P. 2000. Black Feminist Thought: Knowledge, Consciousness, and the Politics of Empowerment (2nd ed). New York: Routledge.

Darden, Joe T. and Richard W. Thomas. 2013. *Detroit: Race Riots, Racial Conflicts, and Efforts to Bridge the Racial Divide*. East Lansing, Michigan: Michigan State University.

Davis, Angela Y. 1997. "Race and Criminalization: Black Americans and the Punishment Industry." Pp. 264-79 in *The House That Race Built*, edited by Wahneema Lubiano. New York: Pantheon.

Du Bois, William E.B. 1903/1997. *The Souls of Black Folk*. New York: Bedford Books.

Early, Gerald. 2004. One Nation Under a Groove: Motown and American Culture. Ann Arbor, Michigan: University of Michigan Press.

Fager, Charles. 2015. *Selma 1965: The Marches That Changed the South.* Durham, NC: Kimo Press.

Farber, David. 1994. *The Age of Great Dreams: America in the 1960s*. New York: Hill and Wang.

Garrow, David J. 2015. Protest at Selma: Martin Luther King, Jr., and the Voting Rights Act of 1965. New York: Open Road Media.

George, Nelson. 2007. Where Did Our Love Go? The Rise and Fall of the Motown Sound. Chicago: University of Illinois Press.

Goffman, Erving. 1959. *The Presentation of Self in Every Day Life*. New York: Anchor Books.

Johnson, Lyndon B. 1964, "Great Society' Speech." Retrieved March 20, 2021, from https://teachingamericanhistory.org/library/document/ great-society-speech/.

King, Martin Luther, Jr. 1963. "I Have A Dream..." At the "March on Washington." Retrieved March 20, 2021 from http://teachtnhistory. org/file/I%20Have%20A%20Dream%20Speech.pdf

Klug, Thomas A. 2017. "The Deindustrialization of Detroit." Pp. 65-75 in *Detroit 1967: Origins, Impacts, Legacies*, edited by Joel Stone. Detroit: Wayne State University Press.

Kurlansky, Mark. 2013. *Ready for a Brand New Beat: How "Dancing in the Street" Became the Anthem for a Changing America*. New York: Riverhead Books.

Lofland, John and Lyn H. Lofland. 1995. *Analyzing Social Settings: A Guide to Qualitative Observation and Analysis*. 3rd ed. Belmont, CA: Wadsworth.

Marsh, Peter K. 2020. "Language, Media and Globalization in the Periphery: The Linguascapes of Popular Music in Mongolia." *Journal of Sociolinguistics* 24(2): 281-285.

Mays, Kyle T. "Decolonial Hip Hop: Indigenous Hip Hop and the disruption of settler colonialism." *Cultural Studies* 33(3): 460-479.

Mitchell, Bonnie L. and Joe R. Feagin. 1995. "America's Racial-Ethnic Cultures: Opposition within a Mythical Melting Pot." Pp. 65-86 in *Toward the Multicultural University*, edited by B. Bowser, T. Jones and G. A. Young. Westport, CT: Praeger.

Morgan, Benjamin A. 2020. "Revenue, Access, and Engagement via the In-house Curated Spotify Playlist in Australia." *Popular Communication* 18(1): 32-47.

Mustamo, Aila. 2020. "The Crisis of the Welfare State and the Politics of the Past in Black Metal and Folk Metal Subcultures." *Nordic Journal of Youth Research*. 28(1): 69-84.

Neal, Mark Anthony. 1997. "Sold Out on Soul: The Corporate Annexation of Black Popular Music." *Popular Music and Society* 21(3): 117-135.

Posner, Gerald. 2002. *Motown: Music, Money, Sex, and Power*. New York: Random House.

Reinharz, Shulamit. 1992. *Feminist Methods in Social Research*. New York: Oxford University Press.

Ribowsky, Mark. 2010a. *Ain't Too Proud to Beg: The Troubled Lives and Enduring Soul of the Temptations*. Hoboken, New Jersey: John Wiley & Sons.

—. 2010b. *Signed, Sealed, and Delivered: The Soulful Journey of Stevie Wonder*. Hoboken, New Jersey: John Wiley & Sons.

Ritz, David. 1985. *Divided Soul: The Life of Marvin Gaye*. Cambridge, MA: Da Capo Press.

Robinson, Smokey. 1989. *Smokey: Inside My Life*, with David Ritz. New York: McGraw-Hill.

Scott, James. 1985. *Weapons of the Weak: Everyday Forms of Peasant Resistance*. New Haven, CT: Yale University Press.

Smith, Andrew. 2019. *Moondust: In Search of the Men Who Fell to Earth.* New York: HarperCollins.

Smith, Suzanne E. 1999. *Dancing in the Street: Motown and the Cultural Politics of Detroit*. Cambridge, MA: Harvard University Press.

Smock, Raymond W. 2009. *Booker T. Washington: Black Leadership in the Age of Jim Crow*. Chicago: Ivan R. Dee.

Sugrue, Thomas J. 2017. "Foreward." Pp. ix-xii in *Detroit 1967:* Origins, Impacts, Legacies, edited by Joel Stone. Detroit: Wayne State University Press.

Ward, Brian. 1998. Just My Soul Responding. London: University of London Press.

Washington, Booker T. 1901/1995. Up From Slavery. New York: Dover.

Zeitz, Joshua. 2018. Building the Great Society: Inside Lyndon Johnson's White House. New York: Penguin Books.

MUSIC REFERENCES

Gaye, Marvin. 1971. "Inner City Blues (Make Me Wanna Holler)." What's Going On. Motown.

Martha and the Vandellas. 1964. "Dancing in the Street." Motown.

The Temptations. 1964. "My Girl." Gordy.

Wells, Mary. 1964. "My Guy." Mary Wells Sings My Guy. Motown.

Wonder, Stevie. 1973. "Higher Ground." Innervisions. Tamla.

Abstracts

ARTS

The Pierian Spring Nicholas Jolley-Harding Utah Valley University

A little learning is a dangerous thing / Drink deep, or taste not the Pierian spring / There shallow droughts intoxicate the brain / And drinking largely sobers us again. - Alexander Pope

The Pierian Spring is a modern dance piece inspired by the poem of the same title from Alexander Pope's An Essay on Criticism. It seeks to explore the concepts of "knowing" and "not-knowing"—drinking deeply and the shallow droughts—and the descriptors experienced through them: hubris, exposure, ignorance, vulnerability, exploration, and humility. Through movement-based research and the trials of life, three types of knowledge came to fruition within the piece: general knowledge, self-knowledge, and knowledge of others. This piece, above all else, showcases the individual journey of each dancer through physically embodied expressions of knowing and not-knowing. Although the poem itself was the impetus of meaning-making, the inspirational choreographic methodologies of Trisha Brown, Ohad Naharin, and Liz Lerman, in pairing with the experiences and values of the choreographer and performers, facilitated the amalgamation of movement representative of the poem's interpreted intent.

ARTS

Rota Fortuna: Divining the Future of Viewership & Arts Consumption

Courtney R. Davis

Utah Valley University

As gallery and museum spaces closed their doors to visitors in 2020 because of Covid-19, arts organizations and artists sought opportunities

to reinvent the viewing space. While many explored virtual exhibitions, some turned to the storefront as a locus of display in which to present site-specific public-facing installations, echoing the contemporary interest in the democratization of viewership. This paper focuses on The Wheel of Fortune (2020), a multimedia work temporarily installed in a consignment boutique in Taos, New Mexico. Based on the ancient theme of the Rota Fortuna, the collaborative effort of artists Sarah Bush and Tawni Shuler melded Victorian, Dada, and Surrealist impulses with the symbolic traditions of astrology, palmistry, and card-reading. A contemporary moment mori, The Wheel echoes the disequilibrium, disquiet, and irresolution of the historic summer of 2020. The shift to experimental and online viewing spaces also coincided with impassioned debates focusing on the function of museums and galleries as appropriate intermediaries of knowledge, prominence, and historical value. The Wheel, and similar installations, revives the centuries-old tradition of utilizing storefront windows for public consumption, a practice that arguably increases accessibility and egalitarianism. But what are the implications of privatized display? Does decentralized exhibition simply trade one form of hierarchy for another? This paper seeks to divine the future of viewership and arts consumption by examining the aesthetic and curatorial implications of Bush and Shuler's The Wheel of Fortune.

ARTS

Why We Adapt Tragedy: Parallels between the Orpheus Myth and Frankenstein Films (1931/1935)

Madison Sheldrake

Brigham Young University

Adaptation is an extremely popular mode of storytelling. Stories that are retold often hinge on universal themes that are applied to new audiences and ideals across generations. This paper focuses on two such stories: the Greek myth of Orpheus and the story of Frankenstein. These stories are similar in their tragic nature and their character arcs. By comparing the two, Orpheus through the modern musical Hadestown and Frankenstein through its first two film adaptations, the reasons tragedies are adapted so often are revealed, along with more hopeful themes from both stories. These themes are revealed through character arc. Both Orpheus and Frankenstein embody an arc that I call "the Orphic journey." In short, this arc refers to a character achieving great success, then succumbing to a flaw that leads to their tragic downfall. Analyzing Orphic journeys brings a tragedy's universal themes and message of hope to the forefront of the story, illuminating the true purpose of the original narrative and its adaptations. For Orpheus, this message is that sad stories show the possibilities of life as it could be and that love is worth fighting for, even when it is fleeting; For Frankenstein, this message is that sad stories show that things are not always what they seem and that purpose is something you find for yourself. This paper uses the analysis of the Orphic journeys in these stories to prove the existence of these messages within the tragic narratives. These hopeful messages, at first hidden by the tragic natures of the story, are what bring artists and audiences alike back to adapting tragedy.

ARTS

Navigating Trauma While Seeking Connection and Community Through Dance During COVID-1

LeGrande Lolo, Francesca DeMartino, Jessica Ketchum-Lee

Utah Valley University

COVID-19 has had far-reaching, devastating effects on everything from daily life to economics on a global scale, mental health being no exception. Joann Kealiinohomoku states that "Dance reflects the cultural traditions within which they developed." One can therefore assume that dances created during 2020 will reflect current events. Within our respective choreographic processes, each choreographer sought to use dance to explore human responses to COVID-19. Humans have a natural neural synchronization to an outside rhythm, called entrainment, which engenders connection to one another. Currently starved of human interactions, it is clear how essential finding community is. Trauma and negative emotions arise from a lack of socialization. Each choreographer chose to incorporate these facts into our three respective Modern Dance works. Using conversation, improvisation, and choreography, dancers applied personal experiences to create movements that reflected social interactions. Space and complex floor patterns were utilized to offer creative solutions while remaining socially distant. Gestural motifs, audible breath, and diverging movement pathways reflected dancers' relationships to each other individually and as a whole. Unable to physically touch, it became essential to allow dancers to partner with each other through usage of dance props, line of sight, and specific lighting. Breath by Jessica Ketchum-Lee explores the ideas of breath and synchronization to demonstrate how people unconsciously connect with

one another. Red Thread by LeGrande Lolo uses a physical set of ribbons, facilitating both abstract and literal partnering to explore socially distanced ritual and community building. In the Eye of the Storm by Francesca DeMartino showcases how individual emotions are translated into physical experiences, allowing audience members to empathetically connect and find personal meaning within their own pandemic experiences. From our combined intents, it is clear that dance, in this exploration, is an outlet for reconciling emotional pain and a desire for human connection.

BIOLOGICAL SCIENCES

Using a Virus Model System to Determine the Effect of Ozone in Locker Room Sanitation

Justin Coles, Clark Madsen, Craig Steiner, Caleb Nyone, Josh Hansen, Berkley Scharmann, Stephen Scharmann, Niharika Mishra, Craig Oberg

Weber State University and McKay Dee Family Medicine Residency

Viral infections can spread rapidly through a team, with surface contamination a common vector for viral transmission between individuals. Ozone has been shown in several studies to be effective in inactivating viruses and bacterial pathogens. We examined the effectiveness of ozone for viral inactivation on solid surfaces in an active Division I collegiate locker room. Plastic sterile petri plates were inoculated with E. coli bacteriophage T7 (DNA non-encapsulated virus), which was used as the viral model system, and placed in triplicate at a variety of distances (3-27 ft) from an ozonator (Extreme Ozone Co.) in a collegiate locker room. With the room emptied, the virus-containing plates was exposed to either 2 or 3 hours of ozone. The virus was harvested from the plates with sterile saline, diluted, and enumerated using the soft agar overlay procedure with E. coli B as the host. After incubating for 24 h at 37°C, viral plaques were counted on each plate and compared with controls not exposed to ozone. Results from the control and test plates verified the experimental procedure with virus successfully harvested at the expected concentration from the control plates. An ozone meter in the room measured a peak ozone level of 3.6 ppm and an average of 1.6 ppm during the 3-hour exposure. Results showed a significant decrease in viral load in 8/20 test plates between 50 and 97%. Plates laid next to each other showed wide variability in viral inactivation. When the ozone was run for 2 hours, no viral inactivation was observed. At 3-hour exposure, ozone was observed to effectively reduce viral counts by up to 2 logs on some exposed plates, but the effect was variable and did not correlate with the distance from the ozone generator. The variable effect of ozone on virus inactivation may be related to several real-world variables not seen in previous studies. Although duration of ozone exposure appears to play a role in viral inactivation (2 vs. 3 hours), other factors such as room ventilation and humidity could also play a role. Our results are consistent with other studies examining viral inactivation in aerosols and on surfaces, which also observed a 1- to 2-log decrease in viral load after ozone exposure. In comparison, with use of a similar methodology with two bacterial models (Staphylococcus aureus and E. coli), results showed consistent kill rates of <90%. Although further study is needed, our work indicated that typical ozonation treatment of locker rooms may have more variable real-world results compared with experiments done in controlled laboratory settings, and ozone should not solely be relied upon for locker room virus control.

BIOLOGICAL SCIENCES

Antimicrobial Metabolites of Latilactobacillus curvatus

Dallin Leatham, Taylor Oberg, Robert Ward, Craig Oberg

Weber State University, Utah State University

Lactilactobacillus curvatus is a common non-starter lactic acid bacteria (NSLAB) in cheese. If L. curvatus is induced to produce antimicrobial compounds it would be important to the food industry, because it could be used to inhibit pathogens and/or spoilage organisms in cheese. Using the L. curvatus WSU1 genome, bioinformatics analysis revealed genes for a metabolic pathway that utilized lactic acid to produce propanol and propionic acid, two antimicrobial compounds. Among these genes were three encoding for the enzyme diol dehydratase. This enzyme is present in Lactobacillus reuteri, a NSLAB that can utilize glycerol to produce 3hydroxypropionic acid and 3-hydroxypropionaldehyde (reuterin), two antimicrobials. It is hypothesized that L. curvatus could also produce these compounds. Because these metabolic processes are anaerobic, cultures were grown in septum-sealed medicine bottles with the headspace purged using 95% N₂/5% CO₂. Cultures were grown in carbohydrate-restricted MRS media containing either lactate, 1,2propanediol, hydroxyacetate, acetate, or glycerol at an 80 mM concentration. They were grown in duplicate with half containing B12 because diol dehydratase is B12-dependent. A gas chromatography analysis was done to test for the presence of 3-hydroxypropionaldehyde, propionic acid, propanol, and 3-hydroxypropionic acid at days 0, 1, and 7. Preliminary gas chromatography results showed that *L. curvatus* WSU1 cannot produce propionate from lactate but can produce propionate when given 1,2-propanediol. This indicates the genome is lacking the gene to convert lactate to lactaldehyde but does have functioning genes to convert 1,2-propanediol to propionate. When grown on glycerol, small amounts of 3-hydroxyproprionate were produced, indicating either the fermentation conditions were not ideal for the pathway or the diol dehydratase had less affinity for glycerol than for 1,2-propanediol. These results indicate the potential for *L. curvatus* WSU1 to be used as a functional adjunct in dairy fermentations.

BIOLOGICAL SCIENCES

Effect of Inorganic Salts on the Growth of Probiotic Lactic Acid Bacteria

Joshua O. Gee, Tallon Nielsen, Daniel N. Clark

Weber State University

Dairy-based products are often used as delivery systems for probiotics. Unfortunately, many people miss the benefits of probiotic-enhanced products because they cannot consume dairy foods because of lactose intolerance or allergies. Our research explores using plant-based products as a delivery system for probiotics. Previous research showed promising results, but many commercial products contain phosphate salts, which have been shown to inhibit some probiotic lactobacilli. Our research examined the growth of lactic acid bacteria (LAB) in a plantbased product, "oat milk," and the impact of phosphate salt preservatives on LAB growth. Oat-based beverages with phosphate-containing salts were inoculated with 24 h cultures of commercial probiotic strains: Lactobacillus acidophilus LA-5, Bifidobacterium BB12, Lb. casei 431, Lb. casei F-19, Lb. rhamnosis BLC-48, and Lb. rhamnosis LGG. LAB survival was enumerated using MRS agar for Lactobacillus and MRS+cystine for Bifidobacterium strains. Plates were incubated anaerobically at 35°C, with counts done at day 0, 7, and 14. Results showed some strains of LAB grew in the oat beverages with or without added salts and that all cultures survived, regardless of the composition; however, most strains preferred growth in specific brands. Simple Truth "oat milk" brand gave the best growth results for most strains. We expect differences in probiotic strains growth was due to the composition of each brand. The protocol was repeated using only Chobani oat-beverage products that were either treated with phosphate salts or left untreated. All cultures survived independent of the phosphate concentration, but most did not grow over the 14 days of refrigerated incubation. Four of five strains survived approximately 10-fold better in the treated product. These results show the addition of phosphate-containing salts as stabilizers in "oat milk" do not inhibit most probiotic strains so it can be used as a probiotic delivery system.

BIOLOGICAL SCIENCES

Paucilactobacillus wasatchsensis WCD04 biofilm formation and adherence to stainless steel

Lizell A. Mejias, Michele C. Culumber, Craig J. Oberg Weber State University

Paucilactobacillus wasatchsensis WCD04 is a non-starter lactic acid bacterium (NSLAB) that can cause gas production during cheese aging. This NSLAB is thought to be an environmental contaminant, but its reservoir is unknown. Because Plb. wasatchensis does not survive pasteurization, its persistence in cheese manufacturing could be caused by postpasteurization contamination due to biofilm formation in cheese vats. We investigated physiological conditions in which Plb. wasatchsensis reaches optimal growth for biofilm formation on stainless steel. Biofilms were grown on sterilized stainless steel washers (5.92 cm²) in the wells of sterile, 24-well polystyrene culture plates. Washers were added to 2 ml of MRS+R broth amended independently for each experiment. Wells were inoculated with either 10 or 100 µl of a 4-d culture of Plb. wasatchensis WDC04. Variables tested were pH (4, 5, or 6), galactose concentration (0.5%, 1%, or 2% v/v), lactose (1% or 2%), glucose (1% or 2%), and oxyrase (1%). Biofilms developed for 1 wk at 30°F. Washers were aseptically removed and rinsed with sterile distilled water to remove planktonic cells. Attached biofilm was removed by vortexing in sterile saline for 1 min. The solution was serially diluted and plated in triplicate on MRS+R agar and incubated at 30°F for 5 d. Biofilm growth was below detection at pH 4 and 7. Biofilm formation utilizing residual sugars was the greatest at pH 6 with 2% galactose (6.8 $\times 10^4$ cfu/cm²). Similar growth was observed with 1% lactose (5.2 $\times 10^4$ cfu/cm²). Cell recovery was the greatest overall with 1% oxyrase (5.8 \times 10⁶ cfu/cm²). Plb. wasatchsensis exuberates exopolysaccharide synthesis under low-oxygen conditions, as they exist in the cheese packaging process. Understanding optimal growth conditions for biofilm formation will provide opportunities to test methods for the prevention or removal of *Plb. wasatchensis* biofilms that may occur in dairy processing facilities.

BIOLOGICAL SCIENCES

Burn Scar: An Assessment of a Course-Based Undergraduate Research Experience on the Effects of the Brian Head Wildfire

Sheridan Lloyd and Carrie J. Bucklin

Southern Utah University

This study aims to assess the implementation and results of a coursebased undergraduate research experience (CURE) for students in an ecology course at a primarily undergraduate institution in the Intermountain West. This CURE focuses on place-based learning in regards to a large (70K + acre) wildfire that affected a local area. Because of the direct effect that place-based research experiences have on students, CUREs have shown to benefit students' long-term knowledge retention and can lead to a greater motivation in these students to make significant impacts in their communities and future fields of research. Participants in this study consisted of the students in two sections of an ecology course. We used questionnaires with both open and closedended questions to assess how the course impacted the students' knowledge and opinions of both wildfires; questionnaires were administered at the beginning and end of the semester. Preliminary results show an increase in factual knowledge of wildfires and a greater appreciation for the biological sciences as whole.
BUSINESS

Business Ethics Education in Utah: How Are We Teaching Ethics and Why?

Chelsea Dye, Chari 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 not only reflects on you, but also impacts your neighbors and the larger community. 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

A Descriptive Analysis of Cross-National Differences in Job Satisfaction by Gender

Maureen Andrade, Jonathan Westover, Angela Schill, Jacque Westover, Cambree King

Utah Valley University

Comparative studies on job satisfaction for men and women have been inconclusive, with some finding that women are more satisfied on the job than men and others finding no difference. Previous research has also identified similarities and differences in gender and job satisfaction globally based on cultural, economic, social, and political factors across countries and world regions. Overall, however, limited cross-national or global research has been conducted in this area. The current study uses International Social Survey Program data to investigate the role of gender and country on job satisfaction. Variables involving extrinsic and intrinsic factors, work relations, and work–life balance are examined. Although the findings were inconclusive as to whether women are more satisfied than men, the findings showed there are clear differences in the factors that contribute to job satisfaction between males and females. Factors such as helping others, working weekends, and flexibility to deal with family matters are on average more important to women in the workplace than men. On the other hand, men prefer better pay, promotional opportunities, and physical effort in relation to women. Breaking the variables down by country shows where the greater disparities exist and where genders within countries behave opposite of the norm. These instances highlight areas where management can shift its focus to better serve both men and women individually in the workforce of the country.

BUSINESS

Does Charter Growth Wreck District Schools, or Does Competition Lift All Boats? Trends in School Proficiency among Public Schools in Utah

Michael Mamo

Westminster College

The goal of this project was to estimate the impact of charter school expansion on traditional district schools. On the one hand, as charter school enrollments grow, district schools face financial losses that could harm teaching and learning in the district schools. At the same time, however, it is possible the harmful effects on school resources are more than offset by the competitive effects of charter schools that are reflected in improvements in student achievements in district schools. Many similar studies have arrived at conflicting conclusions and have found evidence supporting one or another claim regarding charter schools. Part of the ambiguity in outcomes stems from problems related to the availability of data and the failure to sufficiently account for heterogeneity. In this project, I propose to explicitly address these questions in a few ways. I will utilize school-level panel data that would allow me to account (and control for) school-specific, unobserved effects that would otherwise lead to biased and inconsistent results. Second, I will use a variety of measures of charter competition including the number of charter schools in the vicinity of the district school as well as the quality of charter schools. The underlying logic to focus on the quality as opposed to the quantity of charter schools is the likely correlation between charter school location decision and the poor performance of the district school. Such correlation is unlikely to exist between the quality of the charter school and poor performance of the

district school. Another improvement that I propose in this project involves the estimation strategy. I propose a random trends model that will allow me to introduce a second source of heterogeneity into the estimating equation.

BUSINESS

Self Efficacy, Emotional Intelligence, Self Determination and Learning Strategy: Student Survey Results and Relationship to Practice CPA Exam Scores in an Auditing Course

Jeff Davis

Weber State University

A long and rich research history in self efficacy, emotional intelligence, self-determination, and learning strategy ties these cognitive constructs to academic performance. The current study reports survey results of a self-reported questionnaire related to these constructs obtained from the literature. The paper makes a simple relationship to academic performance of these students in the form of two practice exams for the auditing section of the certified public accountant exam. Students took the first practice exam before taking the survey, and took the second practice exam after taking the survey. Preliminary analysis suggests that the test scores improved after being introduced to the cognitive principles incorporated in the survey questions. More research needs to be done to isolate any confounding variables for the improvement on the second test.

BUSINESS

The Disparity in Understanding Governmental Policy and Healthcare Economics, from Premedical Students to Physicians

Pierce Bassett

Brigham Young University

Last year, more than 53,000 hopeful undergraduates submitted their application to medical school. While coming from diverse backgrounds,

these students have all successfully completed virtually identical prerequisite science courses, in addition to a standardized examination known as the MCAT, which measures student aptitude on these blanket prerequisite courses to demonstrate their readiness for a medical education. Once in medical school, students will learn the basic sciences, study how to interact with patients, and try to determine the type of physician that suits them best to continue with in their careers. In total, this process usually requires eight years of formal post-university education. Although this system achieves its designed purpose to train physicians in the processes of diagnosing and treating, it fails to address some of the most pertinent topics that our contemporary society faces: healthcare policy and economics. This paper illustrates the current disparity of both premedical and medical students' preparatory education in these fields, proposes simplistic solutions to address this issue, and elaborates on the quintessential nature of understanding these topics to properly address the healthcare policies and accompanying economics that impact everyone.

EDUCATION

Competency-Based Education: Opportunities and Possibilities

Anthony Beal

Snow College

Competency-based education (CBE) is lauded for its ability to get higher education to a larger number of nontraditional students in assessing the mastery of competencies rather than how many hours they have spent in a classroom. This personalized approach of higher education gives credit according to demonstrated competencies regardless of specific time measurement. CBE is focused on the learner both in terms of affordability and accountability with its relatively low tuition costs and high academic standards for its learners. It is recognized as a strategic method for ensuring students are career-ready upon completion of college. Opponents of CBE claim that competency models can only be as good as the assessment mechanisms they utilize. Additionally, some believe that CBE programs are widening the divide between traditional and non-traditional approaches to higher education. Lastly, some worry that CBE graduates will possess the skill, but not the theoretical knowledge necessary to compete in the workforce today. In their groundbreaking study, Johnstone and Soares focused on new approaches in

higher education and their potential for changing the economic landscape. CBE topped the list for two reasons: its direct application of knowledge and real-world skills and its ability to simultaneously offer quality and affordability. Although the CBE approach at each school is unique, they have each focused their efforts on students and how they learn. A majority of the programs mention working adults as their target audience. Students are supported to take control of their education by creating learning plans, making their schedules, and more easily monitor their academic progress

EDUCATION

Developing Student–Teacher Relationships through Integrated STEM Curricula Kristin A. Searle, Colby Tofel-Grehl, Andrea Hawkman, Beth MacDonald, Mario Suarez

Utah State University

Research repeatedly shows that students who are more culturally connected do better in school. Further, many nondominant students value relationships of caring with their teachers. In this paper, we draw on elementary teachers' and students' experiences with the Elementary STEM Teaching Integrating Textiles and Computing Holistically (ESTITCH) curriculum and professional development to show how culturally responsive, integrated science, technology, engineering, and math (STEM) curricula can create opportunities for dialog across the development of student-teacher cultural differences and relationships. The ESTITCH curriculum centers experiences of migration, immigration, and forced relocation, experiences that are familiar to many students in Utah schools today, whether through their own experiences or those of their ancestors. Drawing on teacher reflections from professional development, reflective teacher interviews post-professional development and post-instruction, and classroom observations, we explore the opportunities ESTITCH provided for student-teacher relationship building. For instance, one teacher in our study described teaching the history of the French and Indian Wars in conjunction with the ESTITCH curriculum. One of their Indigenous students got very upset at the use of the word "Indian." The teacher was able to use the conversation to explain the historical usage of the term Indian and also as an opportunity to learn more about the student's Navajo background. While this presented a teachable moment in relation

to the usage of the word "Indian" throughout history, it also provided an opportunity for the teacher to learn more about the student. Based on our analyses, we conclude with a discussion of how integrated STEM curricula can foster student-teacher relationships and dialog across difference, particularly through the use of difficult or challenging topics like immigration, migration, and forced relocation.

EDUCATION

The Journey Through Higher Education: The Role of Mentors in Student Veteran Educational Experiences

David Brian Kartchner, Kristin A. Searle

Utah State University

Veterans are a growing presence on college campuses around the country. As student veterans become more ubiquitous, there is an increasing need to better understand this unique population of students. Veteran critical theory (VCT) addresses the necessity of understanding the student veteran experience by focusing on student veterans' narratives and counter-narratives while pushing for a generative model of practice and inquiry, in place of the transitional and deficit models that are widely used at academic institutions. We report on data from a pilot study of student veterans' experiences with higher education, focusing on the role of mentoring in their ongoing educational journeys. The project was conducted as a narrative inquiry using journey maps and a single interview, which was analyzed using VCT. We found that the experiences of student veterans, while enlisted in the military, impacted how they perceived and interacted with faculty. In the military, superior commissioned military officers command respect, which is reinforced by tradition and military law. This respect takes on verbal and physical forms that demonstrate deference to the authority of commissioned officers. When student veterans are no longer enlisted, some continued to treat those in authority, including faculty, in similar ways. Additionally, we address the positive impact that mentors, especially mentors who are veterans themselves, can have on student veterans. We discuss how mentors are not addressed by VCT. We conclude with implications of our findings regarding mentors pertaining to the educational experiences of student veterans as they navigate civilian educational institutions, as well as a discussion of how universities might leverage these findings to change how they serve student veterans.

EDUCATION

Improving Self-Determination for High Students with Disabilities: ActNow

Shirley Dawson

Weber State University

Self-determination and self-advocacy are critical skills for students with disabilities (SWD). The Apply and Communicate for Transition Now (ActNow) Discussion Tool was purposefully developed using evidencebased practices (EBP) and best practices by practitioners working directly with SWD. Practitioners from community and school agencies express concern that students who apply for support often lack self advocacy and awareness to discuss their strengths and needs in relation to their chosen post-high school setting. This lack creates barriers for students to communicate their goals and needs to be successful in life ActNow incorporates collaboration school. after high and communication regarding student goals into one document via a systematic process. Research to evaluate use ActNow to improve SWD self-determination was supported by the Institute of Education Sciences in a one-year randomized controlled trial design. Participants (n=115) were matched on key variables before random assignment. In the RCT, both treatment and control groups received regular tiered transition services, activities, and support, while the treatment group also received ActNow instruction and intervention. As part of a two-year analyses, initial results demonstrate that ActNow is an effective practice to increase student self-determination. Both group and individual preliminary results will be shared and discussed. Overall, treatment group students had greater increases in self-determination than the control group across all disability categories and service levels. Benefits of the tool and intervention allow for increased interagency communication; needs from stakeholders to be addressed; field testing of EBP and best practices; support of legal compliance; opportunities to teach self-advocacy, awareness, determination, choice-making, and social skills in a systematic student-centered format; and use of authentic settings to support community, education, and work experiences while students are still in high school.

ENGINEERING

Lumped Capacitance Method Analytical and Experimental Evaluation

Kyler Reinhold, Owen Telford, Collin Cutler

Southern Utah University

In this paper, a simple experiment was conducted to evaluate the limitation and validity of assumptions associated with the lumped capacitance method. This method evaluates temperature variations due to transient convection heat transfer. The experiment was conducted using a small aluminum cylinder, first placed into hot water and then into cold water. The results of the experiment were compared with three different analytical approaches. One is an incomplete response method, another is a predict-and-check method, and the last is aluminum cylinder convection coefficient method. The validity and limitations of the lumped method are then discussed.

ENGINEERING

Effectiveness of Plane Wall Radiation Shielding

Cierra Salcido, Collin Cutler

Southern Utah University

Radiation shielding is the reflection of thermal radiation by using materials whose surface has a high reflectivity and low emissivity. This experiment attempts to replicate thermal radiation shielding by placing two identical steel plates parallel to each other and heating one of the steel plates with heating pads. After recording the temperature of each steel plate, a reflective aluminum plate was placed between the steel plates to shield thermal radiation created by the heating pads. The heating pads were heated, and the temperature of the steel plates was measured. Heat transfer analysis was performed to calculate the theoretical temperature of the steel plates and the required heat transfer rate to maintain the final experimental temperatures. The experimental temperature difference of the steel plates was 1.15% different with no shielding and 13.78% with shielding. The experimental heat transfer rate used was 41.53% with no shielding 78.56% with shielding. The experimental heat transfer rate was significantly greater than the theoretical, meaning the experiment required more heat to maintain the final temperatures of the steel plates. Future improvements consist of spacing around the border of each plate to maintain equal distance between each plate, increased heat generation by heating pads to allow more radiation heat transfer, adding insulation to both steel plates, and performing the experiment under vacuum to reduce convection.

ENGINEERING

Cost-Effective Solar Water Heater

Aaron J.G. Dockins, Noah A. Mollner, Kyler A. Reinhold, Omar R. Campos

Southern Utah University

Hot water has been used around the world for centuries for bathing, medical purposes, cleaning, and cooking. In today's society, the source that is used to heat water is typically a water heater that utilizes a nonrenewable energy source to heat the water. In this paper, a passive solar-powered water heater was constructed and tested to verify whether the sun's energy can be an alternative source of energy in locations where other options are limited. Before testing, a theoretical analysis for the constructed solar water heater was conducted and theoretical values were predicted. The theoretical values were then compared with the values obtained after the experimental results were obtained. The theoretical water temperature values were much higher than the actual experimental temperature, but the overall water temperature still increased to a comfortable temperature, indicating that the sun's radiation could be a potential alternative energy source under certain conditions.

ENGINEERING

Direct Evaporative Cooling—Simple Analysis

Matt Bennion, Skyler Ipsen, Colby Thorton, Andrew Logan, Austin Banks

Southern Utah University

Evaporative coolers are an excellent alternative to air conditioning (A/C) systems for dry climates. Contrary to A/C removing moisture from the air, evaporative coolers lower temperatures by the latent heat of evaporation and increasing air moisture. Warm air energy is used in evaporative cooling to evaporate water, resulting in cooler temperatures.

There are 3 types of evaporative coolers: direct, indirect, and hybrid systems. This paper focuses on direct evaporative cooling (DEC). The efficiency, cooling capacity, consumption of water, and volume capacity of DEC's can be calculated by measuring inlet and outlet temperatures and relative humidities. To support the theory and measure these attributes, a simple in-house DEC cooler was built and tested. Ultimately, even though not as efficient as commercial coolers, our evaporative cooler decreased the temperature and increased the relative humidity of the ambient air.

ENGINEERING

Analysis of Electrical Resistivity and Conductivity of Materials

Noah Swenson

Southern Utah University

As the temperature of a material increases, the electrical resistance of the material rises in correlation; this linear relationship allows for a theoretical prediction of that material's electrical resistance using the coefficient of resistance. This coefficient of resistance differs for every material and must be found by experimentally determining a resistance at a specific temperature. Through performing tests that increase the temperature of a material, the linearity of temperature and resistance can be observed, and a coefficient of resistance can be found with relative accuracy for the material through the linear relationship's slope. A positive, linear correlation was experimentally observed, and an accurate theoretical value for the resistivity of copper was found. Therefore, a prediction of a material's resistance at any temperature is possible within 5% error, and a linear correlation can be confirmed.

ENGINEERING

Semi-Translucent Concrete

Tanya Jones, Matthew Bayreder, Mako Bennett Southern Utah University

The need for energy efficiency and strength in building materials is growing across the United States and the world. Concrete is a commonly

used high-strength building material but significantly lacks in aesthetic characteristics and translucent properties because it is gray, dark, and dull. Semi-translucent concrete is an alternative being studied extensively by universities and companies across the globe. This experiment studies the feasibility of using glass to substitute for gravel as an aggregate in concrete. This study includes testing the structural, optical, and thermal properties of concrete with varying amounts and types of glass when used as aggregate in concrete. The resultant data indicated that the maximum stress of regular concrete was 16.26 MPa, whereas the glass aggregates ranged from 11.48 to 18.77 MPa. The optical tests indicated that clear glass aggregate allowed the broadest range of wavelengths to pass through the concrete at 418.31 to 739.04 nm. The coffee cup calorimeter thermal tests indicated minimal differences between the glass aggregate and the control mix of concrete at 2.2 J/g.°C (avg.) and 3.00 J/g.°C, respectively. These data suggest that using different size of glass as an aggregate can be an effective replacement for gravel and sand in buildings using concrete as aesthetic and structural elements.

ENGINEERING

Calibration and Testing of Budget Extensometer to Accurately Evaluate the Modulus of Elasticity of Steel Wire

Owen Telford, Alicyn Astle, Collin Cutler, Cameron Pepi

Southern Utah University

The modulus of elasticity is one of many properties used when predicting the behavior of materials. An accurate measurement of the modulus of elasticity is found using precise measurements of elongation and stress. Commercial testing machines use extensometers and load cells to measure these values; however, these machines are very expensive for educational laboratory use. At Southern Utah University, Dr. Jacob Bishop created cost-effective universal testing machines and purchased a budget extensometer. The purpose of this project is to calibrate the extensometer to give accurate results of elongation. Multiple tensile tests were performed on steel tie wire using the universal testing machine and the calibrated extensometer. The average modulus of elasticity found was 25,220 ksi with a percent error of 13.09%. Performing the test very slowly with a strain rate below 0.05/hr results in poor data. The recommended strain rate to perform tensile test is from 1/hr to 2/hr. A motor can be incorporated with the testing machine to allow consistent movement of the cross head during multiple tests.

ENGINEERING

Heat Transfer Analysis of Eicosane During Melting Sabrina Kim and Bill Maxwell

Southern Utah University

Interest is growing in utilizing the thermal energy stored or released when a material changes phase. There are a variety of applications for this energy from building heating, ventilation, and air conditioning systems to passive heating and cooling of satellites. The possibilities to use this type of energy are just beginning to unfold. In previous research, inward freezing of eicosane (paraffin, $C_{20}H_{42}$), as phase change material was tested and analyzed while the performance of the system was studied and improved. The scope of this project included evaluating the performance of $C_{20}H_{42}$ PCMs for releasing thermal energy (melting). The melt-testing and performance of the paraffin PCMs was assessed. Data from thermocouples were collected, and heat transfer analysis consisted of (1) conducting a melting incremental convection heat transfer analysis utilizing data from thermocouples; (2) implementing a calorimetric heat transfer analysis; and (3) evaluating the melt front vs. time. The knowledge gained from this project will be used to further research on new applications and optimize the existing system.

ENGINEERING

Controller Design Using Laguerre Basis Functions

Philip Olivier

Engineering Analysis and Design

A new feedback controller design technique using Laguerre basis functions is presented. The input to the technique is a) the plant transfer function, G(s); b) the transfer function, T(s), that embodies the desired closed loop behavior; and c) the order of the desired controller, with tobe-determined transfer function, C(s). Laguerre expansions of the known and unknown transfer functions, as well as the PRODUCT PROPERTY of Laguerre basis functions are used to determine the coefficients of the unknown controller.

ENGINEERING

Fully Printed Solar Cells Design Project

Daniel Philpot and Justin B. Jackson

Weber State University

Recent advances in inkjet technology have enabled the material printing of semiconductor devices. With potential cost reduction and simple design customization, inkjet printing has become a major field of semiconductor research. The purpose of this design project was to develop a solar cell printing process, fabricate the solar cell using the Dimatix DMP-2850 materials printer, and evaluate the solar cell's performance. A solar cell printing process based on existing research was developed. Layers of material ink were deposited on a glass substrate using the printer. The organic solar cell stack structure consists of four different material layers, each requiring unique printing parameter settings to produce the desired patterns. Throughout the fabrication process, the solar cell was heated on a hot plate between material layer printing. The developed printing process was use to produce functional solar cells whose performance was evaluated using an ELH light source, Keithley source meter, and IV software on a computer. The solar cells were exposed to the light source, and a voltage-current sweep was performed. Voltage vs. current plots were obtained using the IV software. The voltage-current curves depict the solar cell's open-circuit voltage and closed-circuit current. The developed printing process has successfully been used to fabricate fully printed solar cells. The evaluation process characterized the solar cell's open-circuit voltage and closed-circuit current when exposed to a specific light source. The fabricated solar cells and IV curve data require more analysis to better quantify the solar cells performance characteristics. The developed printing process will serve as a baseline for further solar cell research at Weber State University.

ENGINEERING

Applying Binary Phase-Shift Keying to an Open Environment Antenna Pattern Range

Cade A. Moody and Justin B. Jackson Weber State University

Many studies have been done related to antenna patterns and their importance in defining an antenna's characteristics. The Weber State

University Electrical & Computer Engineering department developed an open source antenna pattern range to record antenna patterns in an open environment. This pattern range used a simple noise subtraction method where it takes a measurement of the current electrical noise in the environment and a measurement of the broadcast signal. The system subtracts the noise from the measured signal to determine the magnitude of the signal. This uses two software-defined radios (SDRs), one for the transmit antenna and another for the antenna under test (AUT). The system transmits the signal, rotates the AUT, and retransmits. This sampling is done for a full rotation. From these data, antenna patterns are generated for the AUT's radial radiation pattern. Although this approach is able to acquire antenna patterns, these patterns are generally noisy because of external radiation affecting each sample. Phase-shift keying (PSK) has been proposed to improve the rejection of these external signals. Data are sent from the transmitting antenna to the receiving antenna. The data re ias verified against the information transmitted to accept or reject the signal. Adding this level of discrimination will allow for the validation of signals from the transmitter and external signal will be rejected. A PSK algorithm has been developed to aid in the discrimination of these external signals. This SDR program transmits data packets for signal verification utilizing binary PSK. This is what helps verify the data. Verified signals are added to the antenna pattern characterizing the AUT. The program offers the option to not plot false data points when the noise in the environment exceeds the threshold of which the system can verify the signal similar to modern networking techniques.

ENGINEERING

Construction Key Performance Indicators Initial Reactions to the COVID-19 Pandemic: A Case Study on Design-Build Project

Xinzi Cui, Qingyang Chen, Mohamed Askar Southern Utah University

Tracking and carefully interpreting an array of key performance indicators (KPIs) helps a construction company build long-term resilience and performance while also meeting short-term financial and performance goals when affected by the novel coronavirus. At the start of the novel coronavirus, COVID-19, pandemic, most construction companies throughout the US were affected by closures or slowdown. This study's primary purpose was to determine the impact of COVID-19 on the construction KPIs, such as delays caused by public service interruption or by temporary termination of work on-site. Especially when dealing with some risky projects, how to avoid accidents to monitor the profit margin to ensure the project's smooth progress. Seven important KPIs were determined, and a dashboard was designed to follow the performance indicators during the project construction phase. A gap analysis was processed to compare the actual performance or results with what was expected or desired. A comparative study between the performance indicators before and after COVID-19 was accomplished. The study included an observation of major KPI statistics that were affected by COVID-19 and needed to be added to these KPIs under the danger of COVID-19 to improve them. The study is implemented on a design-build project. The context of the COVID-19 pandemic is the nowadays themes in the construction industry. Initial coding identified familiar terms in the Covid response, like reduced resource sizes, fewer projects, and cost reduction. The study concluded several ideas to improve the use of KPIs in the construction industry during crisis times.

ENGINEERING

Effect of COVID-19 on Risk Management of Construction Projects: A Case Study on High-Rise Building in China

Hongyu Hu, Mycrae Tebbs, Mohamed Askar

Southern Utah University

China's construction industry is China's pillar industry. Since 2004, the year-on-year contribution rate of the construction industry to GDP has averaged around 6.3%. Unlike the United States, China is still a developing country. Public facilities and infrastructure are still a key part of the country. State-owned enterprises occupy a dominant position and play an important role in the industry. Based on the statistics of 118 listed construction companies in 2018, the total revenue of construction state-owned enterprises accounted for 94% of the entire sector, and the proportion of net profit reached 91%. The impact of COVID-19 in China from December 2019 to March 2020 has had a significant impact on the construction industry. There is no doubt that the COVID-19 isolation system has caused many risk categories, and the construction risk management has become more complicated and

inappropriate. This research focuses mainly on an environmental project, which encountered risk management difficulties because of COVID-19. The main objective of this research was to develop a model that includes a risk dashboard with different risk indicators. The research methodology focuses on how to determine the possible risks of construction projects and use good management methods to control them. Risk management should focus on risk control and adopting active measures to control risks by reducing the probability of risk occurrence and/or risk impact. Under the circumstance that the established goals remain unchanged, change the implementation path of the plan to fundamentally eliminate specific risk factors. The research offered a risk management model and possible suggestions and procedures to avoid the risks, as possible.

ENGINEERING

Construction Safety Plans Initial Reactions and Responses to the COVID-19 Pandemic: A Case Study on Commercial Project

Olive Musimbi, Hang Chu, Mohamed Askar

Southern Utah University

The construction industry has faced many alterations through the years. In response to the COVID-19 pandemic, the most recent change may be the revisions in personal protection equipment (PPE) as research on health and safety has progressed over time. Most construction companies throughout the US were affected by closures or slowdown. Initial coding identified familiar terms in the COVID-19 response, like face coverings, hand sanitizer, social distancing, and health screening of all employees prior to entering the construction site, such as temperature checks, put forward some requirements to guard against COVID-19 at work, using remote monitoring to supervise the construction site, submit, and review and revise problems on-site by means of internet communication. This study's main objective was to develop a construction project safety plan to match the current situation. The Associated General Contractors of America (AGC) reported in March 2020 that COVID-19 was starting to affect construction through delays, logistics issues in obtaining material and PPE and worker concerns. A short survey, COVID-19 and Construction Safety, was developed in Google Forms for construction companies. A link to the survey was posted on social media and emailed out to contractors. The Centers for Disease Control and Prevention (CDC) has issued construction workers guidelines that include handwashing stations, social distancing, and face coverings. Most of the survey responses included that it is required to focus on the PPE at the office and on construction sites. Based on the survey question responses, an updated construction safety plan has been developed. The safety plan has been tested on a commercial project. The study concluded several ideas to improve the health and safety of the construction workers and equipment.

ENGINEERING

Delay Challenges in the USA Construction Projects due to COVID-19: A Case Study on Commercial Project

Yufan Xiong, Zimei Zhang, Mohamed Askar

Southern Utah University

The United States construction industry is one of the largest construction markets worldwide, with annual expenditures of over \$1,293 billion in 2020. However, the coronavirus (COVID-19) pandemic has harmed the construction industry, prompting project delays, cancellations, and increasing projects' overall cost. With construction projects facing delays, disruptions, and uncertainty of completion because of the COVID-19 pandemic, many construction companies are looking to their force majeure coverage and delay clauses to determine what is considered eligible for claim submission. COVID-19 has delayed close to 5,500 U.S. projects as of June 2020. There have been various publications issued on the topic of mitigating risk and legal issues associated with the construction industry response to COVID-19. The main objective of this study was to focus on a regularly updated project schedule that was crucial because project teams rely on accurate schedules to plan and do their work. This study focused on outlining the best practices for construction project planning, schedulingd and delay analysis updating of various activities in one commercial project using MS Project software. The resources of each activity were determined and allocation was done using the software. An updated schedule, which helps to finish the project well in time with optimum resources and delay reasons and analysis, has been considered in this study on the commercial project. The study concluded several ideas to improve the construction project progress and minimize the projects' overall cost, such as contractor adjustment of crew sizes, shifts, or equipment to speed or slow the progress.

ENGINEERING

The Impact of COVID-19 on Construction Project Financial Management: A Case Study on Heavy Civil Construction Project

Xin Wan, Mohamed Askar, Jared Baker

Southern Utah University

On 11 March 2020, the World Health Organisation declared COVID-19 to be a pandemic, with the WHO "deeply concerned by the alarming levels of spread and severity" of the outbreak. In response, the financial markets have plummeted to levels not seen since the 1987 stock market crash. This affected the construction industry's financial status and brought many uncertain factors to the project's financial management, such as problems related to the project cash flow. These problems are bound to cause significant distress to the project's finance. The importance of financial management has increased substantially compared with previous periods. This study's main objective was to develop a project financial management model to help improve the financial situation of construction projects. The secondary objective was to analyze the impact of COVID-19 on project financial management by focusing on a series of specific data to improve the financial status, such as the project's cash flow. This study used pie charts and data comparison methods to examine the impact of COVID-19 on the financial management of a heavy civil construction project and through the final data analysis to show the effect of the COVID-19 pandemic and suitable response methods. The financial model was tested on a heavy civil construction project to summarize several measures to deal with the impact of the COVID-19 pandemic. The study concluded several possibilities of reducing the impact of COVID-19 on the project financial management and reduced the project costs by optimizing productivity. The study recommended some effective measures to control financial expenditures and project costs.

ENGINEERING

Developing a Quantitative Quality Control System to Overcome the Impact of COVID-19 on the Constriction Projects in the USA: A Case Study on a Commercial Project

Xingqi Yu, Mohamed Askar, Jared Baker

Southern Utah University

Construction is a significant contributor to the US economy. The industry has more than 680,000 employers with over 7 million employees and creates nearly \$1.3 trillion worth of structures each year. Unfortunately, the outbreak of COVID-19 has changed all of that, disrupting the construction industry's pace. Construction laborers are required to work while maintaining social distance, resulting in reduced productivity and poor quality. This research's primary goal was to develop a quantitative quality control system to overcome the negative impact of COVID-19 on the quality of construction projects in the US. The secondary objectives were to focus on the regular monitoring of the construction site's conditions of the commercial project and effectively solve the quality problems. The methodology of this research was to outline the best practices for using application software and quality checklists to discover, raise, and solve problems of the construction process due to the effect of COVID-19. A quality dashboard and statistical analyses were developed to measure the quality of the construction items and the general quality index. The software will be used for monitoring each problem and scheduling solutions. More complete checklists and management methods have been considered, ensuring that the project meets a certain quality level with practical strategies, solutions, and safe communication methods. The research concluded several ideas to identify, resolve and report project quality issues in a timely manner to protect workers' safety and ensure project quality, such as improving the quality checklists for COVID-19, internet monitoring, and spot-checking the quality of the project.

LETTERS—HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

The Overlooked Diderot

Zahran Austin

Weber State University

This essay aims to explore an often-overlooked work by Dennis Diderot, *Les Bijouxs Indiscrets*, and to place it within its historical and literary context. The novel may not be a masterpiece; however, it is heavily reflective of the rest of Diderot's works. Themes found in this novel appear regularly throughout his other writings, and the novel marks a turning point in Diderot's life and career. *Les Bijouxs Indiscrets* also mirrors several literary and social trends sweeping France as it was written. Whereas most scholars either ignore or malign this work, this essay intends to demonstrate that it is worthy of further interpretation and analysis.

LETTERS—HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

Bartleby, the Hypothetical

Brady Earley

Brigham Young University

The Law and Literature movement has long recognized the contribution of Herman Melville to the field with works such as "Bartleby, the Scrivener." The legal analysis of this story has often been viewed as a response to the legal philosophy of Melville's father-in-law Chief Justice Lemuel Shaw. In doing so, scholars have implicitly recognized the way in which "Bartleby" is employed as a hypothetical to Shaw's judicial reasoning. Explicitly exploring this novel implication of "Bartleby" uncovers the vast influence of the hypothetical on American legal thinking that immediately followed Melville's short story. Whereas most scholars agree that legal issues influenced Melville's literature, I argue that the influence also went the other way: Melville has impacted the law's development, specifically in the way he invites legal minds to consider the often-overlooked consequences of their logic. From the case method in law schools to the recent Supreme Court decision in National Federation of Independent Business v. Sebelius, the use of hypotheticals has become foundational to the development of American law. In turn, Melville's discernible and lasting impact on the law articulates the transcendence of his literature that has posthumously endeared Americans to his work.

LETTERS—HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

"Something Large and Old Awoke": Ecopoetics and Compassion in Tracy K. Smith's *Wade in the Water*

Kaitlin Hoelzer

Brigham Young University

Tracy K. Smith's volume Wade in the Water: Poems (2018) connects environmental degradation and racial injustice and responds to these issues with a call for compassion. In this paper, I situate Smith's work within Black ecocriticism, which moves beyond pastoral aesthetics to identify the oppressive structures that tie racial injustice to environmental degradation. I also argue that Wade in the Water engages with the work of contemporary Black theorists such as bell hooks, Brittney Cooper, and Charlene Carruthers, who argue that compassion is necessary to fight oppression. Wade in the Water, in particular the poems "Watershed," "Wade in the Water," and "An Old Story," discusses both racial and environmental injustice and violence, but at the same time, Smith's book is infused with a compassion the book and other scholars argue is essential to fight unjust systems and bring about healing. With Wade in the Water, Tracy K. Smith joins other contemporary Black women theorists in offering up a vision of a compassionate society that recognizes the value in all humanity as well as the earth.

LETTERS—HUMANITIES, PHILOSOPHY, FOREIGN LANGUAGE

Recreating the Anastasis in 3D

Bob deWitt

Utah Valley University

The so-called "Anastasis" was the 11th-century iteration of the Church of the Holy Sepulcher in Jerusalem. After the destruction of the Constantinian-era Church of the Holy Sepulcher by the "Mad Caliph of

Cairo," al-Hakim bi-Amr Allah, in 1009, the site lay in ruins until the Byzantine emperor Michael IV signed a treaty with the Caliph al-Zahir in 1038 in which the emperor was allowed to rebuild the church at his own expense. The edifice that arose on the ruins of the Church of the Holy Sepulcher was very different than the original church and came to be called the "Anastasis" or "Resurrection." This church stood until it was extensively remodeled in a Romanesque style by the Crusaders in 1149 (the version that we see today). Nothing of the Anastasis remains except portions that were incorporated into the Crusader church. In my paper, I use the surviving archaeological, visual, and written evidence to recreate with 3D software the likely appearance of the Anastasis as constructed by the Byzantines and compare it with the original Constantinian structure. This both demonstrates what the church may have looked like and how 3D models can help illuminate long-lost structures from the past.

LETTERS—LANGUAGE AND LITERATURE

Putting It on the Page: Grief and Loss through Fiction

Lisa Christensen, Chanel Earl, Dallin Hunt, Madalyn McRae Brigham Young University

Four MFA students share short fiction addressing different types of loss. Here are questions they asked as they wrote—and that they ask their listeners to consider: How do literary or aesthetic elements enable writers to share the intensity of grief or loss? How do speculative elements potentially enhance this process? How do texts focused on grief or loss enable both writers and readers to better understand and process difficult experiences and feelings and needs?

PHYSICAL SCIENCES

3D-Printable Cell Phone Spectrophotometer for Chemistry Education

Brittany Christensen, Chris Monson Southern Utah University

High school chemistry classes typically teach about light over several classes. This is commonly done from a largely theoretical perspective,

perhaps with a demonstration to better illustrate specific aspects of light and its interactions with matter. At a college level, the interaction of light with matter is usually taught with spectrophotometers. However, the cost of a classroom set of spectrophotometers and the difficulty using them means many schools may not have access to them. We have designed a 3D-printed spectrophotometer that is inexpensive and uses student cell phones as detectors. This device contains three cuvette holders and a spot for a smart phone camera to view all three of the resulting spectra. In addition to the 3D-printable device, we have developed a laboratory to use with the devices that can help teach high school students concepts from absorbance and reflection to creating a calibration curve and identifying concentrations of unknown solutions. This cell phone spectrophotometer may be more accessible to schools because of its inexpensive design and can be used to teach the concepts within light chemistry more effectively. Students will also be able to explore a new field of chemistry with this hands-on spectroscopy laboratory and may discover a new interest and appreciation for the study of chemistry.

PHYSICAL SCIENCES

Inverse Frit Semipermeable PDMS Membranes

Mikey Savage, Aubriel Koehler, Megan Jensen, and Christopher Monson

Southern Utah University

Separations of liquid mixtures are important in a number of scientific fields. Separation techniques use a variety of criteria to determine how molecules are separated, but several common methods use molecular size. Semipermeable membranes have holes of specific sizes to allow molecules of that size or smaller to pass through the membrane and are commonly made of cellulose. We have created porous membranes out of polydimethylsiloxane (PDMS), an elastomer. We created these porous membranes using a PDMS and magnesium mixture. When the PDMS is polymerized, the magnesium is locked in place, and then the magnesium is dissolved out to create the membranes. We are testing the filtration of these membranes using water and proteins of varying size. As expected, so far we have found that using larger magnesium pieces results in better water flow and poorer filtration because larger holes in the membrane are created. However, the filtration does not behave as might be expected, with relatively large magnesium pieces creating membranes that have some protein-filtering abilities. We will report our results

working with different sizes of magnesium, which we hope may eventually lead to membranes that are as capable as those used in a dialysis machine.

PHYSICAL SCIENCES

Using Silver Nanoparticles to Detect Early Onset of Disease

Porter Wilkes, Payton Riggs, Jonah Babbel, Christopher 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 (PDMS). 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 (1,2dioleoyl-sn-glycero-3-phospho-L-serine), a vitamin (vitamin B), and several proteins (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. We observed that nanoparticles made from the distinct proteins fluoresced differently. We have examined the effects of diluting the concentration of nanoparticles and have found that as the nanoparticle solution is progressively diluted, the fluorescence spectra shows a trend of blue-shifting/increase in intensity, followed by stabilizing at approximately λ =460nm/decrease in intensity. We have also examined the nanoparticles formed from mixtures of ligands (protein/protein mix and lipid/protein mix) and have observed that these nanoparticles fluoresce differently than nanoparticles formed from each of the pure capping ligands. Our objective is to distinguishing features between the fluorescence identify of nanoparticles fabricated 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 created from samples of subjects believed to have a disease to those who do not.

PHYSICAL SCIENCES

Home Made Raman Spectrometer

Hamza Samha, Mathew Rowley

Southern Utah University

Raman spectroscopy is one useful method for determining the chemical makeup of samples. Raman spectroscopy relies on Raman scatter, an event where visible light is used to excite a sample to a virtual excited state. This state is very short-lived, and the sample will quickly return to the ground electronic state but with vibrational modes activated. The relaxation emits a photon whose energy is lower than the excitation photon by the amount of vibrational energy now held by the sample. Thus, a spectrum of the Raman scatter photons is characteristic of the vibrational structure of the sample. These characteristic vibration modes can give insight into the chemical structure of the sample and may even be unique enough to provide the chemical identity when compared against a database of known spectra. We are designing and building an inexpensive spectrometer to be used in both teaching and research here at Southern Utah University. In addition to designing the optics of the spectrometer, this project involves designing detection and amplification circuits, a hardware controller, and both control and user-interface software with detection and sample analysis in mind. Once the apparatus is completed, its performance will be characterized using a sample with experimentally known vibrational modes. We ultimately hope to use the instrument in collaboration with others to study the surface enhancement of Raman signals by nanomaterials.

PHYSICAL SCIENCES

Biomolecular Separation via Microfluidic Devices

Payden Harrah, Christopher F. Monson Southern Utah University

Microfluidic devices consist of channels small enough to control the flow of fluid inside them with great precision, which allows the device to perform many scientific and medicinal functions. In particular, microfluidic devices allow for the separation of biomolecules based on weight, charge, and function. Microfluidic devices must balance functionality and cost. Often, devices with multiple functionalities are more complex and therefore expensive to fabricate. As microfluidic devices continually expand in functionality and decrease in cost, many new applications develop, in our case the identification and characterization of biomolecules in different samples including tissues, soil, and blood. The applications of identifying the biomolecules present in these various samples can be used in extremely diverse scientific fields. We have developed a microfluidic device that offers a cost-effective field flow fractionation system that has the potential to separate biological materials in a complex sample easily and efficiently. We will present our work on this device.

PHYSICAL SCIENCES

Changing the Paradigm on Copper Nanoparticle Formation

Jessie Fischer, Tanner Stenlund, Christopher Monson Southern Utah University

Copper nanoparticles have a variety of uses and applications in many different fields. Current fabrication methods start with copper ions and build them up to the desired nanoparticle size. We developed a new way to synthesize copper nanoparticles starting with a sheet of solid copper and sonicating it in hydrochloric acid. Although copper is a relatively unreactive metal and is not known to react with hydrochloric acid (HCl), this method has been found to break down solid copper into nanoparticles in a predictable fashion. Using ultraviolet-visual and fluorescence analysis as well as atomic force microscopy, we were able to determine that nanoparticles are being created and that the concentration of HCl affects their formation. Additionally, these nanoparticles are stable over long periods of time, unlike traditionally fabricated nanoparticles, which tend to decompose relatively quickly. Furthermore, preliminary data suggest that the nanoparticles may be able to catalyze the formation of additional nanoparticles under certain conditions. We are currently exploring the properties and fabrication of these nanoparticles.

PHYSICAL SCIENCES

Possible Synapsid Tracks from the Lower Jurassic Moenave Formation, Southwestern Utah

Holly Hurtado, Jerald D. Harris, Andrew R.C. Milner

Dixie State University

Sedimentary rocks from southwest Utah preserve a diversity of tracks from the Lower Jurassic Moenave Formation. Among the animals leaving these tracks were early dinosaurs and crocodylians, but two previously undescribed, tetradactyl footprints preserved at the St. George Dinosaur Discovery Site (SGDS) at Johnson Farm do not match the morphologies of either dinosaurian or crocodylian tracks. SGDS 18 is a toe-tip-only trackway that includes drag marks between steps, possibly made in wet sediment. SGDS 190 is a single, isolated track with short digit impressions that lack obvious claw marks. Originally, these tracks were tentatively referred to the ichnogenus *Brasilichnium*, but this is uncertain. Quantitative measurements of the tracks were taken for comparison with those of other ichnotaxa. Our preliminary results find similarities to multiple ichnotaxa, but lean toward mammalian or near-mammalian synapsid interpretation.

PHYSICAL SCIENCES

Evaluation of Super Fund Removal Action at the King Edward Mine

Robert Davidson, Andreas Lippert, Charles Davidson, Tori Schaffer, Dale Harber

Weber State University

There are thousands of abandoned uranium mines located in the Four Corners Area from mining during the 1940s through the 1970s. The King Edward Mine complex ranked high on the Manti-La Sal National Forests list of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites because of both environmental and safety issues, which include discharge of water contaminated with radionuclides and metals, eroding waste rock piles, and open adits. The site is on the west bank of South Cottonwood Creek, which flows south and is used for irrigation on Ute Mountain Ute allotments and culinary water for the city of Bluff, Utah. The aim of this study was to test the effectiveness of the superfund action at the King Edward Mine complex. Water and soil samples from the remediated mine site were analyzed for six elements to determine whether the removal action is working. The elements analyzed were arsenic, cadmium, lead, selenium, uranium, and vanadium. Four water samples and four soil samples were collected from different areas around the mine site. Water samples from the mine adits and soil samples from the mine substantially exceeded the elemental concentration limits for drinking water set by the U.S. Environmental Protection Agency (EPA). Water samples taken from the stream above and below the mine had concentrations that were lower than the EPA drinking water regulations for five of the elements studied. The uranium concentrations from the samples taken upstream and downstream were higher than EPA drinking water regulations, but they were not statistically different. Therefore, there is no evidence of additional seepage coming from the mine into the stream at the time of this study.

PHYSICAL SCIENCES

Investigating Mutual Inductance Coefficients using Theta Pinches

Thayne Hansen, Shaun Cluff, Theodore Lane

Southern Utah University

Theta pinches are devices that are frequently used in science demonstrations. Theta pinches used to crush metal objects have not been used for anything more than crushing empty aluminum cans, so our experiments will push the capabilities of a theta pinch to its limits. In order to do this, we have created a modular theta pinch that allows for different coils of wire to be attached to our capacitor. By varying coil loop density, wire gauge, and maximum voltage in the capacitor, experimental values for coefficients of mutual inductance can be found. These can be compared with measured can deformation values determined by a known pressure, allowing for the efficiency of the theta pinch to be determined. These values can then be used to optimize theta pinches for the crushing of various other metal objects.

PHYSICAL SCIENCES

Rocketing Ahead with Fusion?

Christopher Hooper, Phil Matheson

Utah Valley University

"Direct-drive fusion" rocket motors have recently become of interest with the advent of start-up companies such as Princeton Satellite Systems and their speculative foray into nuclear fusion-driven thrust. Assuming heating mechanisms are developed to produce the required temperatures, we examine the basic parameters of such a rocket that place constraints on its operation. We consider feed rates and fusion rates necessary to sustain a given level of power. Unlike schemes to produce commercial fusion, the relevant plasmas must fuse over shorter time and distance scales and at high temperatures and densities. This undergraduate project is a simple sketch of the parameter space based on rudimentary physics, intended to give insight to the magnitude of creating such a formidable rocket.

PHYSICAL SCIENCES

The Fractal Dimension of Product Sets

Clayton Williams, Machiel van Frankenhuijsen

Brigham Young University, Utah Valley University

There are several notions of dimension used in fractal geometry, which coincide for many sets but have important, distinct properties. Using methods from nonstandard analysis, we define a nonstandard Minkowski dimension with the property that $\dim(A \times B) = \dim(A) + \dim(B)$. That is, our new dimension is "product-summable." To illustrate our result, we generalize a classical example from geometric measure theory to show that the standard upper Minkowski dimension, as well as the Hausdorff dimension, are not product-summable. We also include a method for creating sets of arbitrary rational dimension.

POSTER: BIOLOGICAL SCIENCES

Possible Thermal and Respiratory Constraints for Fleas (Siphonaptera: Ceratophyllidae) on North American Deer Mice (Mammalia: Rodentia)

Robert L. Bossard

Bossard Consulting

There are numerous examples of terrestrialization and diversification of ceratophyllid fleas in North American. The flea genus Aetheca is confined to western North America, and its two species appear currently allopatric. Aetheca thamba is at high elevations in the U.S. Rocky Mountains and lower elevations in Canada, but Aetheca wagneri is at lower elevations in the western U.S. Parapatric thermal speciation may have occurred since the last Ice Age, because deer mice hosts (Peromyscus spp.) are abundant throughout these fleas' ranges. Thermal speciation and thermal niches are reported in the ocean and the terrestrial tropics for diverse phyla. In addition to direct effects of temperature on the growth of larval fleas, correlated processes such as respiration may constrain flea occurrence. The flea Orchopeas leucopus co-occurs with A. wagneri in the Great Basin Desert, often infesting the same individual mouse. However, O. leucopus appears constrained to cool moist times of the year, but with a widespread distribution in eastern North America, unlike A. wagneri, which occurs throughout the year but only in western North America. The contrasting geography and seasonality of O. *leucopus* and *A. wagneri* may be partly a result of thermal and respiratory constraints peculiar to their respective phylogenies. The importance of competition in mediating abiotic factors among flea larvae or among flea adults is unclear. Aetheca and Orchopeas are both Ceratophyllidae, a new flea family possibly originating in the Himalaya Mountains, which radiated explosively all through the Holarctic region, by colonizing new hosts in extreme environments by using unknown adaptations. Flea respiratory systems are exceedingly diverse, dynamic, and phylogenetically conserved but have not been linked clearly to species habitat or seasonality. Fleas on deer mice are an exciting community for understanding physiological ecology.

POSTER: BIOLOGICAL SCIENCES

Exploring the Role of Lipid Metabolism in Hepatocellular Carcinoma

Noelle Reimers, Greg Ducker

University of Utah

Hepatocellular carcinoma (HCC) is an aggressive cancer with poor survival rates and limited treatment options whose prevalence is expected to increase up to 137% by 2030. Existing therapies outside of liver resection or transplantation have poor efficacy, and few new treatment options have been developed in recent decades. It is now known that the lipid metabolism of HCC cells is significantly altered relative to that of normal liver cells, often involving upregulation of fatty acid synthesis and oxidation enzymes. These lipid metabolic enzymes could represent a class of novel therapeutic targets for the treatment of HCC. To investigate this possibility, we designed a targeted library of existing lipid metabolic drugs for a repurposing screen. We treated a liver cancer cell line with 187 lipid metabolic drugs and clinical compounds to determine their relative antiproliferative effects and therapeutic potential. The initial screening on Huh7 liver cancer cells identified 24 compounds of interest based on a dose-dependent antiproliferative response. The hits largely came from drugs targeting phospholipase, cytochrome P450, FAAH, and autophagy enzymes. We continue to screen in 2 additional liver cell lines and follow up on compounds identified as hits using a dose response assay. In the future, we hope to further elucidate the metabolic effects of the drugs by using mass spectrometry to identify specific lipid metabolites in treated cells.

POSTER: BIOLOGICAL SCIENCES

Investigating the Presence of *Streptomyces* Streptomycin in Utah Insects

Sarah Wilcox and Nathaniel Cannon

Southern Utah University

Antibiotic resistance is one of the biggest threats to healthcare occurring around the world. The naturally occurring bacteria *Streptomyces* is the source for many commonly used antibiotics. Antibiotic resistance can be fought with the development of alternative antibiotics created from any

newly discovered strains of Streptomyces. New compounds of Streptomyces are rarely discovered when sought in common locations (such as soil or plants), but new research has found Streptomyces in unusual places. According to a 2019 study by Chevrette et al., insects have been discovered as vessels carrying new compounds of Streptomyces that potentially can be an original source of antibiotic material. The study tested insects from all around the United States, but no samples were collected in Utah. I will be testing for the presence of Streptomyces in insects collected from three different Southern Utah sampling locations: Woods Ranch, Cedar City's Veteran's Park, and St. George's Red Hills Desert Garden. My research will focus on the common insects collected at each location including grasshoppers (Orthoptera) and bees, wasps, and ants (Hymenoptera). This experiment's procedures include DNA extraction, DNA sequencing, determining which bacterial primers result in optimal PCR results, and gel electrophoresis to analyze bacterial presence. I hypothesize that Streptomyces will be present in at least one of my collected insect samples. The discovery of new forms of *Streptomyces* can lead to the formation of new antibiotics that can be used to fight against the increasingly dangerous phenomenon of antibiotic resistance.

POSTER: BIOLOGICAL SCIENCES

Combination Phage-Antibiotic Therapy on MRSA in Broth and Biofilms

Adam E. Jordan, Caleb R. Harrop, Zackary A. Pedersen, Heather L. Sheehan, Michael Otterstrom, Usama Barnawi, Jacob J. Bullough, Daniel N. Clark

Weber State University

Because of continued issues regarding the resistance of *Staphylococcus aureus* (*S. aureus*) to common therapeutic antibiotics, the need to establish supplementary or complementary treatment options is paramount. Indeed, the well-known methicillin-resistant *S. aureus* (MRSA) can destroy beta-lactam antibiotics, is difficult to treat, grows in biofilms, and can lead to fatal infections. Although there are many ways to kill bacteria, very few may be used as a treatment for health care purposes. One such method to inhibit bacterial growth and destroy sticky biofilm layers is the use of bacteriophage or "phage," a virus that infects bacteria but not human cells. We employed phage K, which causes lytic infections in MRSA bacteria. Phage K was used in combination with the

beta-lactam antibiotic carbenicillin (to which MRSA is resistant) and the common MRSA antibiotic vancomycin (to which MRSA is sensitive). After testing the minimum inhibitory concentrations required to kill MRSA, we used sublethal doses of antibiotics combined with phage K. We found that bacteriophages were better able to clear MRSA compared with antibiotics alone. The effect of phage K killing was estimated by measuring phage DNA levels with RT-PCR. Both MRSA broth cultures and MRSA biofilms grown on glass and plastic surfaces were tested. It is hoped that the combination therapy of phage with antibiotics may prove to break down biofilms and prevent resistant strain survival in hospital settings, thus preventing devastating MRSA infections.

POSTER: BIOLOGICAL SCIENCES

CRISPR Deletion of Viral Receptor Genes in Human Cells

Nicole Skalka, Megan Conroy, Jonathan Spencer, Jareth Aranda, Taylor Demler, Robert Ludlow, Corbin DeSanti, Hunter Branch, Saiman Sadiq, Daniel N. Clark

Weber State University

Enterovirus 71 (EV71) and herpes simplex 1 (HSV-1) are viruses that cause skin lesions in humans. EV71 is a virus that causes hand, foot, and mouth disease (HFMD) and primarily affects young children. In recent outbreaks in Asia, however, there have been reports of more serious and life-threatening brain infections. HSV-1 is a lifelong infection, causing genital herpes and cold sores, which affects 50 to 80% of US adults. In this experiment, we use CRISPR to edit the human genome in cultured cells (HEK293 and HeLa) to decrease the infectivity of these two viruses by deleting their receptors. To delete these receptor genes, a guide RNA (gRNA) was designed for each receptor using the Broad Institute gRNA design tool (ANXA2, SCARB2, and SELPLG for EV71 and Nectin-1 and HVEM for HSV-1). Plasmids that express each gRNA and the CRISPR cutting enzyme Cas9 were transfected into human cells using the base plasmid all in one CRISPR. This plasmid contains a dsRed fluorescent protein and a hygromycin-selectable marker for selection of edited cells. Plaque assays then compare infectivity in parent cells versus receptor-deleted cells. Because viruses use combinations of receptors, the end goal is to determine which receptors are most critical for attachment and entry into cells to target those receptors for virus inhibition.

POSTER: BIOLOGICAL SCIENCES

Undergraduate Student Research Conducting DNA Extraction, sequencing and assessing quality from Angiosperm and Gymnosperm Herbarium Specimens

Ethan M. Rosati

Utah Valley University

The three goals in this investigation were 1) assessing DNA quality; 2) submitting DNA sequences to global barcoding initiatives; and 3) lay the groundwork for future engaged learning opportunities. I compared angiosperm and gymnosperm extraction quality and quantity from exsiccate herbarium specimens. The DNA sequences collected will create a reference collection, building a valuable student resource for future phylogenetic work. DNA was collected by way of a destructive method of grinding. After material collection, DNA extraction kits were used. I amplified the DNA via PCR then observed the quality and quantity of the PCR products though gel electrophoresis and nanodrop. To investigate success in amplification of the target DNA sequence the ITS region was sequenced. Ultimately, the goal is to add our sequenced data to the barcoding body of knowledge to help biologists have intellectual control, conserve, and protect the biota of Utah and the world.

POSTER: BIOLOGICAL SCIENCES

Old World Vigna (Fabaceae) Phylogenetic Analysis

Dasha Horton, Ashley N. Egan

Utah Valley University

The genus *Vigna* includes a number of economically important crop species that provide a significant proportion of the world's plant-based protein. A solid understanding of the evolutionary relationships and taxonomic classification are important to provide contextual understanding of this plant group and relations of crops species to wild relatives. However, the taxonomic classification and circumscription of this genus has had a turbulent past and has not addressed the group wholistically. Here, we incorporate an improved taxonomic sampling from African and Old World *Vigna* species with previously sampled New World taxa to provide a more comprehensive estimate of

evolutionary relationships using molecular phylogenetic analysis. We interpret the results in terms of wild relatives of crop species and in the context of previous botanical classification schemes.

POSTER: BIOLOGICAL SCIENCES

Extraction of Soil Phage Against Local Wild Rhizobia

Krey Ramsey, Matthew Crook, Matthew Domek

Weber State University

Viruses are among the smallest and least complex biological agents on earth, and yet they have a profound impact on all domains of life. The viruses that specifically infect bacteria, known as bacteriophage or phage, have proven to be useful genetic, ecological, and research tools for understanding and manipulating specific species and strains of bacteria. Rhizobia are a group of nitrogen-fixing bacteria that form a symbiotic relationship with certain species of legume, such as clover and alfalfa. These bacteria induce the plant host to form special organs on their roots, called nodules. The rhizobia inhabit the root nodules, where they convert atmospheric nitrogen into the more accessible form of ammonia. In exchange for access to usable nitrogen, the plants provide carbohydrates produced during photosynthesis. Our goal was to find phages that may be used as a vector for horizontal gene transfer in rhizobia. Wild rhizobial strains were isolated from the root nodules of local legume plants collected during spring and summer of 2020. We also collected samples of the soil immediately around each root nodule and produced filtrates from them. We screened for phage in the soil filtrates by comparing 24-hour growth curves of rhizobia grown in TY broth with and without the addition of the corresponding soil filtrate. Rhizobial growth was measured by reading absorbance at 600 nm on a Tecan M200 plate reader. A decrease in absorbance during growth suggests the presence of a phage with lytic activity against that strain of rhizobium. So far, we have evidence of lytic phage activity in one soil filtrate. Verifying the presence of phage by spot test, as well as testing additional soil filtrates for bacteriophage, is ongoing.

POSTER: PHYSICAL SCIENCES

Plasma Spectroscopy as Applied to Astrophysical Observations

Rebecca J. Nelson, Theodore Lane

Southern Utah University

The interpretation of spectral lines for plasma characterization is a wellestablished diagnostic technique for determining number density and electron temperature, essential parameters for predicting radiation dynamics, local thermodynamic equilibrium, and atomic kinetics in laboratory and astrophysical environments. Specifically, spectra are the only way to compare predicted plasma quantities produced by hydrodynamic simulations, such as electron temperature, density, and fluid motion, to what can be observed in astrophysical objects such as supernova remnants and black hole accretion disks. To this end, we are using the atomic kinetics code FLYCHK to create synthetic spectra, which we will convolve to consider temperature and density gradients. We will then compare the spectra we created with spectra collected using the Chandra and XMM-Newton x-ray satellites to determine the accuracy of the hydrodynamic codes.

POSTER: BIOLOGICAL SCIENCES

Selective Media for the Isolation of *Paucilactobacillus* wasatchensis

R. Chase Wahlstrom, Craig Oberg, Matthew Domek

Weber State University

The obligate heterofermentative bacteria *Paucilactobacillus wasatchensis* has been shown to cause late gas blowing in aged cheeses, which results in defects such as splitting and crumbling of the cheese block. The ability to quickly and accurately isolate *Plb. wasatchensis*, especially when it is present at low concentrations compared with other bacteria in a cheese sample, could be very beneficial to the dairy industry. However, the current protocol for isolating *Plb. wasatchensis* is time intensive and imprecise. The goal of this study is to accurately detect *Plb. wasatchensis* when as few as 103 CFU/g are present within 72 hours, as well as be able to inhibit competing SLAB and NSLAB with one medium. Testing was conducted using 24-well plates in a Tecan
infinite 2000 plate reader, in which 7 SLAB and NSLAB strains were tested in triplicate along with the *Plb. wasatchensis* type strain, WDC04. Each well was filled with carbohydrate-restricted MRS (CR-MRS) broth containing 1% ribose, 2% Oxyrase, and .01% 2-deoxyglucose, a glucose analog. Results showed that under these conditions WDC04 could complete its logarithmic growth phase in 28 hours while the glycolysis inhibitor, 2-deoxyglucose, limited the growth of the 7 other SLAB and NSLAB strains. Lacticaseibacillus casei and Lacticaseibacillus paracasei, two of the most common NSLAB strains, showed the greatest level of inhibition between MRS broth (OD600 1.28) and CR-MRS+2deoxyglucose (OD600 0.60 and 0.54, respectively) after 28 h. Preliminary results for the incorporation of 2-deoxyglucose into CR-MRS agar as a selective plating media for Plb. wasatchensis show promise. This method could be used to determine the presence of *Plb*. wasatchensis in cheese at low concentrations (103 CFU/g) versus the high concentration of SLAB (108 CFU/g) that obscure its detection with current isolation techniques.

POSTER: PHYSICAL SCIENCES

Tissue Phantom Study to Characterize Detection of Cancer Cells with Raman Spectroscopy

Priscilla Lagunas, Haidy Rivera, Jordyn Hales, Jessica Jones, Dustin Shipp

Utah Valley University

Raman spectroscopy is an effective method for tissue analysis that has been known to be a precise and noninvasive method for cancerous tissue. This technique may be useful during tumor removal procedures. The goal of these surgeries is to remove all of the tumor while preserving as much healthy tissue as possible. Using Raman spectroscopy during surgery involves the use of a Raman spectrometer to identify tumor cells near the surface of the removed tissue that could indicate cancer remaining in the patient. Our research includes mimicking the samples obtained from this procedure by using tissue phantoms. The tissue phantoms are made of gelatin and doped with different densities of plastic microbeads. The beads represent tumor cells that may be spread throughout the tissue. Our goal is to gather data that would resemble what an actual tumor removal procedure would show. We have found that by adding appropriate amounts of skim milk to the tissue phantoms, the light-scattering properties (i.e., scattering coefficient) of the tissue phantoms can reflect more realistic parameters. The Raman spectrometer measures spectra that are given off by the tissue, including the plastic targets. We then analyze the data using a software program designed by our research group that will help us determine how close we need to be to the beads to detect them. Through the continuation of this process, the collected data will help us determine a connection between the different scattering coefficients and the distance from which the targets can be detected. This supports ongoing research to quickly and accurately detect tumor cells and differentiate them from healthy tissue. This would help make the surgery less invasive and return faster diagnoses compared with the treatment options that are being used currently.

POSTER: PHYSICAL SCIENCES

Synthesis and Characterization of Locked Dipyrroles for Insight into Energy Transfer in Biological Systems

Shardon T. Morrill, Mackay B. Steffensen

Southern Utah University

Our work in collaboration with Dr. Dean of the Physical Science department at Southern Utah University is to inform the structuremotion function relationship between highly efficient, native lightharvesting proteins of cyanobacteria and cryptophyte algae. Tetrameric pyrrole photosystems are used by these organisms, leading us to our previous work regarding the synthesis of dipyrrole molecules. In contrast to the compact and complex nature of binding pockets within biological cells, in vitro, these dipyrroles are subject to rapid deactivation of their excited state because of torsional motion about the pyrrole rings. To address this issue, we have pursued binding of the torsional motion through methyl, ethyl, and propyl alkyl bridges to synthetically tether the pyrroles rings through two physical connections and attempt to mimic the conformations of the molecules in vivo. This will allow our collaborators to use specialized cold spectroscopy instrumentation to monitor the photo-initiated vibrations that mediate efficient, rapid, and long-range energy transfer.

POSTER: PHYSICAL SCIENCES

An Exploration of a Novel Synthesis for Merocyanines

Jacob Newey, Kyler White

Southern Utah University

Merocyanines are a class of dyes having clearly defined structural properties. Some of these compounds change color depending on the solvent they are dissolved in, a phenomenon known as solvatochromism. Molecules that display this property can be used to identify the polarity of solutions. Other possible uses include in sensors and in the field of molecular electronics to construct molecular switches. Brooker's merocyanine, or MOED, is one of the more common solvatochromic compounds. We describe a new route to the synthesis of merocyanines that reduces the standard method two-day process of reaction and isolation to at most an hour. The reaction was optimized using MOED as the target molecule. The procedure is then used in the synthesis of a known MOED derivative as well as a novel compound. The previously unknown compound was characterized, and its properties are discussed.

POSTER: SOCIAL SCIENCES

Assessing the Role of Prescribed Painkillers and its Impact on the Opioid Epidemic

Abel Reed, DrVinod Chellamuthu

Dixie State University

The U.S. is currently facing an opioid crisis that causes two out of three of the overdose deaths within our nation, while addicts of opioids experience side effects such as depression, mood swings, loss of libido, headaches, and death. Over the past decade, the population of opioid addicts in the U.S. has increased, causing a negative impact on our upcoming generations nurture and development. According to data from 2018, 128 people in the United States die after overdosing on opioids every day. The consequence of the increased addicted population size is higher death rates among younger adults and a reduced life expectancy for the U.S. population. To understand why opioid addiction is rising in our society, we need to better understand the relationship between prescribed painkillers and the rate at which opioid addicts enter rehabilitation programs. We have developed a mathematical model that utilizes a system of nonlinear differential equations to investigate addictive phenomena in the opioid epidemic. We solved the model using a nonstandard finite difference numerical scheme. Our numerical simulation results show a broad view of what factors are directly contributing to the growth of the addicted population within our society. We also plan to incorporate seasonality into the model to reflect the variability in prescription rate within opioid dynamics. Our model could be used by hospitals and rehabilitation centers to discern when their patients are most liable to become addicted as well as what factors are directly contributing to them becoming addicted.

POSTER: SOCIAL SCIENCES

Is Thinness Truly Next To Godliness? Examining Moral Judgements Against Women With Larger Bodies in a Latter-day Saint Population

Sydney Rasmussen

Brigham Young University

Weight stigma exists in many ways within our society, although how exactly it manifests in a religious context has not been well researched. This study investigates the relationship between female body size and perceived morality among college-age Latter-day Saints. A total of 260 Latter-day Saint students at Brigham Youn University between the ages of 18 and 30 years were randomly assigned one of two surveys: one featuring the image of a larger-bodied woman and the other featuring the image of a smaller-bodied woman both being similar in complexion and dress. The survey asked participants various questions regarding their assigned woman's moral character, with items adapted from the Ethical Behavior Rating Scale. Our analysis found significant differences when examining only female responses, t(213) = 1.98, p < .05. That is, we found that college-aged Latter-day Saint women did judge smallerbodied females as being more moral than larger-bodied females. One main limitation to our study is that there were significantly more female participants than men. Future versions of this study should include a more balanced participant gender ratio and a larger sample size to either confirm or deny the significance of our findings.

POSTER: SOCIAL SCIENCES

Parental Religiosity and the Coming Out Process

Gabrielle Svozil

Brigham Young University

Within the last decade, there has been an increased acceptance of LGBTQ (lesbian, gay, bisexual, transgender, queer) identity. In recent years, a growing number of organized religious groups in the United States have issued statements officially welcoming LGBTQ people as members. Many religious organizations also have taken supportive stands on the issues that affect LGBTO people in America, such as the fight for freedom from discrimination, the solemnizing of same-sex marriage, and the ordination of openly LGBTQ clergy. However, there are still many religions that oppose LGBTQ rights, identity, and expression. Religion has been a source of both solace and suffering for many LGBTQ Americans. Within the family, religion has played a determining role in whether LGBTO youth feel comfortable coming out, a process by which LGBTQ individuals accept and openly express their identity. This paper will focus on how religiosity of parents affects whether their child feels comfortable being open about their nonheteronormative sexual identity. I use data from The National Longitudinal Study of Adolescent to Adult Health (Add Health) to determine religiosity of parents and whether the child reports a change in sexuality while controlling for race, gender, and parent education. I predict that high levels of parental religiosity will decrease the likelihood that the child reports a change in sexuality.

SOCIAL SCIENCE

Politics, Religion, and Values as Predictors of Support for Sexual Assault Reporting and #MeToo: A National Sample in the United States

R.C. Morris

Weber State University

On October 15, 2017, at 2:21PM actress and activist Alyssa Milano posted the words "Me Too" to her Twitter account. In a little over 12 hours, more than half a million people had posted "Me Too" in response. #MeToo has catalyzed a platform, empowering victims to disclose

incidents of sexual assault not previously reported. The Bureau of Justice Statistics (BJS) data show that reported cases of rape/sexual assault went from 393,979 in 2017 to 734,632 in 2018, an increase of 86.5%. With more than 165 million women/girls in the U.S., based on BJS numbers, sexual assault reporting for this category should be around 27,642,272 lifetime cases, a far cry from current numbers. Despite a growing number of reports spurred by the #MeToo movement, reporting accounts for less than 0.003% of sexual assault. In this moment of increased support for #MeToo, we continue to wonder about the factors keeping sexual assault reporting to less than a percentage point. This study draws upon an emerging literature investigating the linkage between a person's selfreported political orientation and their participation with a religious community; we do this by introducing a novel examination of valueidentities related to conformity and tradition. Results of our analysis find that religiosity and political identification is complexly correlated to sexual assault reporting and support for #MeToo. We further hypothesize that religion acts as a primary source of socialization for higher-order values, with values of this nature filtering down into valuebased identities conceptualized as conformity and tradition. Our further results find that value identities based on conformity and tradition are statistically significant predictors of sexual assault reporting and #MeToo. We conclude with a call for an examination of the role political and religious contexts play as a source of primary socialization "functionally antecedent" to the value identities keeping reporting and support low.

SOCIAL SCIENCE

From Mormon to "None": Dynamics of Latter-day Saint Religious Disaffiliation in Utah

Rick Phillips

University of North Florida

Within the United States, religious switching is common. However, when members of The Church of Jesus Christ of Latter-day Saints change their denominational status, they tend to abandon organized religion altogether. This pattern has been observed for almost 40 years. However, the number of Latter-day Saints leaving religion has accelerated in the 21st century, particularly in Utah. Using ethnographic data collected along the Wasatch Front, this paper presents a sociological framework for studying religious disaffiliation in Utah and examines

why Latter-day Saints are less likely than others to switch to a new denomination when they leave their religion. I provide cultural, demographic, and political reasons for this phenomenon.

SOCIAL SCIENCE

A Summary of the Science of Play in Early Childhood

Reetta Saaski, Abbi Covington, Sarah Prince, Michael J. Guynn, Dannelle Larsen-Rife

Dixie State University

Play is uniquely beneficial to children's development in early childhood and is jeopardized by the growing use of electronic forms of play. Increasingly, too many children have access to electronic devices starting in infancy, which not only negatively affects their learning but also affects their attachment to their primary caregiver during this critical period of brain development. Children learn through play, and play is essential to a child's growth and development. Play promotes academic, social, and emotional benefits in children, and play involving physical activity also promotes physical health. In infancy, children mainly play with their primary caregivers, and the quality of their play is influenced by their attachment style. The quality and complexity of children's play develop in relation to the developing attachment relationship between the primary caregiver and the child. The attachment style that develops influences how beneficial the play can be for a child. If the primary caregiver is engaged with the child and supportive by providing guidance and encouragement, they help the child to achieve new skills that may be too difficult for the child to master on their own. The child learns much more in play with a caregiver than a child whose primary caregiver is absent, otherwise occupied, or inconsistently available. The early developing attachment with the primary caregiver determines a lot of one's development, and play is a primary opportunity to strengthen the relationship between a child and a parent by promoting pleasure and joy. Excessive screen time reduces opportunities for authentic interactions which are important in the play. This paper advocates for policies to prioritize play, especially relational play, to promote secure attachment and child development.

SOCIAL SCIENCE

Silicon Visions: Regional Entrepreneurialism and the Technology Economy in Utah's Silicon Slopes

Jeremy Bryson, Melissa Jensen

Weber State University

Hoping to imitate the successes of Silicon Valley, metropolitan areas around the United States have tried to create similar high technology entrepreneurial regions in an effort to attract high-paying jobs and a skilled workforce. Although researchers have already begun to explore the environmental histories, landscape conflicts, and social impacts of Silicon Valley's development, we know relatively little about the second wave of these self-styled technology hubs. This paper explores one of these newer technology innovation hubs, known as Silicon Slopes, in Utah, to understand the role of regional-scale entrepreneurialism in shaping contemporary metropolitan landscapes.

SOCIAL SCIENCE

A Nuclear Crisis in East Asia: China, Taiwan, and the United States

Sasha Woffinden

Brigham Young University

Taiwan's status is heavily contested. While Taiwan maintains that it is an independent nation, its self-proclaimed status is unrecognized by most international organizations and much of the world. This lack of worldwide recognition is due in part to the massive influence of the People's Republic of China, which, for various purposes, contends that Taiwan is part of China. In the interest of maintaining diplomatic ties with China, the United States also does not formally recognize Taiwan as an independent state. The current policy of the U.S. towards Taiwan is to uphold strategic ambiguity, which has been the prevailing U.S. stance towards Taiwan since Congress passed the Taiwan Relations Act of 1979. My research analyzes the question of how the U.S. can defend its interests in Taiwan while avoiding nuclear war with China, and I analyze four U.S. courses of action towards this end: First, the U.S. could make an official commitment to defending Taiwan; second, the U.S. could abandon Taiwan; third, the U.S. could arm Taiwan; or fourth, the U.S. could seek a diplomatic, international resolution. I conclude by consolidating three of the options into a multistep plan, ultimately recommending that (1) the U.S. formally defend Taiwan, (2) the U.S. continues to arm Taiwan with conventional weapons, and (3) all else failing, the U.S. pursues an international solution on Taiwan.

SOCIAL SCIENCE

Behind the Wall: Climate Change, Global Security, and Border Militarization

Aidan Reed

Southern Utah University

Throughout the world, regions and nations struggling with existing instability are further strained by the effects of climate change. This paper discusses the global security dimensions of climate change and the role of climate change in driving border militarization. I begin by analyzing conflict case studies from around the world, their specific vulnerabilities to climate change, how climate impacts exacerbate existing instability there, and how climate shocks relate to the broader trend of global border militarization. I find that climate shocks are felt unequally, often affecting vulnerable regions and populations that bear the least responsibility for greenhouse gas emissions. Going forward, I expect that climate impacts will continue to contribute to instability in climate vulnerable locations and will continue to influence nations' decisions to militarize their borders and securitize their resources.

SOCIAL SCIENCE

Forgive Me Father For My Children Have Sinned: Religiosity, Intrusive Parenting, and Attachment Styles

Michael J. Guynn, Sarah Prince, Abbi Covington, Dannelle Larsen-Rife

Dixie State University, University of Minnesota

Attachments between children and their caregivers are formed early in life and influence attachment throughout the lifespan. An anxious attachment style is characterized by an inability to regulate one's own emotions. Intrusive parents use high degrees of psychological control, are overinvolved in the lives of their children, and do not prioritize autonomy in their parenting. Intrusive parenting predicts anxious attachment. People create attachments to God as another means of emotional regulation. Strict religious ideologies create an atmosphere of high interpersonal guilt and social pressure that may promote intrusive parenting. We hypothesized that religious affiliation is associated with intrusive parenting and anxious attachment in Utah residents. Results from regression analysis will be presented.