explorations

THE TEXAS A&M UNDERGRADUATE JOURNAL

VOLUME 12

FALL 2020

VOLUME 12 (FALL 2020)

Explorations: The Texas A&M Undergraduate Journal is student-run, faculty/staff-guided, publication dedicated to highlighting exceptional undergraduate research, scholarly, and creative work in all fields. Submissions of broad interest should be submitted online at **explorations.tamu.edu**. Questions about publication, student membership, how to become a faculty/staff reviewer, or how to obtain a printed copy of the journal can be directed to **explorations@tamu.edu**. *Explorations'* home is in the LAUNCH: Undergraduate Research office located inside of Henderson Hall at Texas A&M University in College Station, TX 77840-4233.

ISSN 2668-7525 (print)

ISSN 2688-7533 (online)

explorations

THE TEXAS A&M UNDERGRADUATE JOURNAL

VOLUME 12
FALL 2020

THANKS & GIG 'EM!

Explorations would not be possible without the generous contributions of Mr. and Mrs. Ralph & Barbara Cox, as well as continued support from The Association of Former Students, Office of the Provost, and office of Undergraduate Studies at Texas A&M University. The *Explorations* Board and the LAUNCH office sincerely thank you.

SUPPORT US

For more information on how **you** can help us showcase the best and most vibrant undergraduate research by Aggies, contact the Texas A&M Foundation at **info@txamfoundation.com**. Donations are accepted online at **www.txamfoundation.com/give.aspx**. Checks may be made payable to:

Texas A&M Foundation
ATTN: UGR Explorations: The Texas A&M Undergraduate Journal
Acct. 510025-36000
$25 minimum for online donations

CONTACT US

★ **explorations.tamu.edu**

✉ **explorations@tamu.edu**

facebook.com/explorationstexasam

instgram.com/TAMU_UGR

twitter.com/TAMU_UGR

GET INVOLVED

Opportunities are open to all undergraduate students. Be part of a leadership and learning community through *Explorations* as a board member, an author, or an artist! The student board works year-round to meet the journal's annual publication schedule, and develop skills in areas such as leadership, public speaking, critical thinking, time management, editing, marketing, publishing, and graphic design. Board member applications are accepted in early-fall each year.

Publication in *Explorations* is a multi-stage, refereed process. The first step to publication in *Explorations* is the synopsis submission, which is an article pitch. Synopses are reviewed by faculty reviewers and student board members. If invited, prospective authors then submit a full manuscript. Full manuscripts are requested by mid-spring and undergo a second round of faculty and student review. Final articles are chosen from the full manuscript submissions. Provisionally accepted articles undergo further editing and a final review by a team of student editors, LAUNCH staff members, and a third-party professional editor. Final articles are due in late-spring each year.

Faculty at Texas A&M can mentor undergraduate researchers and encourage them to apply to the board and/or to submit synopses. Faculty and staff can also volunteer to review submissions for *Explorations*. The review process begins each spring semester.

FROM OUR FACULTY

DR. MARK A. BARTEAU

VICE PRESIDENT FOR RESEARCH
TEXAS A&M UNIVERSITY

2020 has not been an easy year for anyone in higher education, whether students, faculty, or staff, as well as the families and communities sustain them. This year's edition of *Explorations* might well be subtitled *A History of the Plague Year* (with appropriate apologies to Daniel Defoe, who originated that title in 1722). Undergraduate research on the Texas A&M campus went on hiatus for five months as we made the massive shift to online courses in mid-semester and ramped down research before ramping it back up under new protocols designed to protect the health and safety of all. The research presented here and in other forums is a testament to the dedication of our students and their mentors in the face of these challenges.

Whenever I hear arguments that a liberal arts education is an unaffordable luxury or that colleges should become STEM-oriented vocational schools, I like to recall the description by James Burke of the dual missions of modern research universities like Texas A&M. Burke pointed out that one of those missions is profoundly conservative – preserving and transmitting the accumulated knowledge of the world to generations of students. The second mission is intrinsically revolutionary – creating new knowledge that will transform the future in ways that we cannot imagine. The support of that intrinsically disruptive activity by our society has created the world as we know it, but it should never be taken for granted.

Enter our students. Educators have long understood that they are not simply "empty vessels" to be filled up, but minds who bring diverse experiences and who learn more effectively when actively engaged. Even now, our teaching approaches are undergoing upheaval as we learn how best to engage students both online and in person, and where the two experiences are simply not interchangeable. But regardless of how our courses and classrooms emerge from the other side of the COVID-19 pandemic, they will still be aimed mainly at the first mission – the transmission of knowledge. The vital intellectual transformations that result are of individuals.

Why would we ever want to restrict our students to join in only one of our dual missions? The answer, of course, is that we don't, but the absence of restriction is not promotion. That is why LAUNCH: Undergraduate Research, our undergraduate research office at Texas A&M, is so important in connecting students with dedicated faculty mentors and in completing the circle by encouraging the communication of their work at a professional level via symposia and publications like *Explorations*. For some students, these experiences may lead to graduate studies and careers in research, but that's not necessarily the objective. It's really about engaging our students in the fullest academic experience, uniting both the traditional and the transformational.

Discovery is addictive! The satisfaction of solving a difficult homework or exam problem simply doesn't compare to the elation of piercing the unknown, of recognizing what no one has recognized before. Our undergraduate researchers have, we hope, tasted such *Eureka!* moments, both large and small, as well as the hard work that leads up to them. We thrill at the excitement of ***their*** stories and their contributions to the engine of discovery that is Texas A&M!

CONTENTS

CONTENTS

The Impact of Aging on Limb Regeneration

By Ian Guang Xia '21

INTRODUCTION

No matter the context, losing a limb is a devastating experience with tremendous impact on an individual's quality of life. In the US alone, there are nearly two million people affected by limb loss,[1] and the only current treatment is replacement of the limb with a prosthesis. Although prosthetic limb technology has been around for a significant portion of recorded human history,[2] evolving from iron hand replacements during the Roman era to modern day microprocessor-controlled prosthetic knees,[3] it is still an imperfect solution to a major quality of life issue.[4] In pursuit of a better treatment, scientists have been inspired by certain specialized vertebrates, such as salamanders, which are able to fully regrow amputated limbs. Studying these vertebrates will allow us to identify mechanisms that could possibly be translated to induce limb regeneration in humans.

STUDYING THESE VERTEBRATES WILL ALLOW US TO IDENTIFY MECHANISMS THAT COULD POSSIBLY BE TRANSLATED TO INDUCE LIMB REGENERATION IN HUMANS.

Similar to salamander limbs, the mouse digit tip is also capable of epimorphic regeneration, or the near perfect replacement of a limb or other complex body structure following injury. However, this regenerative capability is only present at the distal digit tip, or the digit tip furthest from the core of the body. If an amputation injury occurs closer to the body rather than around the middle or end of the distal digit tip bone, the limb will not regenerate and instead undergo a non-regenerative healing response like forming nonfunctional scar tissue.[5] Studying the mechanisms of these regenerative and non-regenerative wound healing processes has led to the discovery of a "regeneration window," or a time period during healing where wounds that normally would not regenerate can undergo partial regeneration in response to treatment with certain morphogenic agents, or proteins that regulate cell development.[6] For example, it has been recently discovered that treatment with morphogenic agents such as bone morphogenic protein 2 (BMP2) and bone morphogenic protein 9 (BMP9) during the regeneration window will stimulate bone and joint regeneration in normally non-regenerative amputation injuries in mice.[7]

With such advancements in mouse regeneration biology, application of these concepts to human biology may not be far behind. According to Dr. Ken Muneoka, a regeneration biologist in Texas A&M University's College of Veterinary Medicine & Biomedical Sciences, "with adequate funding, human-finger regeneration in children will be possible within 20 years."[8] Looking to the future, human regenerative therapies must be effective for all age groups, especially considering that adult and elderly demographics have the largest need for regenerative treatments. With advanced age comes a litany of new variables to account for such as changes in blood pressure, respiratory cycles, vision, and most importantly, overall loss of regenerative capacity. Therefore, exploring the effects of aging on regeneration of the distal (regenerative) part of the mouse digit may give clues for inducing regeneration specifically optimized for older patients. To study this age-related decline of regenerative power, the digit tips of mice modified to have progeria, a disease of accelerated aging, were analyzed at different time points of their regenerative processes.

METHODS

Two groups of lab mice were raised to two months of age: one group with progeria (the mutant/experimental group) and one group without (the wild type/control group). A two-month timeframe was selected from mouse work previously published by our lab in order to keep a consistent procedure.[9] Digit tips on each paw of each mouse were scanned with computer-assisted microtomography analysis (a three-dimensional x-ray scanning technology) to set a normal start-

ing bone volume. The mice were then given inhalation anesthetic and 20-30% of each rear digit tip was amputated to analyze differences in bone formation during the healing process. After amputation, the same digit tips were scanned at 3–7-day intervals to track the progress of bone regeneration, until 28 days post amputation when the regeneration process had finished.

In addition to computer-assisted microtomography analysis, immunohistochemical (IHC) analysis was conducted. In IHC analysis, antibodies are used to mark cells of interest because they can attach to specific cell types within selected tissue samples. This is possible since specific cell types have unique protein markers which only certain antibodies can attach to. For this project, select mice were euthanized to collect samples of their full digits at various time points during the healing process. These samples were immunohistochemically stained to measure the quantities of osteoclasts (bone resorbing cells, or cells that eat and degrade bone) and osteoblasts (bone forming cells). Collected digit samples were fixed in zinc-buffered formalin, decalcified, mounted in paraffin, and serially sectioned to a thickness of 4µm per section. These sections were attached to microscope slides and immunohistochemically stained for osteoclasts and osteoblasts using their respective protein markers, cathepsin K and osterix. These were detected through specific primary antibodies binding onto the markers and fluorescently labeled secondary antibodies binding onto the primary antibodies.[10] Then, an automated microscope took images of the sections to detect the fluorescent label attached to the osteoclasts and osteoblasts.

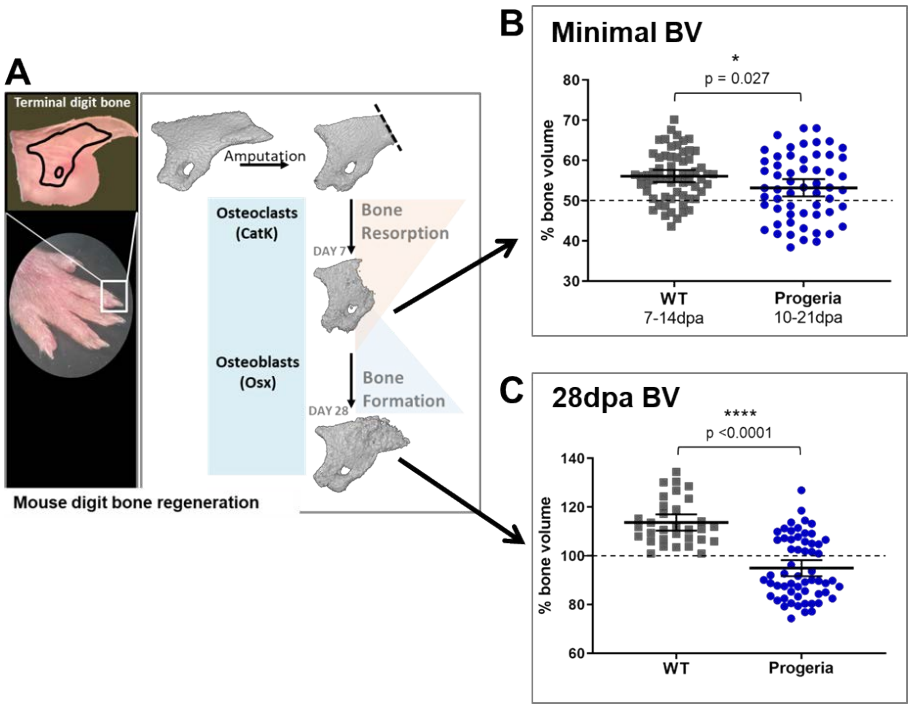


Figure 1. *This figure shows a general schematic of* ***(A)*** *the distinct steps which occur in the process of digit bone regeneration in mice illustrated by how the bone looks during each phase, and* ***(B)*** *differences in minimal bone volume (smallest bone volume caused by bone resorption) and* ***(C)*** *final bone volume (bone volume at 28 DPA), relative to preamputation volume, between progeria mice and healthy control mice (WT). The dashed line indicates 50% of the preamputation bone volume in B and 100% in C. Each data point represents one digit while bars indicate the mean ± 95% confidence interval. BV means bone volume; DPA, days post amputation; WT, wild type.*

TO STUDY THIS AGE-RELATED DECLINE OF REGENERATIVE POWER, THE DIGIT TIPS OF MICE... WERE ANALYZED AT DIFFERENT TIME POINTS OF THEIR REGENERATIVE PROCESSES.

RESULTS

Data generated through computer-assisted microtomography of the regenerating digits found that both bone resorption and bone formation were delayed in the digit tip bone of mice with progeria when compared to mice without it. This data is displayed in **Figure 1**. The point of lowest bone volume occurs at 7–10 days post amputation (DPA) for mice without progeria while occurring at 10–21 DPA for mice with progeria. Before these specified time points, bone resorption or degradation is occurring as osteoclasts eat away at damaged bone structures near the wound site to clear away debris for bone formation to begin. Following bone resorption, new bone is formed, and regeneration is completed at 28 DPA in healthy digits. As can be seen in **Figure 1C**, digits from progeria mice exhibit a much lower bone volume, which may indicate that progeria inhibits regeneration.

Amputation of the distal half (farthest away from the body) of the terminal digit bone induces a regeneration response, starting with bone resorption driven by osteoclasts ("bone-eating cells"). Bone resorption is typically completed by 7–10 DPA and is followed by bone formation driven by osteoblasts ("bone forming cells"). Regeneration is typically completed by 28 DPA. Minimal bone volume in progeria digits is achieved later (between 10–21 DPA) and is significantly lower than minimal bone volume in wild type digits, suggesting higher total osteoclast activity but slower osteoclast activation. Bone volume in progeria digits when compared to wild type digits is significantly lower, suggesting that aging inhibits osteoblast activity and, ultimately, digit regeneration.

Since progeria seemed to affect digit regeneration by affecting both bone resorption and bone formation, it was anticipated that osteoclast and osteoblast behavior must be altered by accelerated aging. Immunohistochemical staining using a primary antibody for the protein cathepsin K was employed to study osteoclast behavior. **Figure 2** shows the results of the his-

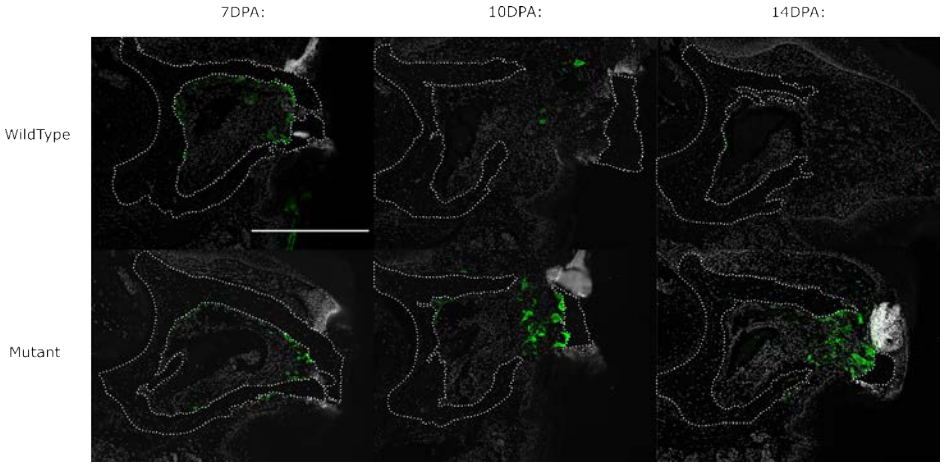


Figure 2. *These images show sections of digit tips stained with an antibody marking the protein cathepsin K (in green) and DAPI, which marks cell nuclei (in grey). The white scale bar in the top left-hand section has been set to 500 μm, and the digit tip bone has been outlined in a white dotted line in each section image. The "Mutant" label refers to image display sections from the experimental group of mice with progeria.*

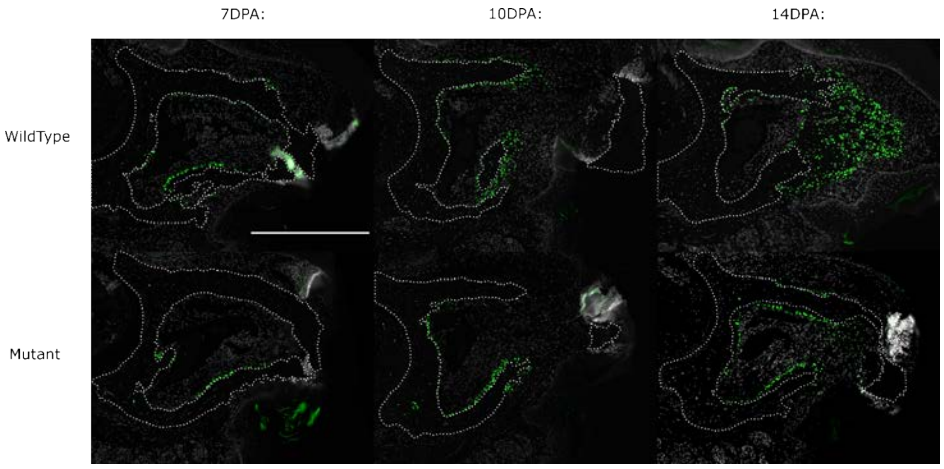


Figure 3. *These images show sections of digit tips stained with an antibody marking the protein osterix (in green), and DAPI, which marks cell nuclei (in grey). The white scale bar in the top left-hand section has been set to 500 μm, and the digit tip bone has been outlined in a white dotted line in each section image.*

tology on representative images (images which can be used to portray data from each group) for each time point, suggesting that osteoclast quantity sharply decreases in wildtype mice around 10 DPA while no such decrease exists for the progeria mice at any time point accounted for in this investigation. This result indicates that progeria extends the timeframe of osteoclast activity and explains the observed reduced bone volume by the end of the resorption phase.

...PROGERIA SIGNIFICANTLY ALTERS THE TIMING AND MAGNITUDE OF BOTH BONE DEGRADATION AND BONE FORMATION...

Furthermore, immunohistochemical staining using a primary antibody for the protein osterix was employed to assess the osteoblast prevalence and temporal changes thereof in the regenerative process. **Figure 3** shows the results of the histology on representative images for each time point, suggesting that osteoblast quantity sharply increases in wildtype mice around 14 DPA while no such increase exists for the progeria mice at 14 DPA. This suggests that the recruitment of osteoblasts to the wound site is impaired by progeria, which explains the lack of regeneration observed in **Figure 1**.

CONCLUSION

This project found that progeria significantly alters the timing and magnitude of both bone degradation and bone formation during the digit tip regeneration process. For progeria mice, bone degradation occurred later and with a greater magnitude than for healthy control mice. While bone formation also occurred later for mice with progeria, the magnitude of bone formation was significantly reduced when compared to mice without progeria. These results suggest that the regeneration window is postponed in older tissues. Since mice share around 97.5% of DNA with humans and are one of the most popular mammalian models for medical research, it can be argued based on the findings in this research that regenerative medicine therapies tailored to older patients should be administered a few days later compared to therapies for younger patients.

Possible future directions for this work include inducing regeneration in typically non-regenerative wounds of progeria or aged mice by adapting existing strategies, and the establishment of a preclinical large animal model such as sheep, bovine, or pig models which more accurately approximate human skeletal physiology. Once further work has been conducted, the novel techniques and theories may be translated to human patients, where induced regeneration may replace prostheses in the treatment of limb loss.

ACKNOWLEDGMENTS

I would like to thank my research advisors, Dr. Regina Brunauer and Dr. Ken Muneoka, for their guidance and support throughout the course of this research.

REFERENCES

1. K. Ziegler-Graham, E. J. MacKenzie, P. L. Ephraim, T. G. Travison, and R. Brookmeyer, “Estimating the prevalence of limb loss in the United States: 2005 to 2050,” *Archives of Physical Medicine and Rehabilitation* 89, (2008): 422–9, **https://doi.org/10.1016/j.apmr.2007.11.005**.

2. K. J. Zuo and J. L. Olson, “The evolution of functional hand replacement: From iron prostheses to hand transplantation,” *Plastic surgery (Oakv)* 22 (2014): 44–51.

3. D. M. Collins, A. Karmarkar, R. Relich, P. F. Pasquina, and R. A. Cooper, “Review of research on prosthetic devices for lower extremity amputation,” *Critical Reviews™ in Biomedical Engineering* 34, (2006): 379–438, **https://doi.org/10.1615/critrevbiomedeng.v34.i5.20**.

4. D. Murray, “Problems in prosthetics,” *Canadian Family Physician* 35, (1989): 309–12.

5. L. A. Dawson, Dawson et al., “The periosteal requirement and temporal dynamics of BMP2-induced middle phalanx regeneration in the adult mouse,” *Regeneration (Oxf)* 4, (2017): 140–50, **https://doi.org/10.1002/reg2.81**.

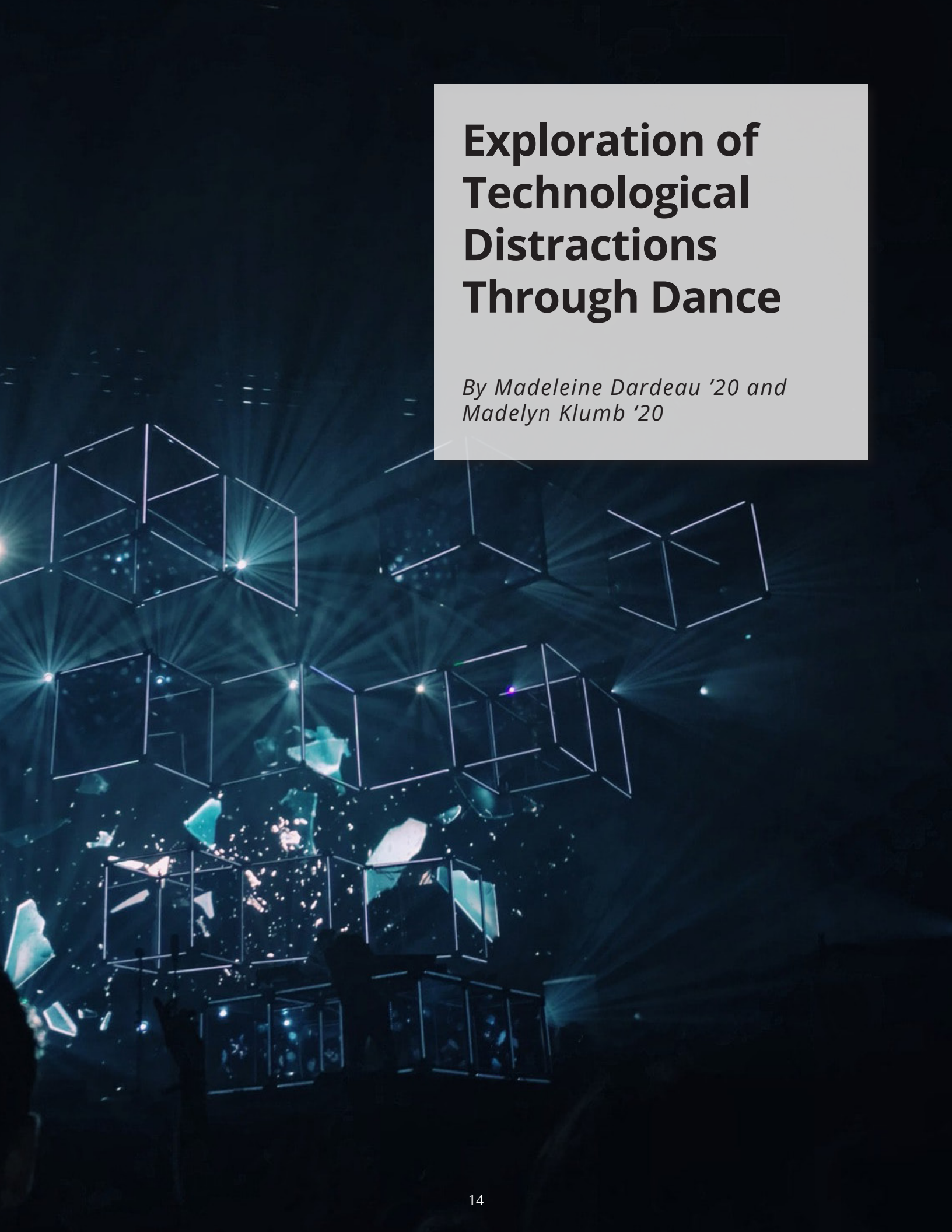
6. C. P. Dolan, L. A. Dawson and K. Muneoka, “Digit Tip Regeneration: Merging Regeneration Biology with Regenerative Medicine,” *Stem cells translational medicine* 7, (2018): 262–70, **https://doi.org/10.1002/sctm.17-0236**.

7. L. You et al., “BMP9 stimulates joint regeneration at digit amputation wounds in mice,” *Nature Communications* 10, (2019): 424, **https://doi.org/10.1038/s41467-018-08278-4**.

8. S. Gupta, “Animal models: Unlock your inner salamander,” *Nature* 540, (2016): S58–9, **https://doi.org/10.1038/540S58a**.

9. C. P. Dolan et al., “Axonal regrowth is impaired during digit tip regeneration in mice,” *Developmental biology* 445, (2019): 237–44, **https://doi.org/10.1016/j.ydbio.2018.11.010**.

10. L. Dawson et al., “Adult Mouse Digit Amputation and Regeneration: A Simple Model to Investigate Mammalian Blastema Formation and Intramembranous Ossification,” *Journal of Visualized Experiments*, (2019): 149, **https://doi.org/10.3791/59749**.



Exploration of Technological Distractions Through Dance

By Madeleine Dardeau ’20 and Madelyn Klumb ‘20

Figure 1. *Image from Default Network performance.*

RESEARCH QUESTION

In an individual's everyday life, distractions cause many unnoticed effects. These may include loss of information and confusion. In situations that only occur once, such as a dance performance, the effects of distractions can be detrimental because the information presented in the situation will never be repeated identically. Our research answers two questions concerning technological distractions during performances. The first question addresses how the effects of technological interruptions can be conveyed through the movement of dance. It was hypothesized that the utilization of dance movements inspired by the human use of devices would provide a visual representation of the effects of technological distractions on social interactions, such as conversations, communication, and exchanges. Dance choreography was developed to reflect the usage of cell phones, smartwatches, laptops, and headphones. The second question addresses how the usage of technology affects the audience's attention in a performance setting. It was hypothesized that the presence of technological distractions in the audience would cause spectators to miss singular moments within the piece. To test this hypothesis, devices, such as cell phones, smartwatches, and laptops, were given to pre-selected audience members during the performance and were used to distract the spectators from the choreography. At the conclusion of the performance, participants were asked to complete a survey about how the technological distractions affected their overall focus, in addition to participating in a Q&A session.

BACKGROUND

Technology has become increasingly integrated in individuals' lives and is observably more prevalent in the lives of younger generations. In particular, Generation Z, which consists of individuals born between 1995 and 2015, is greatly impacted by the use of tech-

DANCE CHOREOGRAPHY WAS DEVELOPED TO REFLECT THE USAGE OF CELL PHONES, SMARTWATCHES, LAPTOPS, AND HEADPHONES.

nology.[1] Although Generation Z experiences the greatest impacts, the high usage of technology has resulted in decreased attention spans, increased distractedness, and increased loneliness and depression in individuals from all generations.[2,3,4]

In a performance setting, the use of technological devices may prevent some audience members from connecting with the presented work because they become distracted by events happening outside of the performance, such as ringtones and flashing phone screens. Interruptions within the audience during performances have become increasingly problematic.[5] The owner of the device and other spectators become distracted from the performance. These disruptions are detrimental to a spectator's reception of the work because details within the work are missed, causing the choreographer's ideas to be improperly received. Because a dance performance will never be repeated identically again, the absence of these details can often leave spectators to misinterpret the true meaning of the work.

EXHIBITION

The choreography for our research project was inspired by common technological devices and their effects on social interactions. Dance majors at Texas A&M University performed the choreography on March 5, 2020 (**Figure 1**). The first section of the dance introduced everyday life with technology. As the section progressed, the dancers became engrossed with their devices and their physical interactions ceased to exist. In the second section, the dancers introduced a new idea of fixed patterns and routines caused by technological interruptions. A few dancers broke free from their distracted routines and attempted to pull others from their trances. While some individuals escaped technology's grasp, others remained trapped.

The lighting for this piece conveyed the physical isolation and distracted routine caused by technology. This was completed by changing the level of the lights, and the color of the background screen to match the mood of the sections in the piece. At the beginning of the performance, the lights moved with the dancers. However, as the piece became somber and the dancers became interrupted, the lights separated the dancers from each other. The piece ended with the lights in the same orientation as the beginning to show that technology traps us in a trance-like routine.

The costumes chosen for this piece were based on the idea of unison and everyday individuals. The dancers represented mundane individuals who continue the same routine due to technology encapsulating their lives. The dancers wore plain black leggings and white long-sleeved shirts to better represent the idea of technology creating a monotonous life for individuals. Monotony is demonstrated by the lack of color in the costumes, which mirrored the aesthetics of technological devices. The unison of the costumes signified the choice we made to prevent one dancer from standing out among the rest, which shows a sense of normalcy and simplicity.

A poster was created to advertise the live performance. Scott Shellhamer's *Distractions* (n.d.), as shown in **Figure 2**, is the image used for the background.[6] The interpretation of the art and the colors used throughout the painting provided the basis for the selection of the piece. Our interpretation of the art is that an individual's attention can be focused on an entire array of possibilities; however, when technological devices distract a person, the number of possibilities decreases and a person is less likely to socially engage with the others around them. This concept is represented by the black box in the artwork because it draws a spectator's focus from the details in the white background to the center of the piece.

The survey completed after the performance consisted of short-answer and rating scale questions. Respondents were asked to rate their magnitude of enjoyment of the piece, their ability to focus on the piece, and their ability to find the meaning behind the work. These questions were rated on a scale of one to seven, where a one represented lower results and seven represented higher results. For example, when a respondent was asked to rate their enjoyment of the piece, a higher result indicated that they had a more positive response to the work.

Certain audience members were planted to cause distractions. These spectators sent and received text messages, used computers, received phone calls, examined smartwatches, and listened to music through headphones. These pre-selected participants were distributed throughout the audience and were instructed when to engage with their devices to optimize the disruptive effects.

DISCUSSION

During the performance, the researchers were able to witness the effects of technological distractions on a live performance setting. According to audience member feedback, the occurrence of disruptions, such as music through headphones, text messages, phone calls, talking into a smartwatch, and typing on a laptop, caused them to turn around, begin conversations with other spectators, and pull out their own devices.

Our first research question aimed to investigate how the effects of technology could be conveyed through dance. Throughout the Q&A session there were several questions regarding choreographic movements that were prevalent throughout the work. Based upon the verbal feedback from audience members, the movements most effective in representing the interactions between individuals and devices were those where the dancers rounded their shoulders and glanced towards their wrists, those that included continuous movement of the hands, and those that featured darting motions using the arms. The rounded shoulders with glances toward the wrists portrayed the change in posture resulting from looking down at devices, such as a smartwatch. The continuous movement of the hands represented the monotonous routine people are drawn into due to the addictive nature of technological devices. Darting motions using the arms suggested the urge individuals feel to send text messages, images, or videos rather than physically interacting with the individuals around them. Upon discussion of these various choreographic elements, the audience successfully identified movements that represented the interactions between individuals and technology.

Our second research question aimed to investigate the effects of an audience's attention to a dance

Figure 2. *Distractions. Artwork by Scott Shellhamer.*

performance with technological interruptions present. Upon examining the results of surveys from 24 participants, 20 participants were successfully distracted from the performance. Spectators were considered distracted if they selected a response of 4 or higher. The average response from participants was 5.125. In addition, one audience member stated that they were interrupted by "phone calls, people talking, phone screen lights, someone le[aving] the room, people turning [their] heads to look at distractions, [and their] internal monologue thinking about the distractions." The survey results showed that audience members were most disrupted by the music playing through headphones and the phone calls. The music playing from the headphones varied greatly from the music used for the choreography. This variance of music caused the audience's attention to be pulled from the piece towards the abnormal music. In addition, the audience member who received phone calls walked across the front of the stage, visually obstructing audience members from the piece. Furthermore, participants were affected by the reactions of their fellow spectators to the distractions. The constant turning of heads, whispers, and interacting with personal devices caused other audience members to break their attention away from the choreography.

...THE AUDIENCE SUCCESSFULLY IDENTIFIED MOVEMENTS THAT REPRESENTED THE INTERACTIONS BETWEEN INDIVIDUALS AND TECHNOLOGY.

Although 20 audience members claimed to lose focus due to the planted distractions, 12 audience members of the total 24 claimed to easily focus back on the performance. These results contradicted our expectations because based upon a study conducted by Thorton, Faires, Robbins, and Rollins (2014), the mere presence of a cell phone was distracting enough to diminish an individual's results on an attention task.[7] Upon analysis, spectators may have refocused easily due to their ability to tune out the distractions. Based upon research conducted by David, Kim, Brickman, Ran, and Curtis (2014), sounds emitted from technological devices were easily tuned out because the subject could continue dedicating attention to the task at hand.[8] One audience member from our research study stated that they "tune out things like that often, but [they] were annoyed." The prevalence of technological devices within society can potentially cause their effects to be easily ignored. The various lights and sounds emitted from devices have become such an integral part of society that although they are noticed, they are easily disregarded.

In summary, the audience was able to identify how some of the choreographic movements portrayed the relationship between humans and devices. Also, distractions planted by the choreographers were successful in diverting the spectators' attention from the choreographic work during the live performance setting. The main limitations of the research were the small participant numbers and invalid responses to the survey due to confusing wording of the questions. For example, one of the questions on the survey asked "how easy did you manage to focus back to watching the dance once you found that you had been distracted," and one participant answered "yes." Although that survey question was implied to be a short answer, for future research we could word it to say "please describe how easily you were able to focus back to the piece after having been distracted." In the future, this research could inspire other ideas about the usage of technology within dance. Moving forward, the effects of technological distractions on dancers and non-dancers in specific situations could be investigated. Due to dancers having to spend time away from technology while participating in dance classes, it could be hypothesized that dancers might have a better ability to overcome interruptions from devices than non-dancers.

Although our research centered on dance, the concepts and results are applicable to daily life. Walking, driving, and studying are common tasks associated

with a prevalence of technological distractions. These disruptions may be the cause of decreased performance and social engagement. The aim of this research was to bring awareness to how easily audience members are distracted from live performances; however, we hope these realizations can be translated to other aspects of life and motivate individuals to put down their devices to provide undivided attention to the task at hand.

ACKNOWLEDGMENTS

We would like to thank Alexandra Pooley for being a constant guide through our research study. Thank you for your commitment and focus to our study. You have been a true blessing for us through this process. We would also like to thank our dancers for their passion and patience through our choreographic process, and our amazing crew for their dedication and hard work to complete the performance part of our research study. Thank you to everyone who helped us reach our goal.

REFERENCES

1. S. F. Persada, B. A. Miraja, and R. Nadlifatin, "Understanding the Generation Z Behavior on D-Learning: A Unified Theory of Acceptance and Use of Technology (UTAUT) Approach," *International Journal of Emerging Technologies in Learning* 14, no. 5 (2019): 20–33, **https://doi.org/10.3991/ijet.v14i05.9993**.

2. B. Thornton, A. Faires, M. Robbins, and E. Rollins, "The Mere Presence of a Cell Phone May be Distracting," *Social Psychology* 45, no. 6 (2014): 479–88, **https://doi.org/10.1027/1864-9335/a000216**.

3. P. David, J. H. Kim, J. S. Brickman, W. Ran, and C. M. Curtis, "Mobile phone distraction while studying," *New Media & Society* 17, no. 10 (2014): 1661–79, **https://doi.org/10.1177/1461444814531692**.

4. Y. F. Chen and S. S. Peng, "University Students Internet Use and Its Relationships with Academic Performance, Interpersonal Relationships, Psychosocial Adjustment, and Self-Evaluation," *CyberPsychology & Behavior* 11, no. 4 (2008): 467–49, **https://doi.org/10.1089/cpb.2007.0128**.

5. J. M. Richardson, "Powerful devices: how teens' smartphones disrupt power in the theatre, classroom and beyond," *Learning, Media & Technology* 39, no. 3 (2013): 368–85, **https://doi.org/10.1080/17439884.2013.867867**.

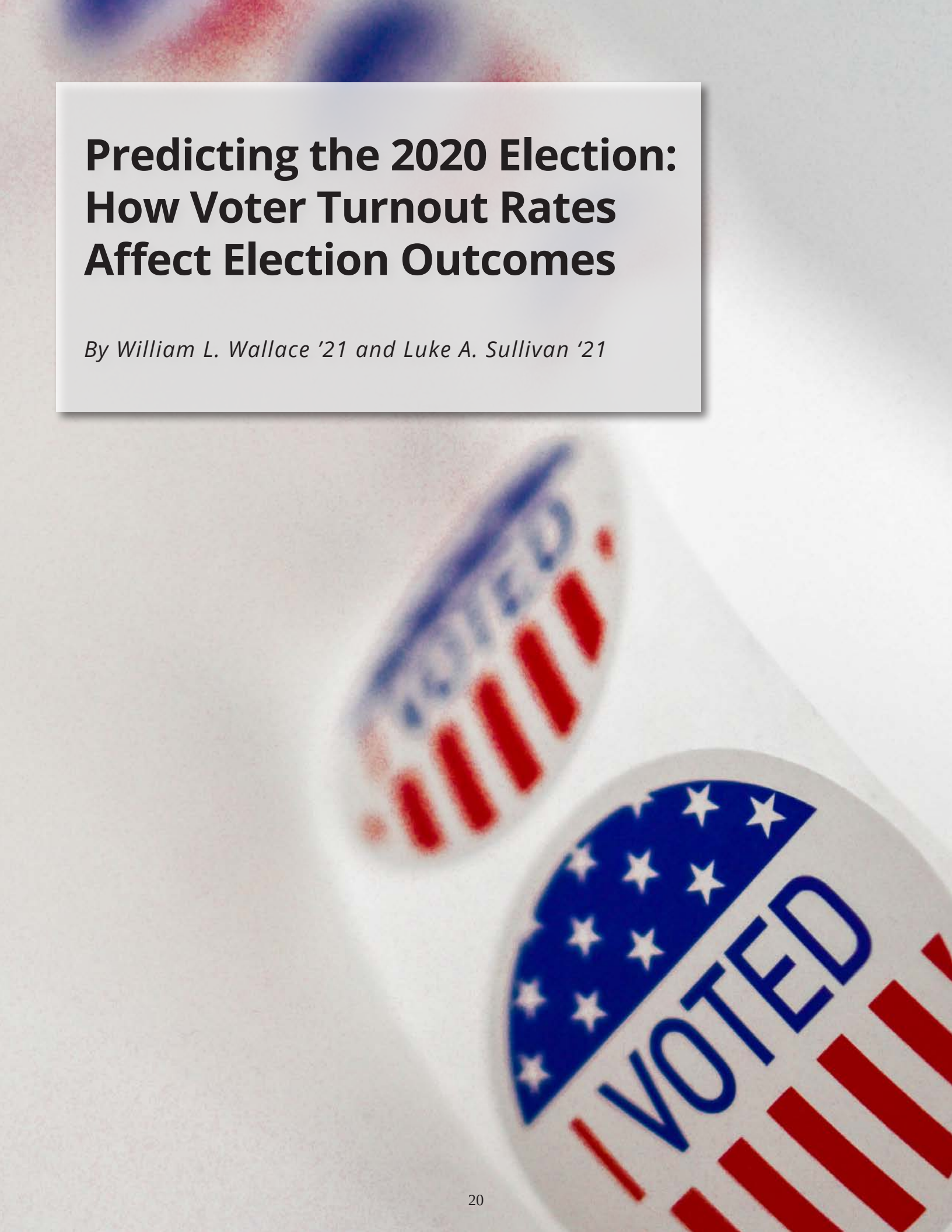
6. Scott Shellhamer, *Distractions*, n.d., Painting, Saatchi Art.

7. Thornton, Faires, Robbins, and Rollins, "The Mere Presence of a Cell Phone," 479–88.

8. David, Kim, Brickman, Ryan, and Curtis, "Mobile phone distraction," 1661–79.

Predicting the 2020 Election: How Voter Turnout Rates Affect Election Outcomes

By William L. Wallace ’21 and Luke A. Sullivan ‘21



INTRODUCTION

Every election cycle, campaigns spend billions of dollars trying to win voters to their side of the political aisle.[1] Since the United States national election turnout rate is, on average, close to 50%,[2] many statewide elections vary widely in their participation rates. This wide variation motivates us to ask and measure whether one political party performs better than the other when voter turnout rates are high. Put simply, will the Democratic Party or Republican Party be more likely to win an election if a high percentage of the eligible voter population votes? Our research measures the variation in statewide elections for a correlation between high voter turnouts and one party winning the election.

Since 1992, Republicans have won a single presidential election with regards to the popular vote. In the years 2000 and 2016, both Republican candidates lost the popular elections but took the presidency due to the Electoral College system. If we were to measure only the popular outcomes of each state's elections, how would Republican candidates fare against Democratic candidates in statewide popular races?

In Arend Lijphart's paper, "Unequal Participation: Democracy's Unresolved Dilemma," he discusses the problems surrounding low voter participation in democracies. Lijphart asserts, low voter participation "means unequal turnout that is systematically biased against less well-to-do citizens" and "unequal turnout spells unequal political influence."[3] Assuming Lijphart's assertions are correct, there should be a traceable correlation between voter turnout and election outcome. We hypothesize, as more people turn out to vote, the Democratic candidates' odds of winning will increase.

...MANY STATEWIDE ELECTIONS VARY WIDELY IN THEIR PARTICIPATION RATES.

METHODS

Regressions are models used in statistics to determine which independent variables affect the dependent variable and by how much. Regressions allow us to determine whether the independent variable has a relationship with the dependent variable as well as test for statistical significance.

To examine how election outcomes correlate with voter turnout, we ran a regression measuring the 50 states' state-wide election outcomes for their highest office for the 2008, 2010, 2012, 2014, 2016, and 2018 elections as the dependent variable. The regression's independent variables include the Voting Eligible Population (VEP) percentage that voted in each state during each election,[4] the GDP of each state during each election year,[5] an indicator variable for whether each state had voter ID restrictions at the time of the election,[6,7] and another indicator variable representing election year. Using data from Ballotpedia and the National Governors Association, we were able to find election outcomes for the statewide elections in our sample.[8,9,10] To generate a regression equation (**Equation 1**), each of the variables were assigned to a symbol (**Table 1**) and multiplied by a coefficient provided by the regression.

Equation 1. *OLS Regression Equation*

$$Y_{it} = B_0 + B_1X_{1it} + B_2X_{2it} + B_3X_{3it} + Y_1D_1 + Y_2D_2 + Y_3D_3 + Y_4D_4 + Y_5D_5 + \epsilon_{it}$$

For all the elections in our dataset, we recorded the outcome of the highest office on the ballot for each state that election cycle. If it was a presidential election year, we recorded which party won the state's vote for president. For midterm elections, we recorded the outcome of the governor's election. Since not every state elects a governor during midterm elections, we looked at the senate election outcome if there was no governor race. In years where both a governor and a senator were up for election, we recorded only the governor's outcome. If no gubernatorial nor senate election took place during the midterm election, we omitted the state for that year since there was no comparable state-wide election that took place. After the omissions our sample size was n = 278.

Table 1. *List of Variables with Definitions.*

Independent and Dependent Variables in the Regression		
Independent Variables		
X_{1it}	Voting Eligible Population (VEP) % that voted in that state during that election	
X_{2it}	Indicator variable, if an ID is required to vote in that state during that election	
		$X_{2it} = 1$, there are voter ID restrictions in that state during that election
		$X_{2it} = 0$, there are no voter ID restrictions in that state during that election
X_{3it}	State's annual GDP during the election year, measured in millions of dollars	
D_1	Indicator variable for time, 1 if 2008	
D_2	Indicator variable for time, 1 if 2010	
D_3	Indicator variable for time, 1 if 2012	
D_4	Indicator variable for time, 1 if 2014	
D_5	Indicator variable for time, 1 if 2016	
Dependent Variable		
Y_{it}	Indicator variable, probability of Democratic candidate winning the highest election in the state	
		$Y_{it} = 1$, Democrat won race
		$Y_{it} = 0$, Republican won race

We chose to use data from national election outcomes for each state because they are the most high-profile and expensive elections. By including the senate and gubernatorial races, we added more political candidates, so our data was less reliant on individual political personalities swaying election outcomes.

The focus of this paper is on voter turnout's correlation with election outcome, making the most important independent variable, X_{1it}, the percentage of eligible voters who voted in a state's election. The B_1 coefficient (**Equation 1**) is multiplied by X_{1it} and gives us the change in probability of a Democratic candidate winning the election as an additional 1% of the eligible voting population turns out to vote.

The dependent indicator variable, Y_{it}, represents the estimated probability of a Democratic candidate winning their election. Since Y_{it} is an indicator variable, Y_{it} can only represent values between 0 and 1. For example, if the calculated Y_{it} value for a state's election equals 0.551, then there is a 55.1% chance the Democratic candidate will win the election.

Hypotheses

- Null hypothesis: $H_0: B_1 = 0$
- Alternative hypothesis: $H_1: B_1 \neq 0$

The null hypothesis states that if B_1 equals zero, there is no statistical correlation between the variables X_{1it} and Y_{it}. In other words, if we can disprove the null hypothesis with the regression statistics, we will know there is a statistically significant correlation between voter turnout and election outcomes. Whether the correlation of voter turnout and the probability of a Democratic candidate winning is positive or negative, depends on the sign of the B_1 coefficient.

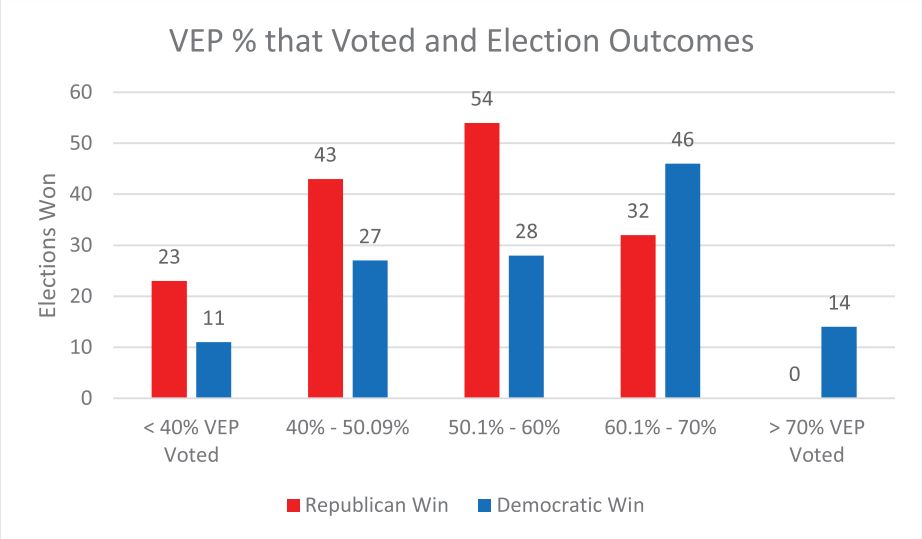


Figure 1. *Graph of election outcomes arranged by Voting Eligible Population (VEP) percentage that voted.*

RESULTS

Seen in **Figure 1**, when voter turnout is lower than 60%, Republican candidates won 54 more elections than candidates in the Democratic Party. However, once the percentage of voters surpasses 60%, the opposite is true; candidates in the Democratic Party have a clear advantage over those in the Republican Party.

The main takeaways from our analysis come from the sections of the graph where voter turnout is at its highest and when it is at its lowest. At the low-end of the graph, Republicans win close to twice as many elections as Democrats, but when the highest percentage of voters turn out, Democrats are significantly more likely to win the election. Republicans did not secure a single statewide victory when over 70% of the eligible voters turned out to vote.

Using the regression, we calculated probabilities of either political party winning the top statewide election in Michigan (**Figure 2**). We chose to calculate Michigan's election outcome probabilities because it is one of the few states that has reliably flipped back and forth between Democratic and Republican control in the last decade and we wanted to see if our model would correctly predict its outcomes. In the elections where the probability of a Democratic candidate winning the race exceeded 50%, like the elections of 2008, 2012, and 2018, the outcome of the elections matched our regression model's prediction.

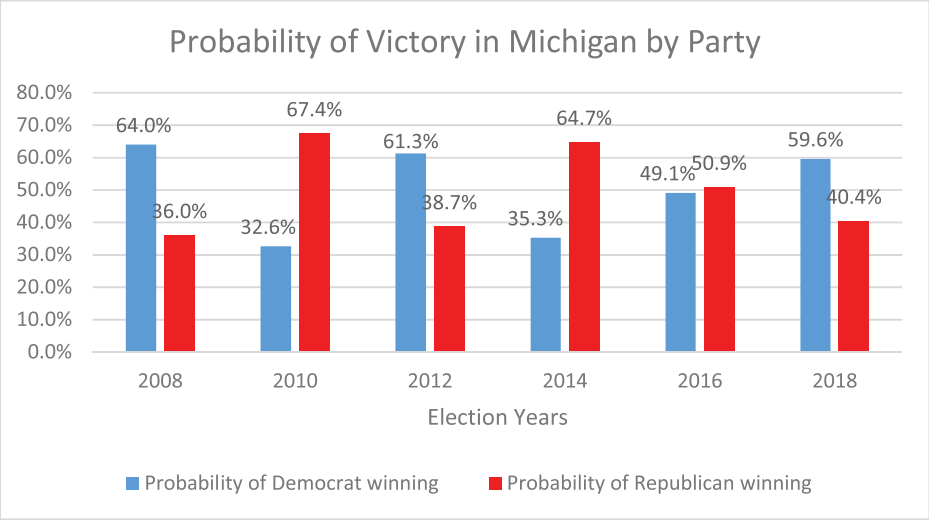


Figure 2. *Graph of the probabilities of either party winning the highest statewide election in Michigan.*

EVEN WITH THIS NARROW MARGIN OF VICTORY, OUR MODEL CORRECTLY PREDICTED THE OUTCOME OF THE 2016 PRESIDENTIAL ELECTION IN MICHIGAN.

Conversely, in the three years our regression model predicted a Republican was more than 50% likely to win the election, the model was correct, and a Republican won. Interestingly, our model correctly predicted the election outcome of 2016, when Democrats lost to Republicans by 0.23% of the vote in Michigan. Even with this narrow margin of victory, our model correctly predicted the outcome of the 2016 presidential election in Michigan.

When finding correlations within large data sets such as election and voter data, it is important to determine if the correlations between the dependent and independent variables are statistically significant. For a result to be statistically significant, there must be a high likelihood the null hypothesis is false, in this case, H_0: $B_1 = 0$. We tested for statistical significance in several ways.

The first way we tested the null hypothesis was to see if the P-value we calculated was less than 0.001 (this means there is less than a one in one thousand chance of the correlation not being statistically significant). For our regression, we calculated 0.0000023683 as our P-value for B_1 and can reject the null hypothesis on this measure alone.

The second way we tested our regression for statistical significance was by seeing if a zero is included in the 99% confidence interval for that variable. If a zero is included in the 99% confidence interval, it is implied that zero is a true possibility for the difference in values. But, since there is no zero included in the confidence interval, it means we do not believe zero is a reasonable possibility for the differences in outcomes and can reject the null hypothesis.

The final variable we used to test for statistical significance within our model was the T-statistic. The T-value measures the size of the difference relative to the variation in the sample data. Put simply, the T-value is the calculated difference in units of standard error. This means the greater the T-value, the more likely we are to reject the null hypothesis. For our model to be statistically significant at the 99% confidence level, our T-value must be greater than 2.576. Since our model's T-value equals 4.82, we can also reject the null hypothesis using this measure.

Statistical Outcomes

- If the eligible voting population that votes increases by 1%, the likelihood of a Democratic candidate winning the race increases by 2.13%. This is statistically significant at the 99% confidence level.
- For our x_2 coefficient, the value is negative and is statistically significant at the 95% confidence level. When voter ID laws are in place, it is less likely a Democratic candidate will win the election.

CONCLUSION

The results of our research show there was a positive relationship between voter turnout and the likelihood that a candidate in the Democratic Party would win an election. Since many US elections do not pass 60% participation,[11] the threshold where candidates in the Republican Party perform best, a potential solution for the Democratic Party would be to expand the number of people who vote.

IF THE ELIGIBLE VOTING POPULATION THAT VOTES INCREASES BY 1%, THE LIKELIHOOD OF A DEMOCRATIC CANDIDATE WINNING THE RACE INCREASES BY 2.13%.

The results of our study also showed that there was a statistically significant negative correlation associated with the state having voter ID restrictions at the time of the election and the likelihood that a Democratic candidate wins. For the Republican Party, it would make sense to ensure every state has some form of voter ID restrictions since, statistically, it will only hurt the Democratic Party. The correlation between voter ID restrictions and the increased probability of a Democratic candidate losing could be a result of the average Democratic voter being less likely than the average Republican voter to have a form of ID. Without further data and analysis, we can only speculate as to why this is.

Finally, this research paper shows, with statistical significance, that as more of the population turns out to vote, it is more probable that a candidate in the Democratic Party will win a state-wide election.

The motivation for researching this topic was to determine if there is a direct relationship between voter turnout and election outcomes. If we had more time to expand this research project in the future, we would gather a sample that included all 435 House of Representative races that occur every other year. This would give us 2,610 observations to add to our regression and would likely give us far more accurate results. Aside from growing our sample size, we are also very interested in how COVID-19 will affect voter turnout in the 2020 election. While some states are rushing to prepare mail-in ballots, New York has already decided to cancel its primary election outright. Since the pan-

demic hit the United States in January and elections are not until November, states will have to see what public health advocates believe is the right move to slow the virus. With so little certainty about what is to come this year, we believe the results after this election could significantly shift our model.

REFERENCES

1. "Cost of Election," *OpenSecrets.org*, **https://www.opensecrets.org/overview/cost.php?display=T&infl=NHighton**.
2. B. Highton, "Voter Registration and Turnout in the United States," *Perspectives on Politics* 2, no. 03 (2004), **https://doi.org/10.1017/s1537592704040307**.
3. A. Lijphart, "Unequal Participation: Democracy's Unresolved Dilemma," *The American Political Science Review* 91, no. 1 (1997): 1–14, **https://www.jstor.com/stable/2952255**.
4. M. McDonald, "Voter Turnout Data," *United States Elections Project*, **www.electproject.org/home/voter-turnout/voter-turnout-data**.
5. "Gross Domestic Product by State, Advance 2014 and Revised 1997-2013," *BEA*, **https://apps.bea.gov/regional/histdata/releases/0615gsp/index.cfm**.
6. "Voter Identification Laws by State," *Ballotpedia*, **https://ballotpedia.org/Voter_identification_laws_by_state#Details_by_state**.
7. Wendy, Underhill and Dan Diorio, *Voter ID History*, **http://www.ncsl.org/research/elections-and-campaigns/voter-id-history.aspx#History**.
8. "Presidential Voting History by State," *Ballotpedia*, **https://ballotpedia.org/Presidential_voting_history_by_state**.
9. "Elections," *National Governors Association*, **https://www.nga.org/governors/elections**.
10. "United States Senate," *Ballotpedia*, **https://ballotpedia.org/United_States_Senate**.
11. B. Highton, "Voter Registration and Turnout in the United States."

Raman Spectroscopy: Protecting Animal and Human Health in One Dimension

By Daniel Andres Garza '20

INTRODUCTION

The animal feed industry in the United States is the foundation for contact between people from all around the world and animal products. As demand for animal products increases, so does the importance of animals remaining healthy in order to keep a steady supply of the products. This can be maintained by ensuring that animals are receiving adequate amounts of nutrients in their diets. Vitamins in animal feed play a significant role in the dietary supplementation of animals, so it is important to satisfy their optimal nutritional requirements in an effort to keep them healthy.[1] Vitamins also benefit animal health by contributing to the development of a higher metabolic rate and immunity to bacterial infections.[2] Although two types of vitamin categories exist—water-soluble vitamins (WSVs) and fat-soluble vitamins (FSVs)—WSVs are the main focus of this research because they are easily absorbed and excreted by animals. WSVs also play important roles in animal health by helping maintain nervous system structure and inactivating harmful free radicals produced under various stress conditions.[3] Making sure animals ingest sufficient amounts of nutrients to increase their immunity to diseases is important so humans can have little to no risk of contamination when consuming animal-sourced food. Due to the increased demand for animal products, the search for a more rapid and less expensive classification and quantification method for detecting WSVs in animal feed has become a priority in regulatory research.[4] This new method will ensure that vitamins can be identified more easily with a lower risk of prediction error.

Of the analytical methods applied for WSV analysis, gas and liquid chromatography combined with mass spectroscopy are commonly used for animal feed.[5] Although these existing standard wet-chemical methods are accurate, reliable, and reproducible, they have major drawbacks such as being time consuming, labor intensive, expensive, and complex.[6] The impracticality of these methods has increased the demand for a more rapid and cost-efficient analytical method with high selectivity and sensitivity for WSVs in animal feed. According to the Food and Drug Administration, the reference daily intake of WSVs for animals needs to be met in animals designated for human consumption.[7] Proper nutrient intake can be evaluated and ensured through the precise quantitative and qualitative analysis of vitamin concentrations in animal feed. Therefore, there has been a high demand from farmers, researchers, and meat processors for the development of a simple, rapid, and inexpensive new technology for detection and quantification of WSVs in animal feed and human food for the effective analysis of large samples.

Of emerging and existing technologies, spectroscopic techniques including near-infrared spectroscopy (NIR), mid-infrared spectroscopy (MIR), and Raman spectroscopy are promising and preferred as new approaches to the analysis of animal feed products due to their many desirable features such as a lack of required sample preparation and pretreatment, low cost, easy operation, analytical rapidity, non-destructive detection, high specificity, and the potential development of computerization.[8] Surface enhanced Raman Spectroscopy (SERS) is one of many advanced Raman spectroscopic techniques which can enhance a weak inelastic-scattering Raman effect of molecules adsorbed on metal particles. A Raman effect is a shift in light frequency caused by the vibration of sample molecules being stimulated with a laser pulse from a Raman spectrometer. The shift in frequency comes from a change in the energy level of the chemical bonds present in each individual molecule of a feed sample. The shift of each molecule provides a singular detection image, thus allowing the classification and quantification

A RAMAN EFFECT IS A SHIFT IN LIGHT FREQUENCY CAUSED BY THE VIBRATION OF SAMPLE MOLECULES BEING STIMULATED WITH A LASER PULSE FROM A RAMAN SPECTROMETER.

of Vitamin B samples, in the case of this research project. The effect also provides the unique identification of each vitamin sample for further processing. SERS enhances the signal of the sample through the addition of gold nanoparticles to the solution. It does not change the profile of the spectra identifying each vitamin, but increases the intensity of the reading, allowing for easier differentiation among samples of different vitamin concentrations. SERS provides higher sensitivity and specificity to supply comprehensive information on target molecules. The enhancement level and feasibility of the SERS technique are largely dependent on its preparation methods, which include chemical reduction of metallic ions and electrical dispersion of nanoparticles.[9] Such a SERS technique can be used as a screening method for routine use and on-site analysis for rapid detection and quantification of the WSVs in animal feed samples.

The main objective of this research project is to explore the feasibility of Raman spectroscopic technique as an alternative analytical tool to develop a simple, low-cost, and non-destructive method for rapid identification and determination of three water-soluble vitamins in animal feed. The results and implications of the findings from the study may provide useful information on the efficiency and applicability of SERS for use as a processing technique in the animal feed industry. The developed method is ultimately aimed at ensuring animals and humans are receiving adequate nutrition from their diets.

METHODS

This project worked with three water soluble vitamins (WSVs) of interest: thiamine, pantothenic acid, and niacinamide. The animal feed samples spiked with different concentrations of WSVs were collected using a series of extraction media. Gold nanoparticles (AuNPs) are the main component of SERS measurements. AuNPs were prepared using kinetically controlled seed nanoparticles (**Figure 1**) and then mixed with the sample extracts to collect Raman spectra. All samples were tested a minimum of three times for quantitative and qualitative analysis. The mixture solution was placed onto a microscope slide and scanned in

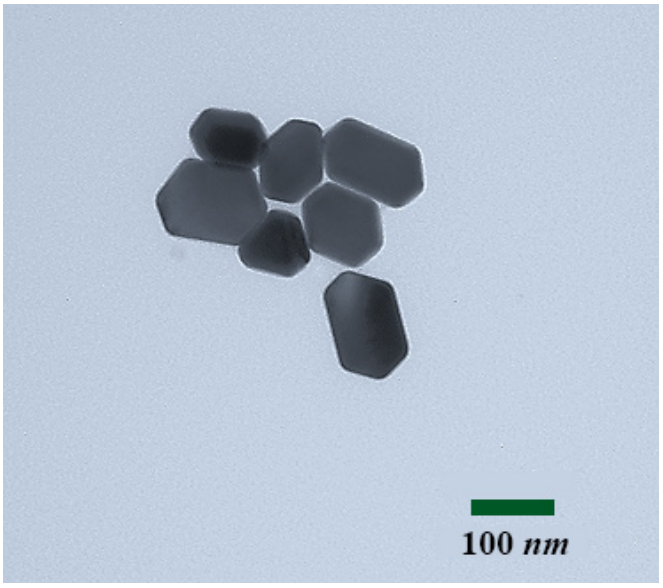


Figure 1. *Transmission electron microscopy (TEM) image of gold nanoparticles (AuNPs) synthesized by kinetically controlled seed nanoparticles for analysis of water-soluble vitamins (WSVs) in animal feed.*

a controlled environment with close monitoring of environmental and machinery temperature changes which could affect data production and quality. The collected spectra were co-added to yield a representative average spectrum of the sample with different concentrations of WSVs.

The Raman spectra for all spiked samples were background-corrected at the time of acquisition and further mathematically preprocessed to develop statistical models for classification and quantification of WSVs in the samples. The qualitative analysis of this project consisted of running a visual comparison of peaks corresponding to each vitamin sample. The quantitative analysis was conducted using statistical approaches that facilitated the interpretation of data produced. All preprocessed spectra were converted to American Standard Code for Information Interchange (ASCII) format that would be easily interpreted by means of mathematical pretreatments. Spectra were further processed using SAS statistical software methods for final clarification of results.

Classification and quantification models were developed using common chemometric methods including linear discriminant analysis (LDA), k-nearest neighbor (KNN), multiple linear regression (MLR), and

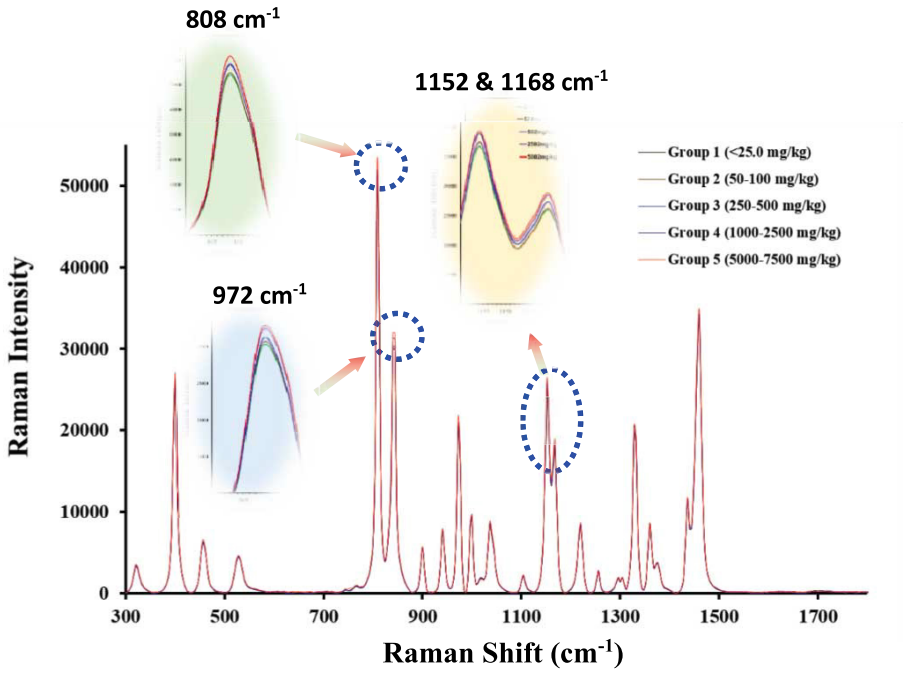


Figure 2. *Average Raman spectra of feed samples containing different concentrations of thiamine.*

partial least squares regression (PLSR). These statistical models were branched into categories associated with the additional concentration of WSVs in feed samples and predicted values of correlation coefficients. Based on these evaluations, the best model suitable for classification of feed samples at different levels of the WSVs could be determined. Likewise, the best model for quantification of the WSVs in animal feed was selected based on root mean standard error of calibration (RMSEC), root mean standard error of prediction (RMSEP), and coefficient of determination (R^2) values using training and external validation datasets.

RESULTS

The Raman spectra showed unique characteristics for all three WSVs. The WSVs were classified and quantified according to their concentration in the samples. Figure 2 shows averaged preprocessed spectra of feed sample extracts representing five different concentration groups of thiamine. It was interpreted that Raman spectral variations were due to distinct thiamine concentrations in several Raman peak regions. As seen in Figure 2, although Raman intensity differences are not visually distinctive over the entire peak region, careful examination of the spectra clearly reveals Raman intensity proportionally correlated with thiamine concentration are displayed in several specific regions. Similar findings were also observed in pantothenic acid and niacinamide samples. The spectral variation between the spiking groups in some Raman peak regions is distinctive enough to produce the statistical models with high classification and quantification accuracy for analysis of WSVs in animal feed.

The statistical models for classification of WSV-spiked samples into predefined groups at different vitamin concentrations were developed using the chemometric methods mentioned above at the Raman shift region of 400–2,500cm^{-1}. The classification accuracy results of the chemometric models developed on the preprocessed spectra data of WSVs are presented in Table 1. The chemometric models developed on a training dataset demonstrated an excellent classification accuracy of 100% cross-validation analysis for all WSVs. However, when the calibration models were applied on a validation dataset, they showed the lower range of classification accuracy (75.0–91.7%). These classification results imply that SERS technique can be used as an alternative analytical tool to existing stan-

Table 1. *Correct classification rates of chemometric models developed on normalized spectral data for thiamine, pantothenic acid, and niacinamide in animal feed.*

Water soluble vitamins	Training dataset		Validation dataset	
	Actual	Prediction (% correct)	Actual	Prediction (% correct)
Thiamine	24	24 (100)	12	10 (83.3)
Pantothenic acid	24	24 (100)	12	11 (91.7)
Niacinamide	24	24 (100)	12	9 (75.0)

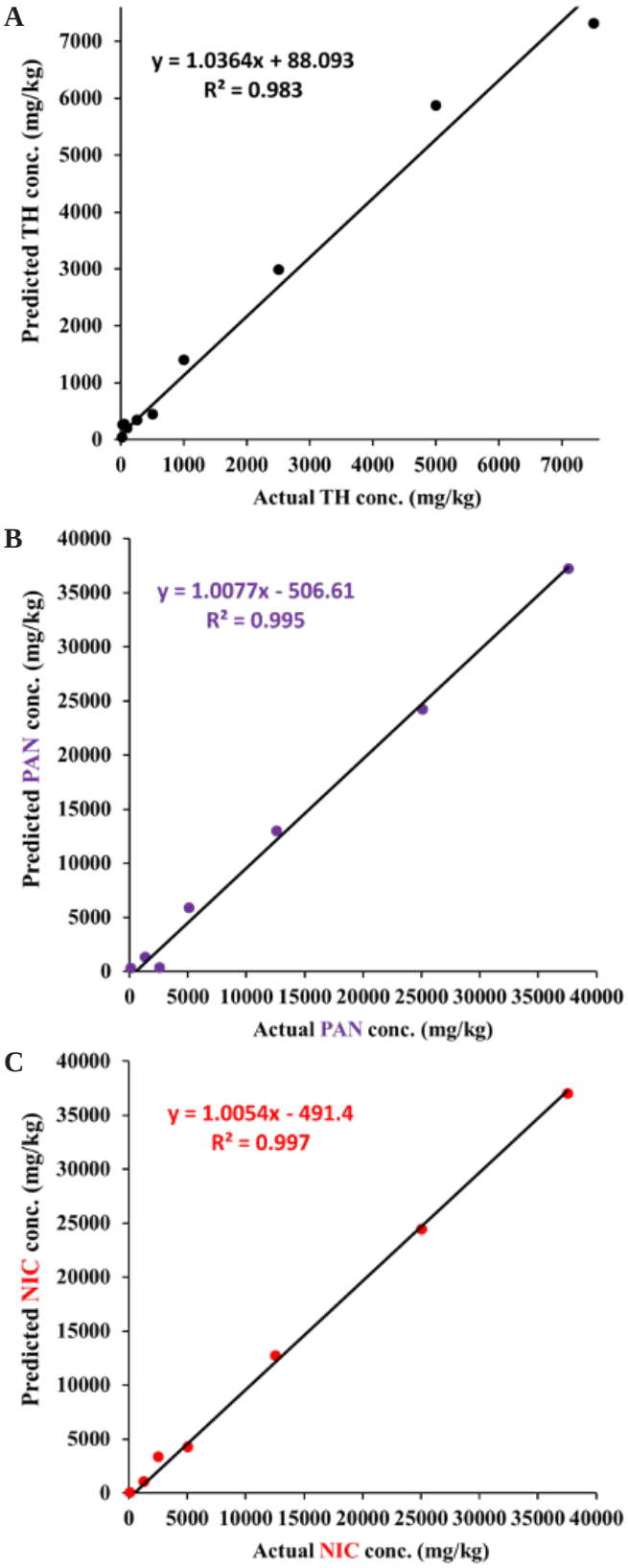


Figure 3. *Linear regression plots of multiple linear regression (MLR) chemometric models developed on SERS spectral data for* ***(A)*** *thiamine (TH),* ***(B)*** *pantothenic acid (PAN), and* ***(C)*** *niacinamide (NIC).*

dard wet chemical methods for a rapid screening and high-throughput analysis of samples containing WSVs in animal feeds.

The chemometric models for WSVs quantification were developed using the Raman shift range including the spectral regions and featured Raman peaks highly correlated with reference values. These chemometric methods are suitable to explain the relationship between the obtained SERS spectra and the concentrations of WSVs in animal feed by extracting the meaningful and critical information from even superimposed and overlapped Raman spectra.

Of the chemometric models for WSV quantification, MLR performed better than other models, displaying better regression quality, higher predictive accuracy, and lower prediction error rate. MLR models applied on the external validation dataset could explain a high degree of variation in SERS spectra data: 98.3% (R^2=0.983) for thiamine, 99.5% (R^2=0.995) for pantothenic acid, and 99.7% (R^2=0.997) for niacinamide (**Figure 3**). The slope of MLR models for the validation dataset also exhibited an excellent linearity in the ranges of 1.0054–1.0364. These values help establish the MLR method as accurate and reliable for quantitative analysis of WSVs in animal feed.

The accuracy of the classification and quantification models used in this project ensures dependable testing on other WSVs and potential expansion on a commercial scale. The definite predictability of these models is strong enough to be a resource for further value predictions, but there is still room for improvement so that validation dataset classification and MLR quantification methods can be more accurate. Increasing the accuracy of these methods can be done by implementing larger sample quantities and additional scanning of the current and new vitamins to have more data to input into the models.

CONCLUSIONS

In this research project, featured Raman bands associated with different levels of three water-soluble vitamins in animal feed were observed in several surface enhanced Raman spectroscopic regions. The

proposed SERS technique combined with select chemometric algorithms demonstrated its potential and feasibility as a simple, fast, and cost-effective analytical tool for early and reliable determination of the WSVs in animal feed. The developed statistical models for classification and quantification of WSV levels also showed a high classification accuracy and a low prediction error. The accuracy of these models may help substantially increase animal feed safety by providing reliable measurements of WSVs in the dietary supplementation for animals. Simultaneously, no misclassification of control samples with absence of WSVs was found. Thus, the advantages and benefits of the SERS technique observed in this research over conventional wet-chemical methods for selected WSVs justify its suitability and wide application for routine analysis and real-time monitoring of WSVs absent or too low in animal feed.

THE DEVELOPED METHOD IS ULTIMATELY AIMED AT ENSURING ANIMALS AND HUMANS ARE RECEIVING ADEQUATE NUTRITION FROM THEIR DIETS.

The SERS technique provides many promising features over conventional standard wet chemical methods and may serve as a very efficient and convenient tool to ensure the supply of sufficient amounts of nutrients. This will help increase animal immunity to diseases as well as improve the safety and quality of feed and food products. Ultimately, this research project has been useful for encompassing animal and public health into one dimension.

ACKNOWLEDGMENTS

I want to thank Dr. Kyung-Min Lee, Dr. Timothy Herrman, Megan Rooney, San Juana Luna, and the other chemists in the Office of the Texas State Chemist (OTSC) for their guidance and mentoring since the start of my journey at OTSC. They have made a tremendous impact in my life by not only teaching me optimal research techniques, but also keeping me focused on my goals and future endeavors.

REFERENCES

1. "CFR-Code of Federal Regulations Title 21," Food and Drug Administration, 2019, accessed March 11, 2020, **https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=101.9**.

2. R. Sapkota, L. Y. Lefferts, S. McKenzie, and P. Walker, "What do we feed to food-production animals? A review of animal feed ingredients and their potential impacts on human health," *Environmental health perspectives* 115, no. 5 (2007): 663–70.

3. Ibid.

4. K. M. Lee, T. J. Herrman, Y. Bisrat, and S. C. Murray, "Feasibility of surface-enhanced Raman spectroscopy for rapid detection of aflatoxins in maize," *Journal of Agricultural and Food Chemistry*, 62 (April 2014): 4466–74, **https://pubs.acs.org/doi/abs/10.1021/jf500854u**.

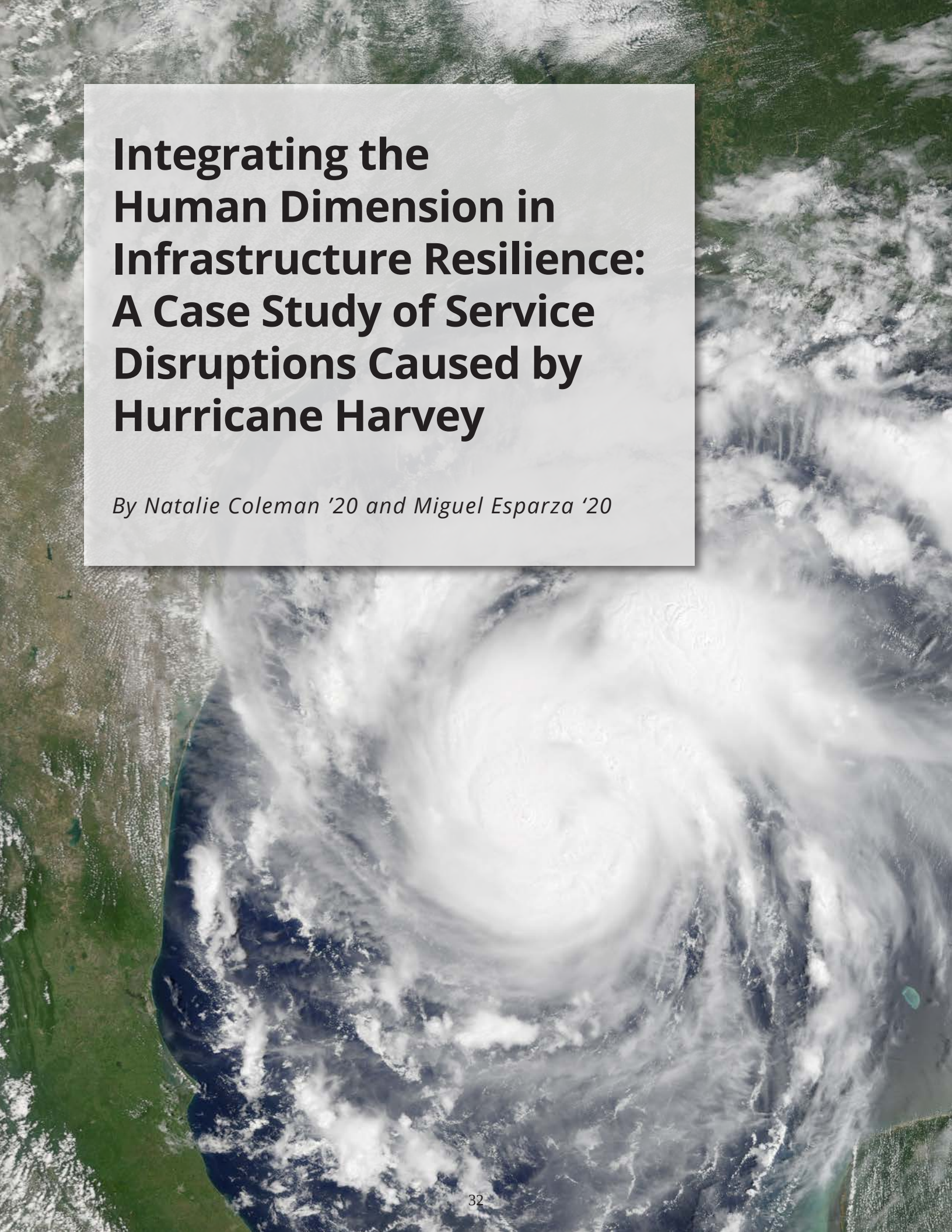
5. K. M. Lee, T. J. Herrman, and U. Yun, "Application of Raman spectroscopy for qualitative and quantitative analysis of aflatoxins in ground maize samples," *Journal of Cereal Science* 59 (January 2014): 70–8, **https://www.sciencedirect.com/science/article/abs/pii/S0733521013001653**.

6. Ibid.

7. "CFR-Code of Federal Regulations Title 21," Food and Drug Administration, 2019, **https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=101.9**.

8. Lee, Herrman, Bisrat, and Murray, "Feasibility of surface-enhanced Raman spectroscopy," 4466–74.

9. Ibid.



Integrating the Human Dimension in Infrastructure Resilience: A Case Study of Service Disruptions Caused by Hurricane Harvey

By Natalie Coleman '20 and Miguel Esparza '20

INTRODUCTION

Hurricane Harvey made landfall in southeast Texas in August of 2017. The Category 4 hurricane greatly impacted the region with a record rainfall of up to 48 inches.[1] The widespread flooding led to several disruptions in infrastructure systems, including fallen communication lines and contaminated water sources. Service disruption risks the well-being of community residents because they lack the proper resources to maintain their health, call for help, or return to normalcy. Given the increasing frequency and intensity of natural hazards, such as high wind speeds and flooding durations, future disasters will inevitably continue to disrupt infrastructure systems when people need these services the most.

Utility companies, policy makers, and emergency management leaders are making difficult decisions regarding the allocation of services during disasters. The majority of research on infrastructure resilience has focused on the physical vulnerabilities of these systems, but this approach neglects the social vulnerabilities surrounding the demand of these services.[2] For instance, civil engineers will invest in maintaining the functionality of infrastructure systems without fully recognizing the varying levels of hardship experienced in different geographic regions and by different sociodemographic groups in the event of a service disruption. This enhances social disparities and risk inequalities during disasters such as Hurricane Harvey. Mitigating these social impacts requires **resilient infrastructure,** or the ability to quickly recover to an acceptable level of service, which can holistically address the **vulnerabilities** of a community.

Currently, there is a need to prioritize the investment and restoration of infrastructure services to vulnerable populations, but inadequate information exists to fulfill this need.[3,4] Little is known about which geographical regions in a community or which sociodemographic groups would be most vulnerable to the impact of service disruption. Thus, the objective of this research is to integrate a much-needed human dimension into infrastructure resilience by determining (1) the most vulnerable regions and (2) the sociodemographic groups most impacted by the disaster-induced service disruptions. Our research hypothesized that households with the following socially vulnerable characteristics would be particularly vulnerable to service disruptions for various reasons:

H1: Households under the poverty line often have limited access to resources due to affordability concerns,[5] and thus have shown lower levels of preparedness.[6,i]

H2: Low-education households may struggle with understanding emergency plans about preparedness.[7,8]

H3: Minority households often have cultural barriers to receiving adequate resources because of institutionalized social systems and a reduced ability to negotiate with bureaucratic entities which lead to lower levels of preparedness.[9]

H4: Households with language barriers face similar issues to minority households. A language barrier can also affect the ability to receive and understand information about preparedness.[10]

H5: Households with elderly residents have physical vulnerabilities and a high dependence on guardians.[11]

[i] Preparedness has many definitions[6,7,8,9,10] according to disaster literature and is unique for each demographic group. This research defines low preparedness as a reduced time, ability, and information to obtain resources before disaster-induced service disruptions.

...THE ANALYSIS HAS THE POTENTIAL TO EFFECTIVELY PRIORITIZE SERVICE RECOVERY IN THE IMMEDIATE AFTERMATH OF A DISASTER...

To fill the gap of empirical understanding, our research examined the experienced hardship households faced from the communication and water outages caused by Hurricane Harvey. Hardship refers to the overall degree of difficulty that service disruptions cause on individual households. Statistical analysis in combination with descriptive and spatial mapping will bring unique insight on the impact of service disruptions and provide decision-makers with necessary tools for future infrastructure resilience plans.

...SOCIALLY VULNERABLE GROUPS WERE...LOCATED IN REGIONS OF HIGHER HARDSHIP.

METHODS

We collected both qualitative and quantitative data from surveys and information databases (**Figure 1**). First, a household survey was distributed to Harris County residents using Qualtrics, an online survey platform. The stratified sampling strategy was based on a census-representative panel to ensure that the collection of empirical data was diverse. The target demographic was residents over 18 years old who had directly experienced the service disruptions, meaning that the household did not evacuate before Hurricane Harvey arrived. Survey respondents were asked to answer questions related to their level of hardship from the service disruptions. This allowed the research to integrate the human dimension into the experience of service disruptions. Hardship was measured on a Likert-scale, with 1–2 being low hardship, 3 being neutral hardship, and 4–5 being high hardship. A total of 1,742 total responses were collected, and after filtering the responses for quality control, 1,052 were considered valid responses.

In addition to the survey data, census data was collected to describe the social background of the community. The variables included the number of households living below the poverty line, having education levels below a completed high school degree, and those with minority residents, language barriers, or elderly residents. Households were then mapped into different

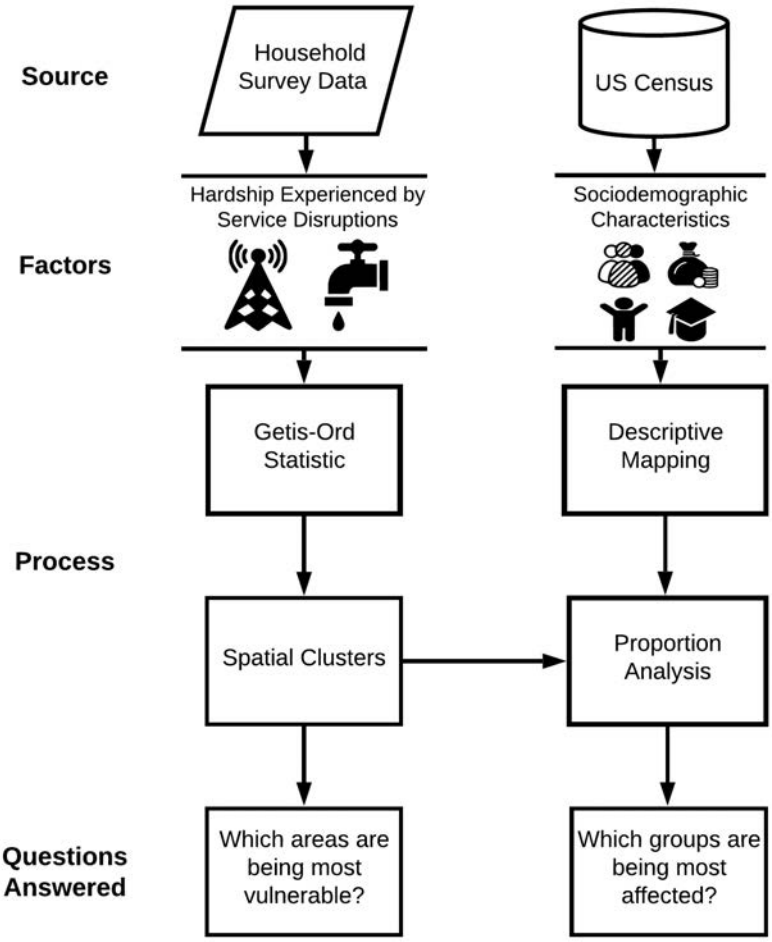


Figure 1. *Framework of research methodology.*

ZIP codes and divided on a scale of low to high social vulnerability using descriptive analysis.

To begin the statistical analysis, the results from the household survey were mapped using local spatial analysis. The research used Getis-Ord Statistic, or the G-statistic, to analyze emerging spatial patterns. This test identified significant clusters of households who shared a similar level of hardship to the infrastructure service disruption. Thus, the analysis has the potential to effectively prioritize service recovery in the immediate aftermath of a disaster and efficiently

create infrastructure resilience plans for future events. The G-statistic is defined by the following equation[12] (Equation 1):

Equation 1.

$$G_i = \frac{\sum_{j \neq i} w_{ij} x_j}{\sum_{j \neq i} x_j}$$

I = the identified ZIP Code

j = an identified neighboring ZIP Code

x_j = the level of hardship

w_{ij} = a spatial weight matrix of binary code to indicate adjacent neighbors

The results of the equation produced statistically significant (p-value < 0.05) clusters of hardship. The clusters are divided into two categories:

- **Hotspots** (High Hardship - High Vulnerability): ZIP Codes that have a high mean of hardship and are surrounded by other ZIP Codes with similar values. These clusters are more likely to be vulnerable to the service disruption.
- **Coldspots** (Low Hardship - Low Vulnerability): ZIP Codes that have a low mean hardship and are surrounded by other ZIP Codes with similar values. These clusters are more likely to be resilient to the service disruption.

The results of the G-statistic only produced spatial patterns, but these do not represent the underlying reasons for their occurrence. Thus, the research also compared the sociodemographic characteristics of the hotspots and coldspots for both infrastructure services using proportion analysis.

Proportion analysis explains whether the sociodemographic proportions between hotspots and coldspots are statistically significant. Based on the hypothesis, inputs of this test were the percentage of each socially vulnerable characteristic compared to the sum of the population according to US census data.[13]

RESULTS

Based on the descriptive mapping of the census data, Figure 2 shows that the eastern and northwestern areas of Harris County are characterized by high social vulnerability. The descriptive mapping also indicates which socially vulnerable groups overlap with each

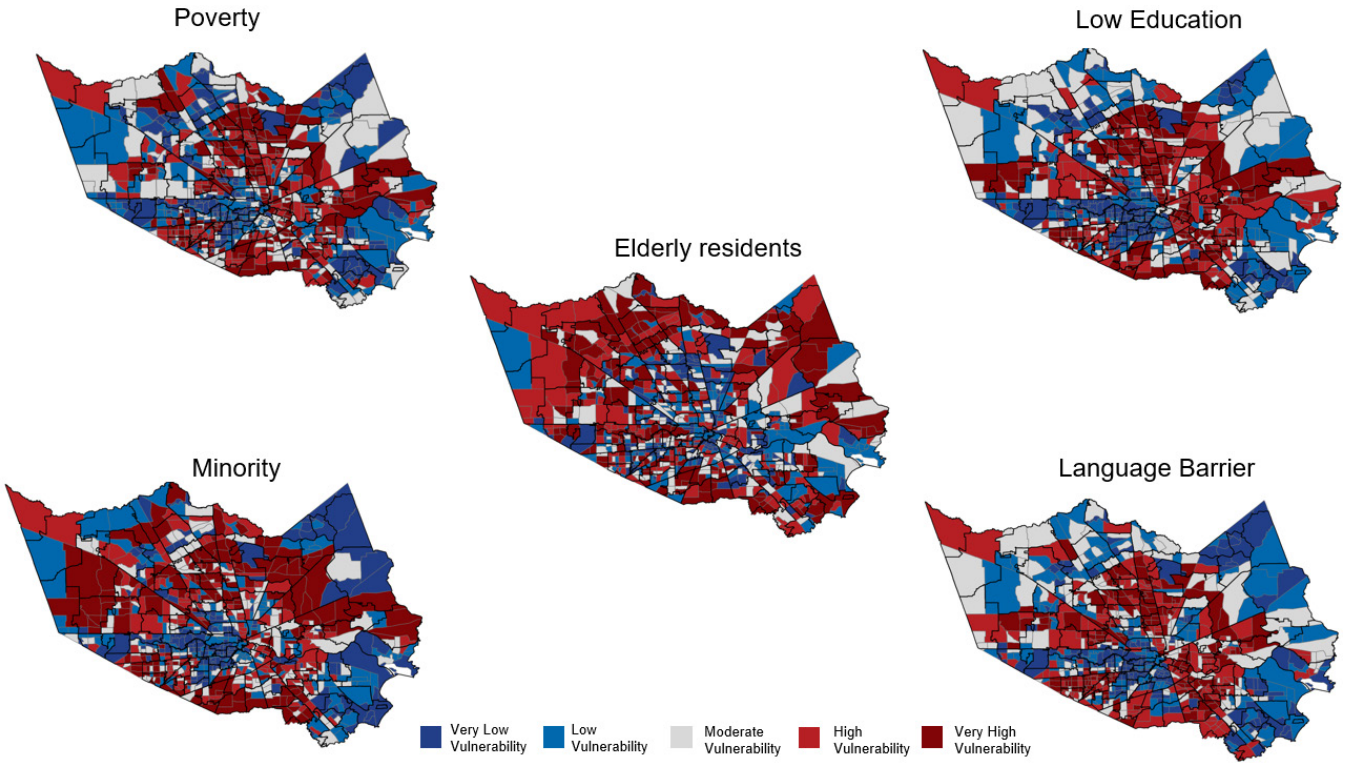


Figure 2. *Descriptive mapping of vulnerable sociodemographic features.*

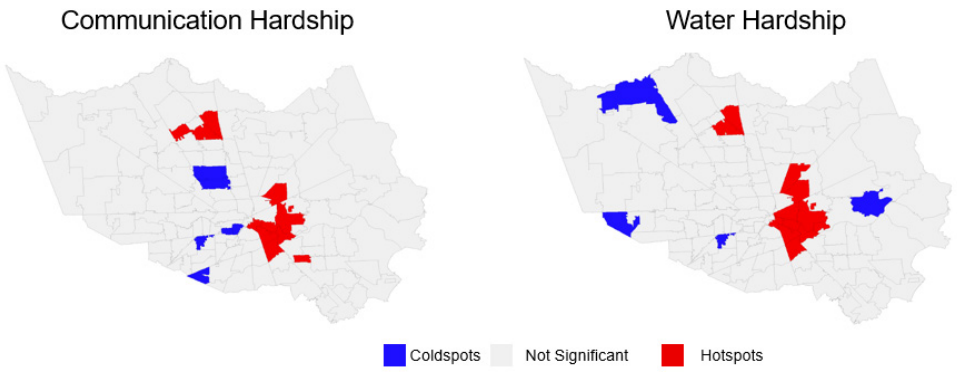


Figure 3. *Clusters of communication and water hardship from spatial mapping.*

other such as the association with minority populations and language barriers.[14] This provides a starting background of the potential vulnerable communities.

Figure 3 shows the results of the statistically significant clusters of hardships for the communication and water disruptions. It emphasizes pockets of ZIP codes across the county that are designated as hotspots (high hardship) or coldspots (low hardship). Both services had common hotspots, located in the eastern and northwestern area of Harris County, similar to the results in Figure 2. This demonstrates a connection between the socially vulnerable groups and hardships from service disruptions. The results also suggest that there may be a level of commonality, meaning if one area experiences high hardship from a service disruption, they may experience high hardship from another disruption. The findings showed which locations in Harris County were most vulnerable or most resilient to the service disruptions.

This research further investigated the underlying reasons for the connection between the sociodemographic groups (Figure 2) and clusters of hardship (Figure 3). Table 1 presents the results of the proportion analysis. These results show that all the tested sociodemographic characteristics were statistically significant; thus, the proportions were not equal in the hotspot and coldspot clusters for the communication and water disruptions. Therefore, the proposed hypotheses were supported by results because the percentages of socially vulnerable groups were shown to contribute to the hardships faced during infrastructure disruptions.

CONCLUSION

The purpose of our research was to integrate the human experience, or the varying levels of hardship to service disruption, into the planning of infrastructure resilience. The research provides much-needed empirical information about the social vulnerabilities of a community associated with service disruption. In particular, the findings highlighted which regions within a community were most vulnerable or most resilient to the communication and water outages caused by Hurricane Harvey. It also investigated the underlying mechanisms behind the clusters of hardship. The results showed that hardship varied among different locations, and in particular, socially vulnerable groups were sig-

Table 1. *Proportion of sociodemographic characteristics in hardship clusters.*

	Communication			Water		
Social Demographics	Proportion of High Hardship	Proportion of Low Hardship	p-value	Proportion of High Hardship	Proportion of Low Hardship	p-value
Below Poverty Line	25.84%	19.60%	<2.2e-16	25.90%	16.55%	<2.2e-16
No High School Education	34.21%	21.63%	<2.2e-16	34.95%	20.52%	<2.2e-16
Minority	55.35%	48.85%	<2.2e-16	54.98%	32.33%	<2.2e-16
Language other than English	60.61%	42.3%	<2.2e-16	59.83%	46.63%	<2.2e-16
Age Older than 65	8.67%	7.26%	<2.2e-16	8.87%	5.83%	<2.2e-16

nificantly located in regions of higher hardship.

Using the research findings, invested stakeholders such as utility companies, policy makers, and emergency planners can invest and restore infrastructure services based on the level of predicted hardship to service disruption. This can assist in the creation of mitigation plans which directly meet the needs of the community and help decision-makers efficiently allocate limited resources in preparation for and in the immediate aftermath of the disaster setting. Hotspot locations suggest that socially vulnerable groups tend to live close to each other and are found in high hardship clusters in regards to communication and water disruption at a statistically significant level. This demonstrates that sociodemographic characteristics could be an indicator of the emerging hotspots, and that these hotspots should be prioritized during disaster recovery efforts for service disruptions. By identifying these hotspots and coldspots on a county level, the study was able to consolidate this information into user-friendly spatial maps. These maps will detect vulnerabilities in a community to build infrastructure resilience and mitigate future disaster impacts.

ACKNOWLEDGMENTS

We would like to acknowledge our faculty advisor, Dr. Ali Mostafavi, and our Ph.D. student mentors, Mr. Amir Esmalian and Mr. Chao Fan, for their mentorship in this research project. We would also like to acknowledge the rest of the Urban Resilience.AI team for their collaborations and friendships. We would like to thank our respective families for their continual support in our college education.

REFERENCES

1. E. S. Blake, and D. A. Zelinsky, *National Hurricane Center Tropical Cyclone Report: Hurricane Harvey* (2017).
2. S. Rufat, E. Tate, C. G. Burton, and A. S. Maroof, "Social vulnerability to floods: Review of case studies and implications for measurement," *International Journal of Disaster Risk Reduction* (2015).
3. Applied Technology Council, *Critical Assessment of Lifeline System Performance: Understanding Societal Needs in Disaster Recovery* (2016).
4. National Research Council, "Facing Hazards and Disasters: Understanding Human Dimensions," *The National Academies Press* (Washington, DC: 2006).
5. A. Fothergill, and L. A. Peek, "Poverty and disasters in the United States: A review of recent sociological findings," *Natural Hazards* (2004).
6. E. J. Baker, "Household preparedness for the Aftermath of Hurricanes in Florida," *Applied Geography* 31, no. 1 (Elsevier Ltd., 2011): 46–52.
7. Ibid.
8. S. L. Cutter, B. J. Boruff, and W. L. Shirley, "Social vulnerability to environmental hazards," *Social Science Quarterly* (2003).
9. Fothergill, J. A. DeRouen Darlington, and, E. G. M. Maestas "Race, ethnicity and disasters in the United States: A review of the literature," *Disasters* (1999).
10. Cutter, Boruff, and Shirley, "Social vulnerability."
11. Rufat, Tate, Burton, and Maroof, "Social vulnerability to floods."
12. Arthur Getis, and J. Keith Ord, "The analysis of spatial association by use of distance statistics," *Perspectives on spatial data analysis* (Springer, Berlin, Heidelberg: 2010), 127–45.
13. "American FactFinder," American FactFinder, 2020, Accessed March 7, 2020, **https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml**.
14. Ibid.

Stay in Your Time Lane: How Thinking during a State of Boredom Tends to Stay in Either the Past, Present, or Future

By Kristen Akin '20

INTRODUCTION

Boredom, as a subject in psychological research, is a drastically under-researched topic. A meta-analysis reviewing studies about boredom from 1926 to 1980 found that published studies averaged less than one per year.[1] The limited amount of studies on the topic means there is no consensus on the definition, causes, consequences, or benefits of boredom. The few studies performed on boredom tend to focus on the negative outcomes associated with people who are frequently bored. Very little of this research is focused on the differences in how people respond to boredom. Understanding how people respond differently to boredom is critical to the development of psychological interventions which can help reduce the negative outcomes associated with frequent boredom, including substance use disorder, depression, and ADHD.[2,3,4]

Researchers in the past have defined boredom as:

- "the aversive experience of wanting, but being unable, to engage in satisfying activity,"[5]
- "a restless, irritable feeling that the subject's current activity or situation holds no appeal,"[6]
- or simply as "a state that monitors and regulates our behavior."[7]

The tendency to experience boredom has been proposed as a personality trait related to substance use disorder and other variables such as depression or the perception of environmental reward.[8,9,10] Recent evidence suggests that when people are in a bored state, they are motivated to seek out any experience, even a negative one.[11] Although boredom has predominantly been researched in correlation with substance use disorder, depression, and ADHD, the view that boredom is entirely negative may not be completely true.[12,13,14] Boredom can also be understood as a state which monitors and regulates our behavior and motivates us to engage in situations that are perceived as fulfilling or meaningful.[15]

UNDERSTANDING HOW THOUGHTS RELATE TO BOREDOM COULD BE INSTRUMENTAL IN HELPING PEOPLE COPE WITH DISORDERS LIKE DEPRESSION, SUBSTANCE USE, OR SMOKING.

From the early 1900s to present day, there have been no investigations on the relationships of thoughts while a person is in a bored state. To address this relationship, this study explored which topics subjects may think about most during a bored state as well as if these topics occur in the past, present, or future. Understanding how thoughts relate to boredom could be instrumental in helping people cope with disorders like depression, substance use, or smoking. As the following is an exploratory study where there has not been much research before, we did not have a hypothesis when beginning the study.

METHODS

In our research, we defined boredom as:

- "a restless, irritable feeling that the subject's current activity or situation holds no appeal and that there is a need to find something interesting."[16]

Although we agreed that boredom is a feeling a person has when their current activity holds no appeal, we felt the second part to this definition was the important one. That feeling leads people to a need to find something interesting, which could have a motivating effect or lead them to more negative outcomes such as substance use disorder, depression and ADHD.[17,18,19]

A total of 95 undergraduate students currently enrolled in an introductory psychology course were recruited for this exploratory study. These students were recruited through the participant management website *Sona* and received course credit for their participation in the study. Five participants were excluded from our analysis due to incomplete responses on their surveys. One other participant was excluded due to experimenter error during the study. Therefore, the total analysis included 89 participants (61 female; 28 male) ranging in age from 18 to 25 years old.

The first survey participants took was the *Big Five Personality* test developed by Oliver P. John and Christopher Soto in 2016.[20] This survey tests agreeableness, extroversion, neuroticism, openness to experience, and conscientiousness in a person with specific questions which target each personality. This survey was included, in part, to disguise the true intent of the study to assess responses to boredom. Participants were either asked to wait in the room while the experimenter gathered materials or to watch a video of two men folding laundry with no sound. Both conditions were intended to elicit the state of boredom for twenty minutes. Participants in the video condition were allowed to click to the next part of the survey after twenty minutes without the experimenter returning to the room, while participants in the no-video condition were stopped at the end of the twenty minutes by the researcher with the second survey.

The second survey started with an emotion check which included 24 emotions, with a focus on five key emotions: boredom, apathy, anger, calmness, and dullness. Boredom, apathy, calmness and dullness were included in the list of key emotions because they are synonyms for boredom. Anger was included in the list because of the nature of the study the researchers expected to elicit this emotion occasionally in participants. Participants were then asked to describe what they thought about for 1) the entire time, 2) the first ten minutes, and 3) the second ten minutes.

Next, participants were asked to describe the topic they thought about the most and which, if any, objects in the room stood out to them. Participants were asked to check any number of 15 items that they thought about during the 20 minutes. These 15 items fell into 5 categories of thoughts: social, past, emotional, present, and future. Three items were included in each of the five categories. In the past category, the participant could choose past conversations, past friendships, and past assignments. The present category consisted of assignments due today, tests you need to study for today, and tasks non-school related that need to be completed today. The future category had schooling after college, jobs after college, and places you would love to visit after college. Included in the social category was upcoming sporting events, plans with friends, and social events with school organizations. Finally, in the emotional category, the options were pets, romantic relationships, and family. Next, a sliding scale was included which asked what percent of the time participants thought about either the past, present, or future during the 20 minutes. After this, the Boredom Proneness Scale, developed by Farmer & Sundberg in 1986, was included to measure the participants' tendency toward a state of boredom. This is a 28-item scale

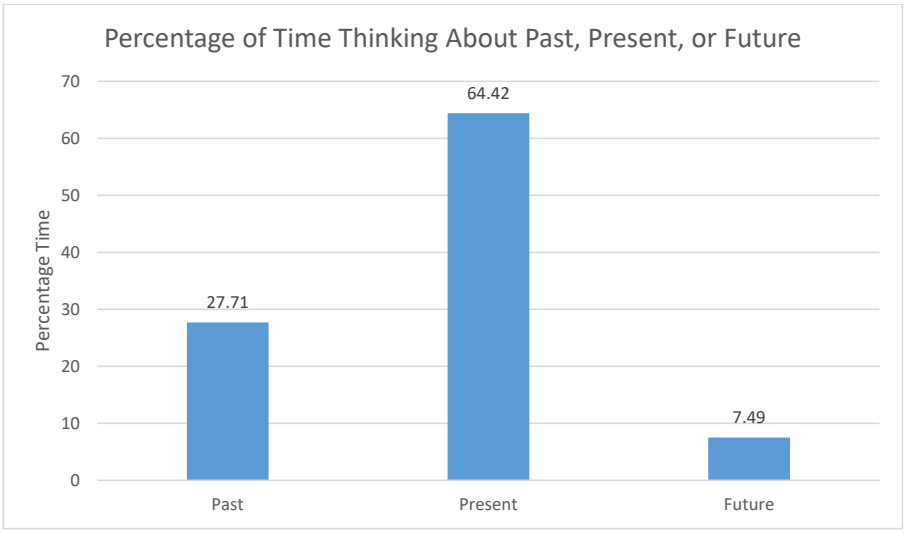


Figure 1. *Bar Graph of Percentage of Time Participants Thought About Past, Present, or Future.*

which includes questions, such as "It is easy for me to concentrate on my activities" on a scale from 1 (strongly disagree) to 7 (strongly agree).

The survey ended with demographic questions which included the participant's age, gender, and racial/ethnic background. Most psychological studies end with demographic questions and asking these questions will give us insight into how the results may correlate with the demographics.

PRELIMINARY RESULTS SHOWED THAT PARTICIPANTS RATED BOREDOM...AND CALMNESS...AS THE MOST STRONGLY FELT EMOTIONS AFTER THE TWENTY MINUTES.

RESULTS

Preliminary results showed that participants rated boredom (M=5.42, SD=1.76) and calmness (M=4.76, SD=1.73) as the most strongly felt emotions after the twenty minutes. The emotion check showed that boredom was the strongest felt emotion compared to the 23 other emotions. Therefore, the manipulations were successful in producing a state of boredom. When comparing the no-video condition, the video condition, and the boredom emotion condition, there was a moderate positive correlation, (r=0.406, p<0.01), showing the video condition tended to produce a higher feeling of boredom (no-video condition was coded as a "1" and the video condition a "2") in the *Statistical Package for the Social Sciences*, or SPSS.

A frequencies analysis was run through SPSS for the list of topics specifically in the past, present, and future categories to assess how often people thought about these categories (**Figure 1**). This analysis showed that the frequency of topics which fell under the present category were checked more often than topics in the other categories. "Assignments due today" (70%), "Tasks non-school related that need to be accomplished today" (66%), and "Tests you need to study for today" (57%) were all included in the present category. On the lower end, one of the least checked topics was in the future categories, "Places you want to visit after college" (0.02%) (**Figure 2**).

A similar analysis showed that "Past conversations" had small positive correlations with "Past friendships" (r=0.228, p<0.05). In the future category, "Schooling after college" had a moderate positive

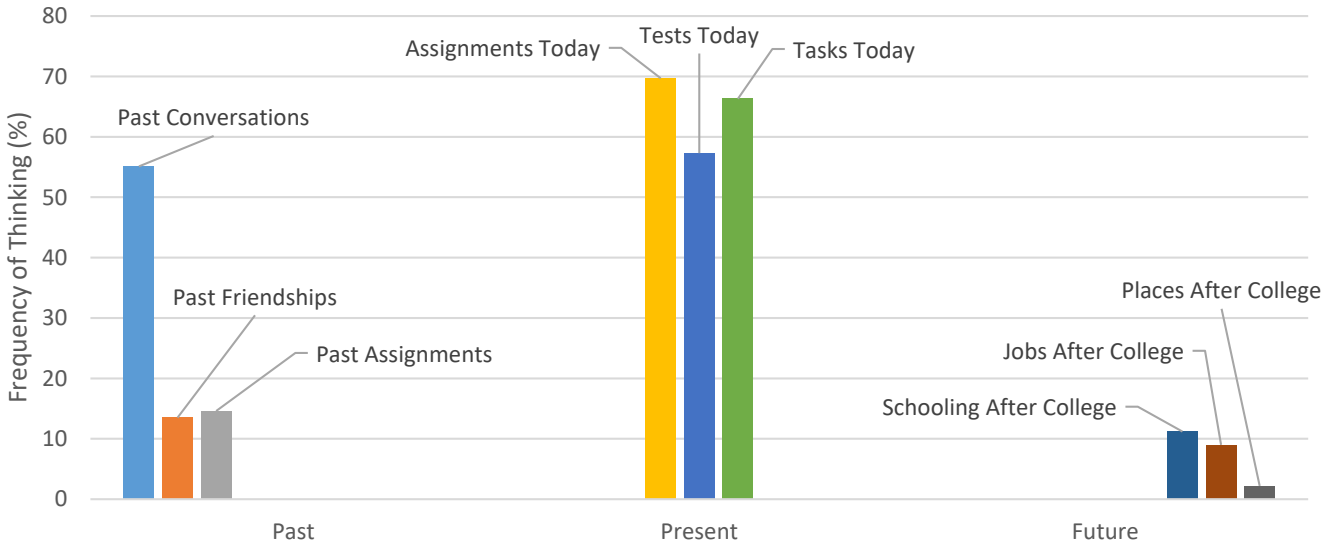


Figure 2. *Bar Graph of Frequencies Participants Thought About Individual Topics.*

BASED ON OUR FINDING, WE FOUND THAT PARTICIPANTS TENDED TO THINK ABOUT THE PRESENT WHILE THEY WERE IN A BORED STATE.

correlation with "Jobs after college" (r=0.511, p<0.01). The present category had the most correlations: "Assignments due today" had a small correlation with "Tests you need to study for today" (r=0.236, p<0.05) and "Past assignments" (r=0.208, p<0.05). Finally, "Tests you need to study for today" also positively correlated with "Past Assignments" (r=0.296, p<0.01). These trends indicate that when participants were bored, they thought about topics in either the past, present, or future and mostly did not vary between these categories.

While no topics were significantly related to the ages of the participants, there were two topics significantly related to their genders. "Assignments due today" had a small positive correlation with the gender of participants (r=0.274, p<0.01). "Places you want to visit after college" was negatively correlated with gender (r=-0.224, p<0.05). This indicates that participants who checked "Assignments due today" were more likely to be female, whereas participants who checked "Places you want to visit after college" were more likely to be male (males were coded as a 1 and females as a 2).

CONCLUSION

As this was an exploratory study and there was no true hypothesis, instead participants' thoughts and emotions while in a bored state were examined. To begin looking at how participants think while in a bored state, we first determined that the participants were in fact in a bored state. We determined that boredom was the highest emotion felt of the 24 by participants, and the second highest emotion felt was calmness. The correlations between the past, present, and future topics also showed some interesting relationships and provided some insight into the minds of our participants during their twenty minutes of boredom. Based on our finding, we found that participants tended to think about the present while they were in a bored state. Our results also showed that participants were least likely to think about future topics compared to the past and present during a bored state, as these topics were the least frequently checked.

Unfortunately, there were no significant findings when looking at how the Boredom Proneness Scale and age were related to the past, present, or future. The relationship between gender and the topics in past, present, and future showed an interesting correlation, as we saw females tended to look at what assignments they needed to do today while males were looking more toward after college. Future studies should focus on having more external validity and how to apply findings to assist people in coping with boredom. Research should focus on different age groups, different racial and ethnic groups, different genders, and how these groups experience boredom differently. This preliminary study used questions tailored to college students. The questions will have to change according to the group of participants when attempting to find how their experiences may be different from participants in this study.

Overall, this study resulted in many interesting correlations for an exploratory study, but moving forward, the psychology community should consider how these findings can be used to inform future studies with larger sample sizes.

Ultimately, our study showed that understanding the topics people think about while they are in a bored state is an important step in moving forward with boredom research. Focusing more on *how* a person thinks when they are in a bored state could be the start of helping them cope with those thought processes, especially concerning groups who have high Boredom Proneness Scores, which are indicative of disorders that impact a person's health and wellbeing.

ACKNOWLEDGMENTS

I would like to thank Dr. Heather Lench for the guidance and support she has given me throughout my entire college career. Neither this project nor the magnitude to which it has been carried out would have been possible without her. This project began as a collection of ideas, but Dr. Lench made them possible and allowed them to exceed my every expectation for what they could ever have become.

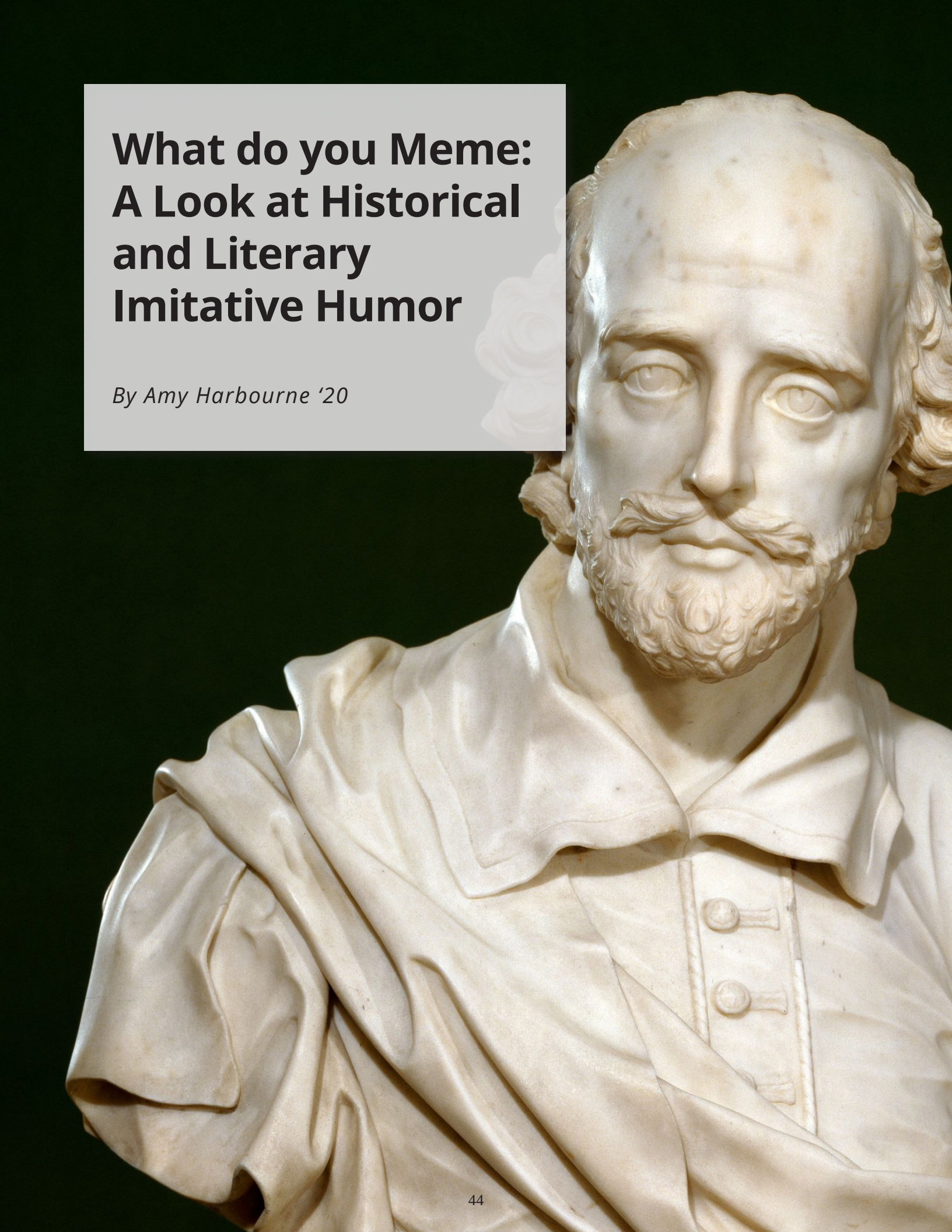
Thank you also to my friends, fellow research assistants, and the department faculty and staff for making my time at Texas A&M University a great experience. This project, IRB2019-1031D, would not have been possible without the work that you have put in and the support you have given me along the way. Finally, I would like to thank the many participants who volunteered their time for this study, for there would be no results without these students.

REFERENCES

1. R. P. Smith, "Boredom: A review," *Human Factors* 23, (1981): 329–40, **http://dx.doi.org/10.1177/001872088102300308**.
2. S. A. Fahlman, K. B. Mercer, P. Gaskovski, A. E. Eastwood, and J. D. Eastwood, "Does a lack of life meaning cause boredom? Results from psychometric, longitudinal, and experimental analyses," *Journal of Social and Clinical Psychology* 28, (2009): 307–40, **https://dx.doi.org/10.1521/jscp.2009.28.3.307**.
3. F. K. S. Lee and D. C. Zelman, "Boredom proneness as a predictor of depression, Anxiety and stress: The moderating effects of dispositional mindfulness," *Personality Individual Differences* 146, (2019): 68–75.
4. Smolkin, N. (2018). The relationship between boredom and relapse in substance use Disorder recovery. Dissertation Abstracts International: Section B: The Sciences and Engineering, 80(2-B).
5. J. D. Eastwood, A. Frischen, M. J. Fenske, and D. Smilek, "The unengaged mind: Defining boredom in terms of attention," *Perspectives on Psychological Science* 7, (2012): 482–95, **https://doi.org/10.1177/1745691612456044**.
6. J. M. Barbalet, "Boredom and social meaning," *British Journal of Sociology* 50, (1999): 631–46, **http://dx.doi.org/10.1080/000713199358572**.
7. Elpidorou, "The bright side of boredom," *Frontiers in Psychology* 5, (2014): 1245, **http://dx.doi.org/10.3389/fpsyg.2014.01245**.
8. J. Danckert and C. Merrifield, "Boredom, sustained attention and the default mode network," *Experimental Brain Research* 234, (2016): 1–12.
9. S. W. Branch and H. C. Lench, "Boredom as a Seeking State: Boredom Prompts the Pursuit of Novel (Even Negative) Experiences," *American Psychological Association* 19, no. 2 (2018): 242–54.
10. Elpidorou, "The bright side of boredom," 1245.
11. W. A. P. Van Tilburg and E. R. Igou, "Can boredom help? Increased prosocial Intentions in response to boredom," *Self and Identity* 16, no. 1 (2017): 82–96.
12. S. Mann and R. Cadman, "Does being bored make us more creative?" *Creativity Research Journal* 26, (2014): 165–73. **http://dx.doi.org/10.1080/10400419.2014.901073**.
13. Elpidorou, "The bright side of boredom," 1245.
14. Barbalet, "Boredom and social meaning," 631– 46.
15. Elpidorou, "The bright side of boredom," 1245.
16. Barbalet, "Boredom and social meaning," 631– 46.
17. Fahlman et. al., "Does a lack of life meaning," 307–40.
18. Lee and Zelman, "Boredom proneness," 68–75.
19. Smolkin, "The relationship between," 80(2-B).
20. Jeff Potter, *The Big Five Project Personality Test*, **https://www.outofservice.com/bigfive/**.

What do you Meme: A Look at Historical and Literary Imitative Humor

By Amy Harbourne ‘20



When you see a funny meme from the internet, do you wonder "Who created it, and why is it funny?" The study of memes is emerging as a new field in humor and socio-cultural history. We can suppose people have most likely always enjoyed humor. Often, the aspects found funny transform over time and depend on cultural referents, and yet there are elements of humor that have persisted over time. In this discussion I will focus on the commonalities between memetics and historical imitative humor in order to establish the types of humor that appear as a recurring characteristic of constantly evolving societies and cultures. In order to investigate the continuity of material within constantly evolving societies, we must look to two particular methodological analysis: Foucauldian Archeology and a comparative textual media framework. These allow for a deep engagement with the material, while using the context of the time period, as well as its later iterations.

PRECURSORS TO THE CONTEMPORARY MEME CAN BE FOUND IN EARLIER FORMS OF IMITATIVE HUMOR.

Definitions offered by the field of memetics do not reflect the current, popular usage of "meme"—one that focuses on humor and, specifically, easily shareable "image macros" that juxtapose text and images to create meaning on social media networks. In the original definition, Richard Dawkins describes a "meme" as something that "conveys the idea of a unit of cultural transmission, or… imitation."[1] Dawkins' definition is problematic for many, because he used biological and evolutionary models in his book *The Selfish Gene* to summarize a cultural phenomenon. For many, this definition makes too great of a metaphorical leap to be accepted. The main characteristic of a meme as we know it today requires a shareable process that is *not* autonomic (as Dawkins suggested)—meaning that it is deliberate or meaningfully reproduced. The definition I will be operating under is a meme is a unit—either a digital image macro or material that has been extracted for circulation—that is an easily propagated element of a culture. In other words, a meme is something that can be transformed and manipulated over time, across cultural boundaries, and through technology.

Precursors to the contemporary meme can be found in earlier forms of imitative humor, and while we may not be able to identify all examples of humor from the past, extant forms do exist in written texts. I intend to investigate where we can identify those earlier forms of humor; I will use models from Ancient Greece and the seventeenth century as examples. In order to fully appreciate the relevance of these memes we must keep in mind the historical contexts in which they were created and what they meant to the people who were creating and consuming them. By studying a particular niche of historical-literary memes, I propose to develop threads that can be used to evaluate the transformations and manipulations of memes in their original contexts as well as those memes that recur throughout history.

LITERATURE REVIEW

Books such as *Because Internet, Memes in Digital Culture,* and *Still Life with Rhetoric* discuss contemporary imitative culture and the linguistic and rhetorical aspects of memes. As anticipated, these texts lack a nuanced discussion of the historical aspects of meme culture. In order to introduce a historical perspective, I began to investigate various examples of written jokes in Greek literature and Shakespeare's famous innuendos or insults. My journey into historical humor begins by studying the humorous nature of these earlier forms and their virality in the context of memetics in order to draw interesting parallels between contemporary and historical contexts for understanding memes. I have vaulted between texts by the Ancient Greeks to those written by Shakespeare because of their individual notoriety, humor, and recognizability. The Greeks are known as the curators of ancient wisdom, but they too, enjoyed humor; *Philogelos,* a book of 265 jokes[2] is the first known jest book, and contains the inspiration for the well-known contemporary sketch by Monty Python called, "The Dead Parrot." Greek comedy contains a form and template, which

JUST AS A MEME CAN GO "VIRAL", SO COULD A LINE FROM A PLAY THAT SOMEONE HEARD IN THE GLOBE IN 1599.

we now associate with memes. Those who are familiar with Shakespeare and his sincerity in absurdity might already be accustomed to his novelty gags, innuendos, and insults that spread across "The Globe." His writings and productions envelope all the properties we would expect from a modern meme, save for the digital medium. Commonplace books were largely responsible for the circulation of the equivalent of today's Shakespearean memes.

MEMES TODAY

In *The Anatomy of a Joke*, Jim Holt, explains the components of a joke, and I argue that these can be applied to memes. According to Holt, jokes contain stock characters, familiar themes, and typically, feature captions. Stock characters include but are not limited to, the drunk, the miser, the braggard, the sex-starved woman, the misogynist, or someone smelly. Familiar themes often showcase relationships between husband and wife or the poor man and rich man, as well as fart jokes, sex jokes, and the ever-present "toilet humor." Using Holt's description of jokes and applying the same elements to memes we can more easily identify parallels in historical contexts.

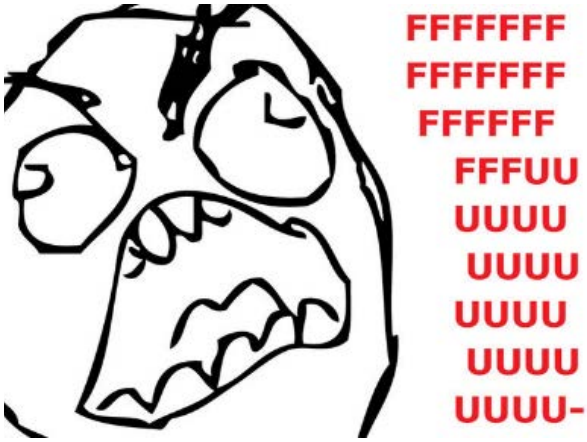


Figure 1. *f7u12, knowyourmeme.com, Jaime Dubs.*

Memes are often grouped together into what is called a memeplex, a group of memes that reinforce each other's replication. Memeplexes also reinforce a theme. In January 2009, a now iconic meme known as "rage guy" was created on reddit and is now widely known as "f7u12" (**Figure 1**).

This meme is a crudely drawn cartoon of a frustrated person. Named after the "rage guy" character, a collection of similarly drawn characters was created, which led to a series called "rage comics" that express all types of emotions—they include themes that Holt describes as essential to a joke. These memes are only a few panels in length and have a quick progression to the punchline or reaction. This follows the pattern described by Holt, who says, "...the classic joke proceeds with arrowlike swiftness, resolving its matter in the form of a two liner… or even a one liner… Often it is signaled by a formulaic setup…"[3] As will be explored further in the discussion section, this formulaic setup is present in Greek humor and both the original and appropriated works of Shakespeare. What this tells us is that historical cases of humor are not entirely different from those which we use today—what has changed is the medium used to share them.

Because Internet, written by Gretchen McCullough, asks the question of how we interpret and use language in our rapidly evolving digital world—specifically acronyms, memes, punctuation, and emojis. She begins her discussion of memes by describing their spread and protocol, as well as how the world of memes has changed since its digital conception. McCullough posits an important question: when does a meme become a meme? She says, "The first time I see a cat or dog with peculiar grammar, I'm somewhere between mildly tickled and simply confused. It's around the third or fifth version that the humor kicks in…"[4] The cat or dog that she sees are caricatures—stock characters and personifications. Cartoons, TV shows, and Bible stories all have stock characters, so why are they not memes too? McCullough explains that memes are not just participatory, but they are exclusive. They are units of a culture that may not be understandable to someone without context. "Memes can be a linguistic

recruitment tool: observers want to be part of the in-group that gets the memes, whether benignly…or for more nefarious purposes," writes McCullough.[5] She conceives a meme in linguistic terms as "an atom of internet culture."

DISCUSSION

While memes are particular to recent internet culture, if we look at history we find that we have been imitating the same comedy for centuries. The Greeks first divided comedy into two categories: Old and New. Old Comedy is composed of satire and politics while New Comedy concerns itself with relationships between people. These components of Old and New Comedy still provide much fodder for comedians, artists, and social satirists. In recent times, memes are seen as imitative forms of those comedies. In essence, memes are one particular "atom," as McCullough puts it, of the larger culture humor. Imitative humor is a long-standing practice in human history and one particularly successful example is the "Dead Parrot Skit" by Monty Python.[6] Many consider this twentieth-century skit to be an iteration of a joke from *Philogelos*[7] which is as follows:

> "The slave you sold me has died," a man complained to an egghead.
>
> "Well, I swear by all the Gods, he never did anything like that when I had him!"[8]

In Monty Python's Flying Circus skit there is a buyer and seller. The buyer enters an animal shop with a cage and a dead bird and complains that the bird he was sold was, in fact, dead. But the shopkeeper insists that the bird is sleeping, not dead. The importance of the parallels drawn between these two cultural artifacts is that they both function as a reflection of particular societies and different time periods while still following a central motif. A joke with a slave would not land quite as well now as it did in 4 A.D., but the central motif of a sketchy seller and an unhappy buyer remains constant.

Based on Foucault's classifications in *The Archaeology of Knowledge*,[9] this exhibits what is called material repeatability. Material repeatability is an enunciation that functions as a material artifact, which can lead to a series of other unique narratives containing the original underlying enunciation. The Dead Parrot sketch is not a meme because it is considered a whole piece of work rather than a single unit from a whole, but it does give an example of how humor is a long practiced imitative form and how *Philogelos* is an impressive artifact and reference for such humor.

Shakespeare's body of work is widely seen as a high form of literature and performance; however, he was not a highbrow man. As time goes on, we inevitably lose some of the cultural specifics that surrounded productions of humor, including those by Shakespeare. His plays were rhetorically rich; the historical contexts in which Shakespeare created his content were such that he had ripe pickings for both satirical and relational comedy. In the seventeenth century, there was no copyright, plagiarism, or high-speed communication. And yet, the people of England reacted to what we would consider a type of meme as "…[a] modular [text] that could be taken apart, recopied and reused."[10] *Dramatic Extracts in Seventeenth-Century English Manuscripts*, by Laura Estell, establishes that "readers and audience members jotted short sentences into their playbooks and also selected passages from plays to copy into other books and manuscripts."[11] They shared, sold, and used excerpts, in their own manuscripts. Just

MATERIAL REPEATABILITY CONCEPTUALIZES THE IDEA THAT WE AS HUMANS ARE NOT ONLY PREDICTABLE IN OUR ACTIONS, BUT OUR LIKES, DISLIKES, AND HUMOR.

Figure 2. *Quote From Man Stabbed, derivative of the What you Egg? Meme, knowyourmeme.com, author unknown.*

as a meme can go "viral," so could a line from a play that someone heard in The Globe in 1599. Circulation of these kinds of units or memes are particularly important because it is consumer interaction (be it in seventeenth century plays or digital media) that drives memes. However, as this example illustrates, the original context for the humor was often displaced or lost.

Shakespeare's legacy and work is enjoyed for more than just his plays, sonnets and general creative genius—he is also well liked for his colorful insults. Shakespearean insults can be found in image macros that circulate across various social media sites. One such example comes from *Macbeth*. *Macbeth* is not a traditionally comic play by any means, however, due to Shakespeare's novel insults found in the play it is hardly surprising that the insults would be extracted and shared for comedic purposes in the twenty-first century.

The quote "What, you egg?" followed by the stage direction "stabs him" taken from Macbeth, is superimposed on an image in **Figure 2** from a news report about a real man who was stabbed. The meme began its viral journey on Tumblr when users shared some of their favorite quotes from Shakespeare.[12] Then, once the meme spread to other social media sites it became popular enough to be featured on **knowourmeme.com**, a site which compiles memes the same way an encyclopedia compiles information.

As we have seen, memes are known for their formulaic set ups or templates; this is what makes some of the more popular memes instantly recognizable. Commonplace books in the seventeenth century shared a common format. The commonplace books that had a closer relationship to understanding a play as a whole, made the extractions more successful. This is also true today. Being able to understand the theme and purpose of the play or meme template is important to being able to make a successful meme. Successful commonplace books and memes both decontextualize extracts from original moments but still maintain the essential connection for those who are more familiar with the origin of the extract. We can see this connection in another example taken from Shakespeare's *Hamlet* with a popular internet meme called the "distracted boyfriend meme" shown in **Figure 3**. Below that is an artist's rendition of the distracted boyfriend meme drawn by Binah Q. from Tumblr.[13] The artist's rendition of Hamlet, donned in his "nighted colour," is distracted by the ghost of his father, while his faithful friend Horatio stands beside him worried that the ghost of his father may drive him insane. The artfully done meme functions in the same way as excerpted text did in seventeenth century

Figure 3. *Distracted Boyfriend and Hamlet Distracted Meme, tumblr.com, Binah Q.*

commonplace books: it decontextualizes a moment from a larger work and applies it in a way that makes the information and joke widely understandable in a contemporary format.

The only difference between these two memes, is that one is about Shakespeare and the other is not. Otherwise, they are fundamentally the same meme, adapted to different contexts, most likely based on the desired audience. The original stock photo/meme template would reach a wider internet audience, while the Shakespearean version would more likely get a chuckle out of those who have read *Hamlet*—although if you understood the first meme, you would understand the basic meaning of the *Hamlet* version.

CONCLUSION

Foucault's concept of material repeatability conceptualizes the idea that we as humans are not only predictable in our actions but our likes, dislikes, and humor, as well. We have only recently begun to identify these imitative humors and concepts "memes," but we have effectively been sharing and imitating humorous excepts throughout our history. The way we share humor has changed in medium as our technology improves—thus supporting the adage, the more things change, the more they stay the same.

ACKNOWLEDGMENTS

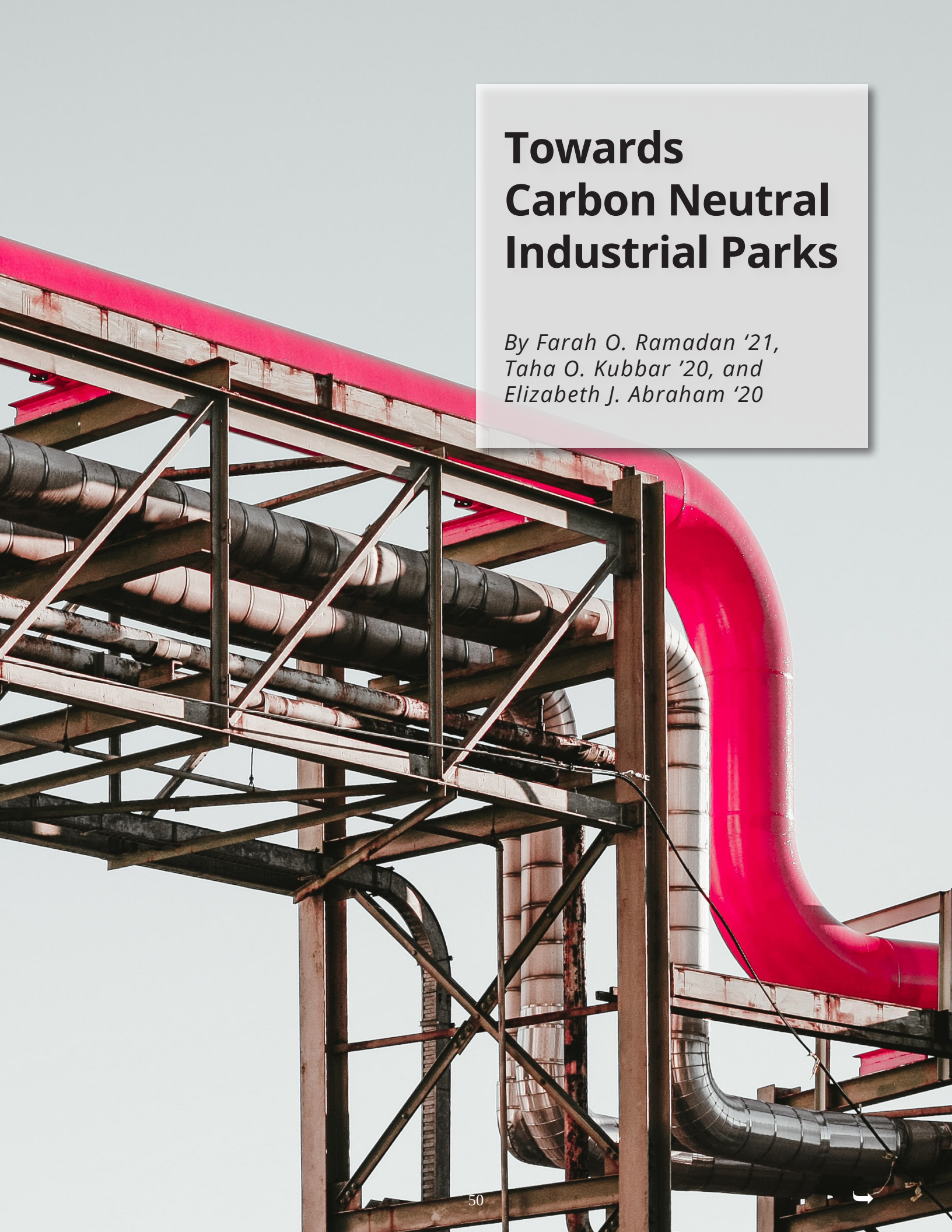
I would like to thank Dr. Andrew Pilsch for supporting me through this project, my partner Benjamin for helping me stay focused, and Leo DiCatprio for giving me company at my desk. They were all a tremendous asset to the completion of this work.

REFERENCES

1. Dawkins, Richard. The Selfish Gene. Oxford: Oxford University Press, 1989. Print.
2. Hierocles and Barry Baldwin, *The Philogelos, or, Laughter-Lover*, (J. C. Gieben, 1983).
3. Jim Holt, *Stop Me if You've Heard this: A History and Philosophy of Jokes*, (W. W. Norton & Company, 2008): 88.
4. Gretchen McCulloch, *Because Internet: Understanding the New Rules of Language*, (Penguin, 2019): 257.
5. Ibid., 258.
6. "Monty Python's Flying Circus," directed by Ian MacNaughton and John Howard Davies, (1969).
7. Stephen Adams, "Dead Parrot Sketch Is 1,600 Years Old," *The Telegraph*, (Telegraph Media Group, November 13, 2008), **www.telegraph.co.uk/news/newstopics/howaboutthat/3454319/Dead-Parrot-sketch-is-1600-years-old.html**.
8. Ibid., 4.
9. Michel Foucault, *The Archaeology of Knowledge: Michel Foucault*, (Pantheon Books: 1972).
10. Laura Estill, *Dramatic Extracts in Seventeenth-Century English Manuscripts: Watching, Reading, Changing Plays*, (Rowman & Littlefield, 2015): 150.
11. Ibid., 1.
12. Sophie, "What, You Egg? [He Stabs Him]," *Know Your Meme*, (December 17, 2019), **https://knowyourmeme.com/memes/what-you-egg-he-stabs-him**.
13. Binah Q., "Tumblr," Tumblr, **https://binary-bird.tumblr.com/post/164915066209/ill-stop-making-hamlet-memes-when-im-dead**.

Towards Carbon Neutral Industrial Parks

By Farah O. Ramadan ‘21, Taha O. Kubbar ’20, and Elizabeth J. Abraham ‘20



INTRODUCTION

Carbon dioxide (CO_2) emissions from anthropogenic activities have dramatically increased in recent years. There is a universal need to reduce these emissions due to the environmental threat they pose. Carbon capture utilization and storage (CCUS) systems that utilize and convert CO_2 into value-added products present immediate solutions to this ongoing emission crisis. Globally, stationary sources (such as power plants, petrochemical plants, oil refineries, etc.) are responsible for about 60% of the carbon release of the total fossil fuel footprint.[1] Thus, stationary sources provide a unique opportunity to capture CO_2 from nearby sources and apply CCUS.[2]

One way to model CO_2 conversion is to develop a source-sink representation between plants that involves CO_2 as a raw material, waste, or by-product. A source-sink representation indicates the integration of carbon using connection lines drawn from sources (plants that produce a certain resource) to sinks (plants that utilize said resource).[3] This is done through an eco-industrial park (EIP), which is a group of plants and processes that exchange energy, water, and material with one another to minimize waste, while remaining economically competitive and sustainable.[4] An EIP can optimize one resource (e.g. water integration) or several resources (e.g. water and energy integration), some of which are referred to in Boix et al.[5] Furthermore, these plants would be located in proximity to one another for ease of material exchange. Designing an industrial park or city with a diversity of plants as an EIP could provide substantial improvements in resource management and emissions reduction. The challenge is that designing an EIP requires the collection of a vast amount of data about the processes involved to tackle the numerous possible interactions that can co-exist in an industrial park.

STATIONARY SOURCES PROVIDE A UNIQUE OPPORTUNITY TO CAPTURE LARGE AMOUNTS OF CO_2.

Several works have attempted to design carbon-neutral industrial parks. Block et al. explored examples of real applications of low-carbon industrial parks such as the Styria industrial park and Hartberg eco-park in Austria, and the ValuePark Schkopau in Germany.[6] Fujii et al. looked into deploying symbiosis (utilizing waste from one process as raw material in another) to reduce emissions from urban Asian cities through a “hybrid industry,” which utilizes recycled and renewable resources as much as possible in addition to fossil resources.[7] A review of other attempts can be found in Geng et al.[8] such as adoption of a circular economy (minimizing waste and efficiently reusing resources). However, the aforementioned designs were reached in an ad-hoc manner, focusing only on one element of integration to reduce emissions and reach carbon neutrality. Hence, they overlook opportunities for savings and increased production.[9]

This project assesses the potential benefits of utilizing resources such as natural gas, water, air, emissions, and energy as heat and power to produce value-added products. The approach described in this work enables use of linear programming to integrate and optimize not only materials but also energy such as heat and power, reducing emissions without compromising other demands. It also provides an opportunity to incorporate renewable energy resources, further reducing emissions with the objective of creating a carbon-neutral industrial park.

The economic attractiveness of the project will also be assessed. Energy requirements will be accounted for in a way that ensures energy resources will not be costly or environmentally damaging, which presents a tempting initiative to undertake as a means to reduce carbon footprint.

METHODS

To achieve the objectives of this research, a six-phase approach was developed as listed in Table 1.

Table 1. *The different phases of the approach developed for this research and their description.*

Phase	*Phase Descriptions*
1	Literature review
2	Plant selection
3	Database creation
4	Ad-hoc plant cluster mapping
5	Model application
6	Sensitivity analysis

The first phase involved a thorough study of eco-industrial parks, chemical conversions, renewable energy technologies, wastewater treatment, and carbon dioxide separation technologies. The candidate plants were selected in the second phase by exploring reaction routes that utilize CO_2. Further elimination was based on interlinkage potential and profitability resulting in the final set of selected plants.

In the third phase, process data such as mass balances, energy requirements, capital, and operating costs were collected and expressed as process parameters. A process parameter is a resource or cost relative to a set amount of the reference product, which is the primary product of a particular process. Process parameters are crucial since they determine the mass and energy requirements needed to achieve a certain production capacity. The required parameters are shown in Figure 1.

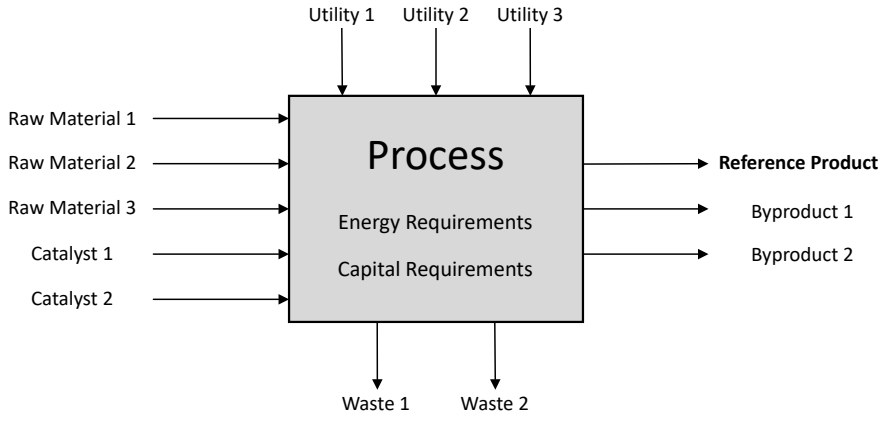


Figure 1. *Process parameter representation for a process. The figure summarizes the process information that needs to be collected and entered into the database such as material balances and energy and capital requirements of the processes.*

In the fourth phase, inter-plant connections were drawn to allow for meaningful exchange of resources between candidate plants from a holistic perspective. These connections were made to achieve the carbon neutrality objective while making a profit. After the connections were made, mass, energy, and cost estimates for the plant cluster were attempted.

In the fifth phase, all the information in the database was fed to a model developed by Shehab et al.[10] The data being expressed as process parameters allows the model to integrate resources, and the What'sBest! plug-in allows users to input different criteria or objectives and then optimize a solution to achieve the set objective, such as maximum profitability.[11] The model developed by Shehab et al. utilizes mass balances, along with its operating and capital requirements, for all the selected processes to achieve a set objective, and is a novel representation of resource management that systematically integrates materials and energy.[12] Figure 2 summarizes the steps to create the industrial park.

The sixth and final phase involved conducting sensitivity analysis in order to understand the impact of changes in parameters on the production capacities and their estimates obtained from the model. It also assessed the complexity behind problems such as ability to achieve carbon neutrality by using natural gas to produce electricity. Furthermore, different environmental protection policies like a carbon tax and subsidies were applied to the cluster to assess its impact on the overall system.

RESULTS

An industrial park can be mapped out in various ways. It is possible to create varying industrial parks out of the ten candidate plants. The plants selected include ethylene, nitric acid, methanol, urea, two ammonia production plants, air separation, water splitting, wastewater treatment, and sequestration units, as shown in Figure 3.

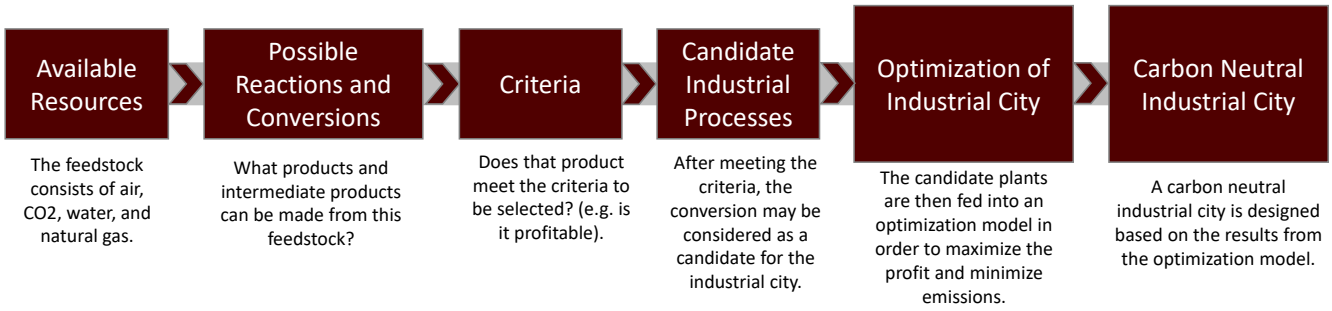


Figure 2. *The five steps to create the industrial city are:*

1. *Identify the available resources that can be utilized in the city.*
2. *Determine the products that can be obtained from these resources.*
3. *Verify if the products meet criteria selected for the city.*
4. *Collect data pertaining to the verified products and their processes.*
5. *Optimize the city using the model and data collected to meet desired objectives.*

Initially, cluster mapping was done by hand, which led to the creation of three hypothetical hand-drawn industrial parks. Each was based on different targets, the first was to integrate all the materials, the second was to minimize emissions, and the last one was to maximize profit. Each of these parks contains a different number of plants. These plants are examples of the model's ability to evaluate the economic potentials of all the plants given set constraints, and identify which plants will be in operation, along with each plant's production capacity.

Ad-hoc Design

Figure 4 displays a potential, hand-drawn industrial park. This industrial park was mapped based on a circular economy. The capacities of the plants were calculated with the objective of carbon neutrality while still making profit. However, this proved to be inefficient, and allowed for an increased appreciation of the model that efficiently conducted all the calculations.

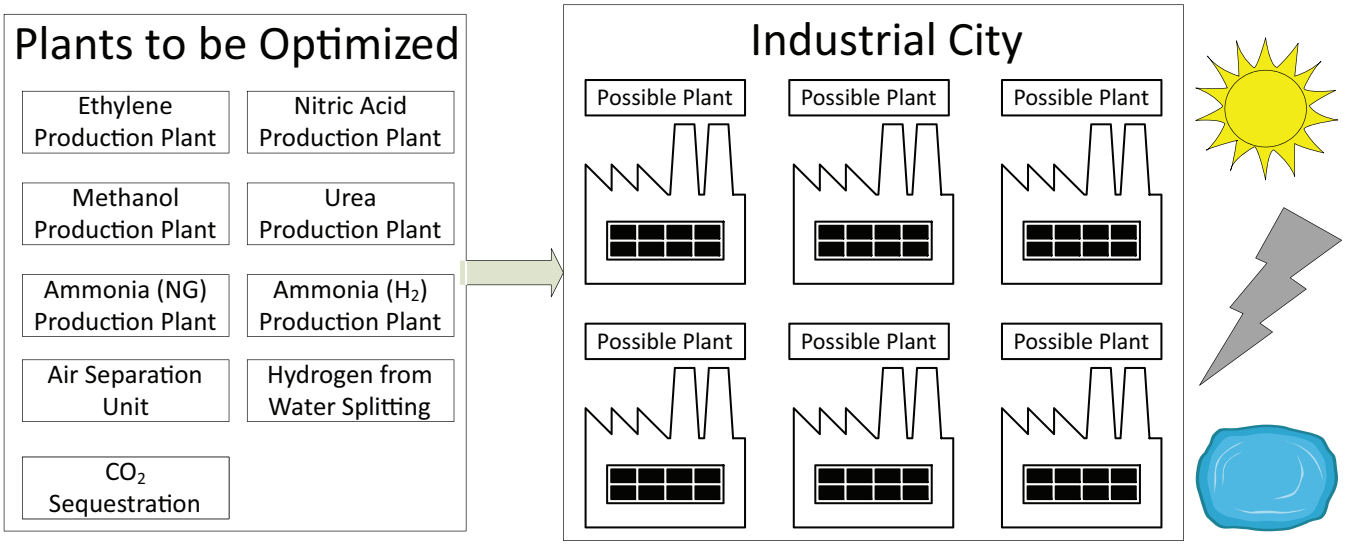


Figure 3. *Representation of industrial city from candidate plants.*

Model Results

The model results obtained are for a standardized case that uses the current costs of utilities and market prices of the products. Based on the information fed into the model, the target was to achieve 90% carbon dioxide conversion. The model used What'sBest! Version 16 solver on PC with 32 bits to determine the most profitable industrial city. This industrial city would have five out of the ten candidate plants in operation. A summary of the results can be seen in **Table 2**.

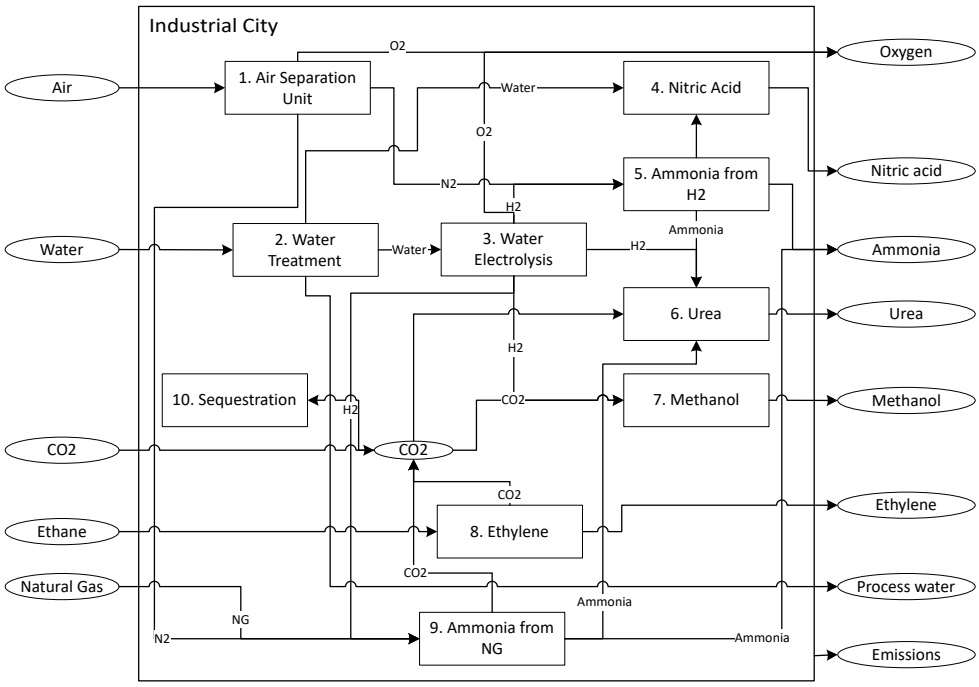


Figure 4. *Industrial Park 3. Third attempt at creating an industrial park.*

The operational plants are the nitric acid plant, urea production plant, ammonia production from natural gas plant with a carbon capture unit, an air separation unit, and lastly the CO_2 sequestration plant. The model determined that, based on utility prices and product costs, the remainder of the plants would hinder either the profitability or the carbon dioxide target. The presented case has a net profit of $35,912,000 per year with a return on investment (ROI) of 11% annually.

The market is constantly changing with fluctuations in the price of materials and electricity based on location. Therefore, it is important to conduct a sensitivity analysis that considers these various fluctuations in prices. A total of six cases were studied, three cases varied electricity costs and three varied material costs, which included the base case as one of the material cost variation cases. The remaining five cases are:

1. Electricity cost was set to a value of $0.04/kWh without varying other prices.
2. Electricity cost was set to a value of $0.06/KWh without varying other prices
3. Electricity cost was set to a value of $0.08/kWh without varying other prices.
4. All resources were set to their highest prices in the last five years.
5. All resources were set to their lowest prices in the last five years.

The results regarding the plant capacity for the sensitivity analysis cases mentioned above are summarized in **Table 3**.

In all six cases, the nitric acid plant and air separation unit were operational and produce ammonia. In addition to that, the industrial city does not require a water treatment unit or carbon capture units for the ethylene, nitric acid, or urea production plants.

Equation 1. *Formula for Return on Investment.*

$$ROI = \frac{Yearly\ revenue\ \left(\frac{\$}{yr}\right) - Yearly\ operational\ costs\ \left(\frac{\$}{yr}\right)}{Total\ Capital\ cost(\$)}$$

Table 2. *Plant capacities results for the base case scenario. Based on the current market prices for materials and energy, the model optimized the industrial park to activate certain plants.*

Plant Number	***Plant***	***Capacity (ton/year)***
1	Ethylene Production Plant	0
	Ethylene Carbon Capture Unit	0
2	Nitric Acid Production Plant	92,546
	Nitric Acid Carbon Capture Unit	0
3	Methanol Production Plant	0
	Methanol Carbon Capture Unit	0
4	Urea Production Plant	1771
	Urea Carbon Capture Unit	0
5	Ammonia Production from N_2 and H_2	0
6	Natural Gas Ammonia Production Plant	26,917
	Natural Gas Ammonia Carbon Capture Unit	1298
7	Air Separation Unit	100,000
8	Water Splitting Unit	0
9	Wastewater Treatment Unit	0
10	CO_2 Sequestration	120,000

Table 3. *Sensitivity analysis on plant capacity results for fluctuations in energy and material costs. In response to changes in variables, the model activated the plants to different capacities.*

	Energy Costs ($/kWh)			***Material Costs***		
Sensitivity Analysis Conditions	0.04	0.06	0.08	Current	Highest	Lowest
Plants	***Capacities (ton/year)***					
Ethylene Production	0	0	0	0	0	0
Ethylene CCU	0	0	0	0	0	0
Nitric Acid Production	93,622	92,546	92,546	92,546	89,096	93,622
Nitric Acid CCU	0	0	0	0	0	0
Methanol Production	765	0	0	0	2920	765
Methanol CCU	82	0	0	0	312	82
Urea Production	0	1771	1771	1771	0	0
Urea CCU	0	0	0	0	0	0
Ammonia Production from N_2 and H_2	0	0	0	0	0	0
Ammonia Production (NG)	26,214	26,917	26,917	26,917	100,000	26,214
Ammonia (NG) CCU	1264	1298	1298	1298	4822	1264
Air Separation	100,000	100,000	100,000	100,000	100,000	100,000
Hydrogen form Water Splitting	153	0	0	0	583	153
Water Treatment Unit	0	0	0	0	0	0
CO_2 Sequestration	120,000	120,000	120,000	120,000	120,000	120,000

Table 4. *Economic analysis and profitability results for the sensitivity analysis. The table indicates that the eco-industrial park is profitable and resilient to changes in material and energy costs.*

	Energy Costs ($/kWh)			***Material Costs***		
Sensitivity Analysis Conditions	0.04	0.06	0.08	Current	Highest	Lowest
Profit from Cluster ($MM/year)	36.540	35.911	35.384	35.911	42.919	46.014
ROI	11.27%	11.05%	10.88%	11.05%	13.23%	8.60%

...IT IS POSSIBLE TO ACHIEVE PROFITABILITY AND CARBON NEUTRALITY THROUGH RESOURCE INTEGRATION OF VARIOUS PROCESSES.

The model had an in-built economic analysis to compute profitability and return on investment for the industrial city. The return on investment measures how much of the initial investment, is returned within an operational year. This is calculated by **Equation 1**. The total profitability results, which include the yearly profit and the return on investment for each of the cases are summarized in **Table 4**.

It must be noted from the results displayed in **Table 4** that as the electricity cost decreases, the profitability of the plant increases. This is because decreasing operational cost will increase annual profits. Furthermore, a CO_2 sequestration plant is expensive to operate, and with the implementation of a carbon tax and low electricity cost, the industrial city is more profitable than for cases where the electricity cost was varied. As for the cost of materials, the current market cost displayed the lowest profits while the condition where material costs were lowest displayed the most profitable condition to operate the industrial city. In all cases considered, carbon emissions were 12,000 ton/year.

It is interesting that for most cases the return on investment was similar. With the exception of when material costs are lowest, the cases showed an ROI of around 12%. This means the industrial city recovers 12% of the initial investment in each operational year and needs approximately nine operational years to recover the total investment before making a profit. It is promising to see that it is possible to produce products from industrial sources, in a way that minimizes the overall net production of CO_2.

The results indicate that it is possible to achieve profitability and carbon neutrality through resource integration of various processes, and under some circumstances it is also possible to achieve carbon negativity. For the base case, the primary products leaving the city are nitric acid, urea, and ammonia, with a number of plants remaining nonoperational since their products hinder profitability (at the given utility and materials costs). In the sensitivity analysis it is evident that on the reduction of these prices, other products such as ethylene and methanol will also be produced by the city.

CONCLUSION

The purpose of this work was to analyze industrial clusters through linear programming to find the optimal operating capacities of individual units within the cluster that would achieve overall carbon neutrality. First, an ad-hoc design, which converted CO_2 into value-added products such as methanol, urea, ammonia, ethylene, and nitric acid was solved to illustrate the method.

This was followed by an optimization model to identify the combination of plants able to convert CO_2 in the most profitable way. This model provided results for a base case determined by the current market and energy costs. This was also coupled with a sensitivity analysis that varied the cost of electricity, in addition to the material prices. The model proved that there is a method to produce value added products that minimize an industrial city's carbon footprint, while remaining profitable.

This work applies an innovative systematic integration model developed by Ahmed et al.[13] to demonstrate that resource integration is possible and can be highly profitable as well as environmentally friendly. The approach we developed may be further explored and applied on the industrial level in the design of eco-industrial parks. We will continue to study and develop our approach by varying candidate plant selection criteria and adding more processes.

ACKNOWLEDGMENTS

We would like to thank Dr. Dhabia Al-Mohannadi and Dr. Patrick Linke for their guidance in addition to Shaza Shehab, Razan Ahmed, and our families for their continuous support of this research project.

REFERENCES

1. Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos, and Leo Meyer, “Carbon Dioxide Capture and Storage,” (Cambridge: 2005).

2. Ali Attiq Al-Yaeeshi, Tareq Al-Ansari, and Rajesh Govindan, “The Potential for Carbon Dioxide Capture and Utilization within the State of Qatar,” *Computer Aided Chemical Engineering* 43 (2018): 1499–504, **https://doi.org/10.1016/B978-0-444-64235-6.50261-8**.

3. Dhabia M. Al-Mohannadi and Patrick Linke, “On the Systematic Carbon Integration of Industrial Parks for Climate Footprint Reduction,” *Journal of Cleaner Production* 112 (2016): 4053–64, **https://doi.org/10.1016/j.jclepro.2015.05.094**.

4. Ebru Susur, Antonio Hidalgo, and Davide Chiaroni, “A Strategic Niche Management Perspective on Transitions to Eco-Industrial Park Development: A Systematic Review of Case Studies,” *Resources, Conservation and Recycling* 140 (January 2019): 338–59, **https://doi.org/10.1016/j.resconrec.2018.06.002**.

5. Marianne Boix, Ludovic Montastruc, Catherine Azzaro-Pantel, and Serge Domenech, “Optimization Methods Applied to the Design of Eco-Industrial Parks: A Literature Review,” *Journal of Cleaner Production* (Elsevier Ltd., 2015), **https://doi.org/10.1016/j.jclepro.2014.09.032**.

6. C. Block, B. Van Praet, T. Windels, I. Vermeulen, G. Dangreau, A. Overmeire, E. D’Hooge, T. Maes, G. Van Eetvelde, and C. Vandecasteele, “Toward a Carbon Dioxide Neutral Industrial Park: A Case Study,” *Journal of Industrial Ecology* 15, no. 4 (2011): 584–96, **https://doi.org/10.1111/j.1530-9290.2011.00355.x**.

7. Minoru Fujii, Tsuyoshi Fujita, Liang Dong, Chengpeng Lu, Yong Geng, Shishir Kumar Behera, Hung Suck Park, and Anthony Shun Fung Chiu, “Possibility of Developing Low-Carbon Industries through Urban Symbiosis in Asian Cities,” *Journal of Cleaner Production* 114 (February 2016): 376–86, **https://doi.org/10.1016/j.jclepro.2015.04.027**.

8. Yong Geng, Tsuyoshi Fujita, Hung Suck Park, Anthony S.F. Chiu, and Donald Huisingh, “Recent Progress on Innovative Eco-Industrial Development,” *Journal of Cleaner Production* 114 (February 2016): 1–10, **https://doi.org/10.1016/j.jclepro.2015.09.051**.

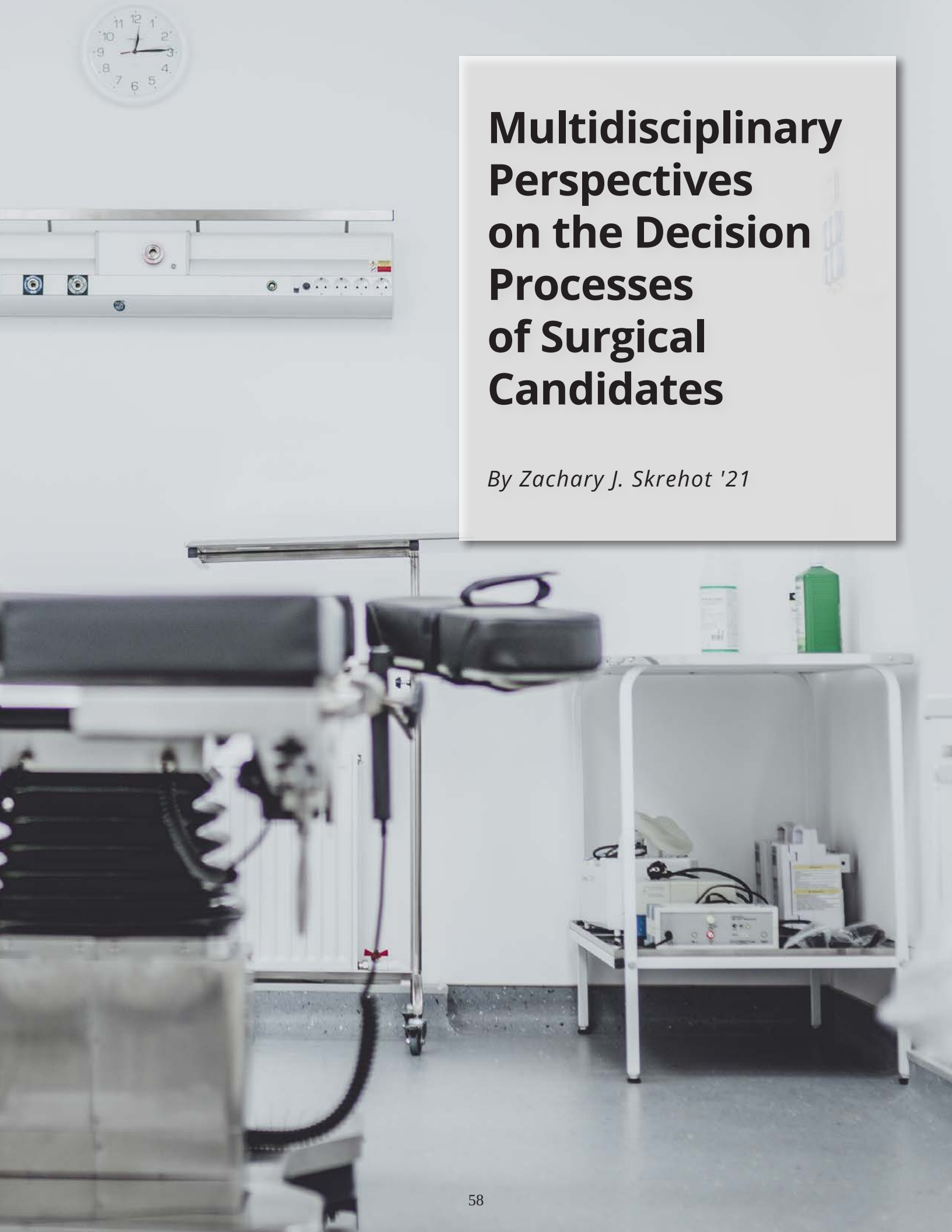
9. Shaza Shehab, Razan Ahmad, Dhabia Al-Mohannadi, and Patrick Linke, “Resource Integration and CO2 Conversion in Industrial Clusters,” *Chemical Engineering Transactions* (2019).

10. Razan Ahmed, Shaza Shehab, Dhabia M. Al-Mohannadi, and Patrick Linke, "Synthesis of integrated processing clusters," *Chemical Engineering Science* (2020): 1–37, **https://doi.org/10.1016/j.ces.2020.115922**.

11. “What'sBest! and Excel Optimization,” *Lindo Systems* (2020): **https://www.lindo.com/index.php/products/what-sbest-and-excel-optimization**.

12. Ahmed et. al., "Synthesis of integrated processing clusters," 1–37.

13. Ibid.



Multidisciplinary Perspectives on the Decision Processes of Surgical Candidates

By Zachary J. Skrehot '21

BACKGROUND

UNNECESSARY INVASIVE PROCEDURES ARE ESTIMATED TO BE RESPONSIBLE FOR THE DEATH OF 30,000 MEDICARE RECIPIENTS ANNUALLY.

Up to 25% of healthcare expenditures in the U.S. are related to avoidable medical procedures.[1] Patients consistently make expensive and risky medical decisions that are not in their best interest. In fact, unnecessary invasive procedures are responsible for the death of approximately 30,000 Medicare recipients annually.[2] Unnecessary invasive procedures are defined as "any surgical intervention that is either not needed, not indicated, or not in the patient's best interest when weighed against other available options."[3] Although the U.S. has the largest healthcare expenditure per capita in the world, they rank last in performance when compared to other industrialized countries.[4] The primary cause of inefficiency in U.S. healthcare spending is the gross overconsumption of medical procedures, specifically unnecessary invasive procedures. Outcomes of patient and physician decisions on surgery must be improved to decrease inefficient spending and unnecessary loss of life. This article analyzes perspectives on decision-making from the fields of economics, psychology, and behavioral economics to identify a generalized approach to address medical decisions.

Unlike pharmaceuticals, surgeries in the U.S. are not federally regulated. Physicians decide whether to implement new surgical techniques and devices. Unfortunately, physicians are slow to respond to research highlighting unnecessary invasive procedures. Surgery rates for procedures such as cesarean sections and lower back surgeries have continued to increase despite research disaffirming their efficacy.[5] Highly criticized common surgeries include partial meniscus removal, the most frequently performed orthopedic surgery in the 2000s, and lumbar spinal surgery, which more than doubled in frequency from 2000 to 2009.[6,7] Physicians are slow to change their practice because of historical behaviors and personal incentives, including lack of awareness, unfamiliarity with new best practices, peer acceptance, and physician compensation schemes that create opportunities to perform procedures for personal financial gain.[8,9,10]

Because many physicians have not adjusted their practices in accordance with recent findings, the burden of avoiding unnecessary procedures falls on the patient. Patients make myriad of decisions during their treatment cycle (**Figure 1**). Due to complexities of medicine and the human body, optimal treatment is often subjective. Although physicians seek to provide patients with positive health outcomes, to err is human, and medical professionals are not immune to error. If

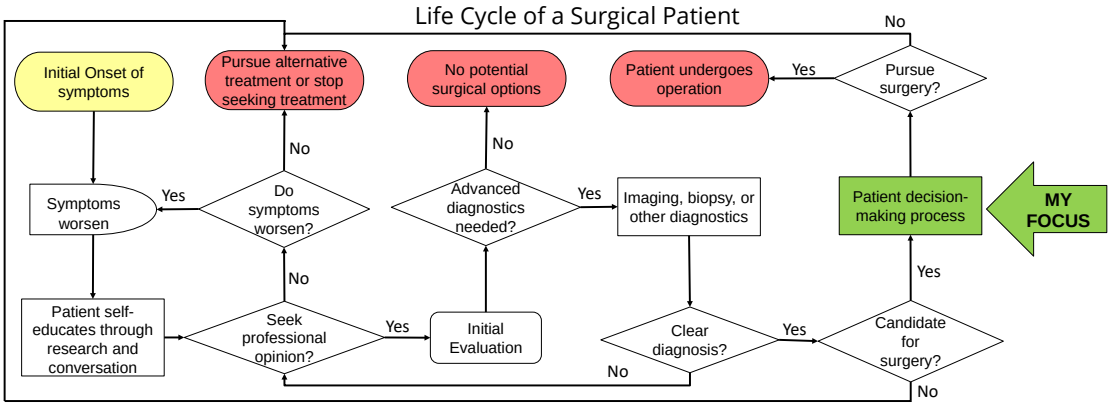


Figure 1. *Life cycle of a surgical patient.*

a patient does not seek multiple opinions, additional information, or self-education, they are making decisions based on partial data pertinent to their situation. However, even with complete information, patients are unable to act as autonomous decision makers due to *bounded rationality*. Economists use *bounded rationality* to explain that no matter how much information is available, human decisions remain limited by factors including time, mental capacity, and complexity of the problem.[11]

RESEARCH OBJECTIVES

Understand the decision-making processes of surgical candidates: Everyone is influenced by personal motives, fears, expectations, and experiences. Although the evaluation differs between patients, models outlining decision processes are useful for identifying potential biases and information gaps that skew elected treatment. Identifying viable decision models for surgical candidates provides opportunity for unaffiliated hospitals/departments to standardize approaches to patient decision-making processes.

Advance the use of decision aids and shared decision-making: Evidence shows that patients desire more information and involvement in the decision-making process; however, it remains unclear what information is useful for patients.[12] Hospitals have begun providing patients with decision aids, informative tools that prepare patients to discuss key decision-making variables preceding surgery with their physicians. Decision aids demonstrate how providers are trying to improve patient decision-processes and are shown to increase selection of conservative treatments.[13] Expanding on and improving the use of decision aids through research on patient utility is tangible and improves the efficiency of patient decisions on surgery. Although patients desire to be involved in decision-making in different capacities, every decision is shared to some degree. The Affordable Care Act encourages shared decision-making, which was found in a review of 24 studies to increase decision quality and patient preparation while decreasing decision conflict and quantity of surgeries.[14] Decision conflict, or uncertainty of choice, is a lack of confidence in one's ability to choose the best course of action. A shared decision entails communication about scientific evidence and patient values between the patient and physician. The most important result of shared decision-making is increased efficiency of decisions on surgical treatment, maximizing benefit to patient health outcomes while minimizing high-risk and high-cost medical inputs like surgery.

Increase compliance to federal regulations: Patients' physical and emotional outcomes are damaged by ineffective communication.[15,16] To protect patients, the U.S. requires hospitals to confirm patients received sufficient information to make an informed decision. This requirement is known as the informed consent process. A survey of 1,034 preoperative patients found that 13% of respondents did not understand what procedure was being performed on them despite the signed informed consent process, and 33% of respondents did not consider their preferences, values, or goals addressed by physicians before surgery.[17] These deficits are the result of insufficient patient-physician communication and can be remedied through improved communication and shared decision-making.

LITERATURE ANALYSIS

There are innumerous disciplinary perspectives on human decision-making, and each academic field's underlying assumptions and motivations influence the lens researchers view human behavior through. This paper investigates decision-making processes from three approaches: economics, psychology, and behavioral economics. These fields were chosen because of their expansive literature and contrasting assumptions of subconscious decision processes. Economic theory predicts how rational humans with unlimited access to information will act; psychological theory suggests why humans act the way they do; and behavioral economic theory utilizes psychology to account for deviances from rationality. These three approaches are displayed relationally in **Figure 2**.

A preliminary literature review revealed that decision process research focuses on physicians, hospital administrators, and other medical institutions. The majority of patient-centered surgical decision-making

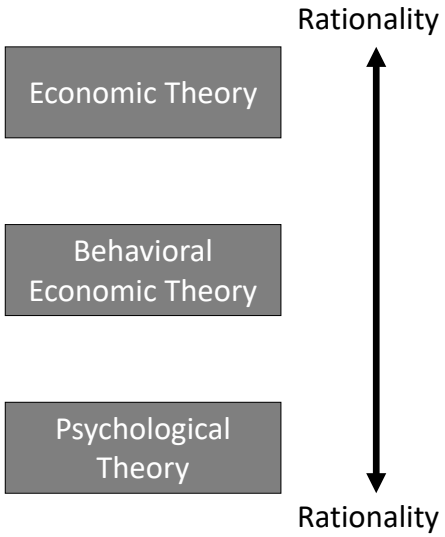


Figure 2. *Spectrum of decision-making perspectives.*

research is focused on variables in specific surgeries or the efficacy of decision aids. Current research lacks a robust understanding of the analysis patients perform when evaluating treatment options.

Utility

In economics, utility refers to the perceived intrinsic value or satisfaction of a product or outcome. This work assumes utility for a possible outcome to be the aggregate of all items of positive or negative value that affect a patient's decision-making. If the outcome provides the patient with usefulness, happiness, satisfaction, etc., it has positive utility. If the outcome leads to diminished intrinsic value, it has negative utility. In the instance of surgery, an item of positive or negative value may include expected recovery time, potential change in pain intensity, cost with or without insurance, or lifestyle adjustment. For example, for an athletic parent of young children, procedures with lengthy recovery times would bring the patient negative utility because they are temporarily unable to adequately care for their children. For the same patient, a surgery that increases functional ability would bring the patient positive utility because they will be able to return to their normal exercise habits. It is important to remember that utility is subjective to the motives, values, and desires of each patient.

Economic Perspective

Economic theory rests on the assumption of rationality. Humans are expected to make perfectly rational (outcome maximizing) decisions based on the information available to them. The predominant decision-making theory in economics is the *Expected Utility Theory*, which states the value of a choice is the sum of each potential outcomes' probability multiplied by its respective utility (**Equation 1**). However, this theory is limited in application because it assumes people will act rationally, which is improbable in emotional decisions like those preceding surgery.

Equation 1.

$$\sum_{i=1}^{n} p_i u_i$$

When evaluating a specific surgery, a rational patient would choose to undergo the surgery if the expected utility of all outcomes is net positive or choose not to if the result is net negative. Economists acknowledge that the rational choice assumed in *Expected Utility Theory* is likely to be violated by humans in real scenarios. The model provides more value when used in principle, rather than in practice.

Psychological Perspective

Psychology does not have one model for decision-making, rather a set of biases and effects that influence humans when making decisions and sway rational choice. Three examples of psychological forces that influence human deviation from rational choice are *hyperbolic discounting*, *optimism bias*, and *source credibility*.

Hyperbolic discounting is a model for expressing human desire for instant gratification. It states that people will choose an immediate smaller reward over a delayed larger reward, such as a spinal injection instead of a physical therapy program.[18] *Optimism bias* is the belief that favorable outcomes are more likely than is probable. An example is a patient undergoing surgery with a 65% success rate believing they have a 90% chance of a successful outcome.[19] Evidence suggests high patient optimism prior to surgery leads to higher perceived quality of life and health after surgery.[20] Optimism toward surgical outcomes is likely the result

of an individual's medical knowledge and their personal or familial experience with prior surgeries. If a patient had a family member whose death was related to surgery, that patient will naturally be less optimistic of surgical outcomes. Optimism also influences *source credibility*, the degree to which a patient trusts or believes a medical professional. Increased perceived physician credibility is shown to relate to increased patient compliance.[21]

Behavioral Economic Perspective

Daniel Kahneman and Amos Tversky founded the field of behavioral economics in 1979. The duo disagreed with the underlying assumption of rationality that much of economic theory is built on, and suspected from their own studies on human decision-making that a more reasonable model could be constructed. *Prospect Theory* challenges *Expected Utility Theory* with the notion of reality over rationality. It incorporates the limits of human judgement and the influence of emotions in decision-making. *Prospect Theory* has been applied in many contexts and is one of the most important additions to research concerning decision-making under risk in recent decades.

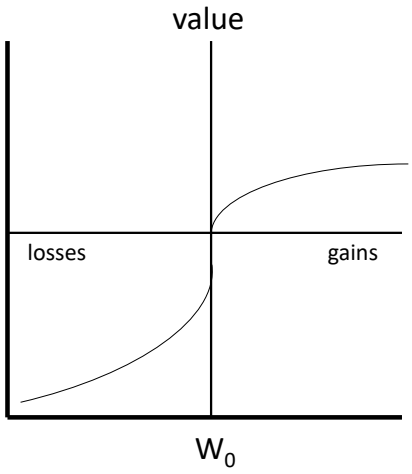


Figure 3. *Prospect theory value function.*

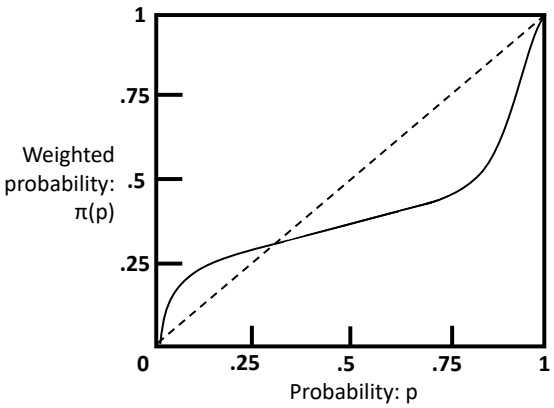


Figure 4. *Prospect theory weighting function.*

There are three key concepts associated with *Prospect Theory*: (1) people avoid losses more than they seek gains, (2) perception is based on *change* in utility, not total utility, (3) people tend to over-expect unlikely events and under-expect likely events.[22] **Figure 3** represents the first two concepts. A surgical candidate's reference point (W_0 in **Figure 3**) would include their physiological, mental, emotional, and fiscal state before seeking treatment. The patient's condition after treatment is then compared to the reference point to evaluate whether a gain or loss in wellbeing occurred. The true gain/loss is shown on the x-axis, while the patient's utility is shown on the y-axis. The third concept is displayed in **Figure 4**, which represents the difference between statistical probability and perceived probability. In **Equation 2** this function is represented as π and transforms probability (x-axis) into weighted probability (y-axis).

Equation 2.

$$\sum_{i=1}^{n} \pi(p_i)\, v(u_i)$$

The total value of potential outcomes in **Equation 2** is the sum of the probabilities of all events (p_1 , p_2 , … p_n) multiplied by the respective utility of each event (u_1 , u_2 , … u_n) where π adjusts true probability to perceived probability and v is a value function that adjusts gains/losses to the amount of utility realized by the patient.

Imagine a surgical option with three potential outcomes:

Outcome 1 has a 60% chance of improving the patient's condition and providing them with 20 units of utility (utils), but the patient believes this outcome to be only 50% likely to occur.

Outcome 2 has a 30% chance of completely curing the patient's condition and providing them 50 utils, but the patient believes this outcome to be 25% likely to occur.

Outcome 3 has a 10% chance of causing the patient permanent nerve damage, paralysis, or death and providing the patient with negative 100 utils; the patient believes this outcome to be 25% likely to occur.

All three concepts of *Prospect Theory* can be seen in this example. To calculate the net expected utility, multiply the patient's perceived probability of each outcome (the result of the weighting function) by the utility of each event (the result of the value function).

Prospect Theory's Net Expected Utility

=

*(.5*20) + (.25*50) + (.25*-100)*

=

-2.5 utils

Since the net expected utility of this surgery is negative, *Prospect Theory* asserts that the patient should/would not elect to undergo the procedure. In essence, the total expected amount of loss exceeds the total expected gain. To find the *Economic Theory Net Expected Utility*, we would multiply the true probability of each event by the subjective utility, which equals 17 expected utils. The differences in perception of probability and utility from unique disciplinary perspectives can have large impacts on decision-making.

DISCUSSION

Humans are emotional beings and allow biases to permeate every decision. Even in the Ultimatum game, an economic scenario with a definitive optimal solution, emotional influences often take precedence over profit maximization.[23] It is unreasonable to expect consistent outcome maximization in irrational individuals and perfect efficiency in healthcare markets. However, unnecessary procedures are not advertised as lemons; perception of a surgery's efficacy is dependent on the patient's access to information. Since economic theory at the market level is flawed, individual surgical candidate decisions cannot be perfectly rational. The aggregation of many inefficient decisions cannot equal market efficiency because an efficient market would not have incentives for providers to perform unnecessary procedures.

Surgical procedures carry significant potential consequences. Negative outcomes include infection, increased pain, or death, and positive outcomes include prolonged life expectancy, pain reduction, or improved functionality. Because of the major implications personal health decisions carry, individuals are more likely to be influenced by emotions, mental predispositions, and developed biases. The key concepts of *Prospect Theory* hold true in decisions made by surgical candidates, but they are magnified by psychological forces and the emotionality of the decision. For example, Kahneman and Tversky's early *Prospect Theory* experiments suggested that individuals are around twice as loss-avoiding as they are gain-seeking.[24] This means individuals may weigh losses at a factor greater than two times the degree they weigh gains.

The behavioral economic perspective is the most appropriate of the disciplines analyzed to use

...THE BURDEN OF AVOIDING AN UNNECESSARY PROCEDURE FALLS HEAVILY ON THE PATIENT...

IT IS THE RESPONSIBILITY OF OUR HEALTHCARE SYSTEM TO ENABLE PATIENTS TO MAKE EFFICIENT DECISIONS

when modeling decision-making scenarios involving candidates for surgery because *Prospect Theory's* incorporation of rationality and emotion accounts for human cognitive processes. As with *Expected Utility Theory*, the subjective utility of each outcome encompasses the cumulative sum of considered factors that differ for each patient, but psychological theory should remain considered because of its connectedness to the emotionality of medical decisions. A patient's optimism, their desperation (or lack of) for immediate health improvement, and the credibility of their physician are all forces that affect perception of probable events and the utility associated with those events. Psychology and behavioral economics do not provide a perfect framework to replicate the decision-making process of surgical candidates, but together the key concepts of *Prospect Theory* and the forces of psychology create a useful approach toward better understanding mental analyses performed by surgical candidates.

While the onus of avoiding unnecessary invasive procedures is on the patient, it is the responsibility of our healthcare system to enable patients to make efficient decisions about treatment plans. The discussions preceding unnecessary invasive procedures must be improved to achieve more socially and economically desirable treatment outcomes. If greater implementation of decision aids, increased shared decision-making, and increased provider-understanding of the patient decision-making process is instigated in our medical system, the U.S. will see reductions in healthcare expenditures and improvements in health outcome ratings concurrently.

ACKNOWLEDGMENTS

This work was brought to fruition because of the encouragement and guidance I received from Kayla Cline, Ph.D. and Brent Garza, Ph.D. My interest in decision-making is the result of conversations with Christopher Yust, Ph.D. and the resources he directed me to. I would also like to thank my close friend Adrian Leos for leading me to research, and for his help in the completion of this article.

REFERENCES

1. Jeanne Lenzer, "Unnecessary care: are doctors in denial and is profit driven healthcare to blame?." BMJ 345 (2012): e6230, **https://doi.org/10.1136/bmj.e6230**.

2. Kaiser Health News, "Unnecessary medical tests, treatments cost $200 billion annually, cause harm," Healthcare Finance, May 24, 2017, **https://www.healthcarefinancenews.com/news/unnecessary-medical-tests-treatments-cost-200-billion-annually-cause-harm**.

3. Philip F. Stahel, Todd F. VanderHeiden, and Fernando J. Kim, "Why do surgeons continue to perform unnecessary surgery?" *Patient Safety in Surgery*, 11, no. 1 (2017) **https://doi.org/10.1186/s13037-016-0117-6**.

4. Karen Davis, Kristof Stremikis, David Squires, and Cathy Schoen, "Mirror, Mirror on the Wall," *Commonwealth Fund*, June 2014, **https://www.commonwealthfund.org/sites/default/files/documents/___media_files_publications_fund_report_2014_jun_1755_davis_mirror_mirror_2014.pdf**.

5. Gina Kolata, "Why 'Useless' Surgery Is Still Popular," *The New York Times*, August 3, 2016, **https://www.nytimes.com/2016/08/04/upshot/the-right-to-know-that-an-operation-is-next-to-useless.html?searchResultPosition=1**.

6. Raine Sihvonen et al., "Arthroscopic partial meniscectomy versus sham surgery for a degenerative meniscal tear," *The New England Journal of Medicine* 369 (2013): 2515–24. **https://doi.org/10.1056/NEJMoa1305189**.

7. Hiroyuki Yoshihara and Daisuke Yoneoka, "National trends in the surgical treatment for lumbar degenerative disc disease: United States, 2000 to 2009," *The Spine Journal* 15, no. 2 (2015): 265–71, **https://doi.org/10.1016/j.spinee.2014.09.026**.

8. Stahel et al.. “Why do,”

9. James M. DuBois et al., "Exploring unnecessary invasive procedures in the United States: a retrospective mixed-methods analysis of cases from 2008-2016," *Patient Safety In Surgery* 11, no. 30 (2017), **https://doi.org/10.1186/s13037-017-0144-y**.

10. M. D. Cabanna et al., “Why don’t physicians follow clinical practice guidelines," *Jama* 282 (1999): 1458-65.

11. John Conlisk, "Why Bounded Rationality?" *Journal of Economic Literature* 34, no. 2 (June 1996): 669-700, **https://www.jstor.org/stable/2729218**.

12. Raisa B. Deber, Nancy Kraetschmer, and Jane Irvine, "What Role Do Patients Wish to Play in Treatment Decision Making?" *Archives of Internal Medicine* 156, no. 3 (1996): 1414–20, doi: 10.1001/archinte.1996.00440120070006.

13. I. Will, "An introduction to patient decision aids," *BMJ* 347 (July 27, 2013) doi: 10.1136/bmj.f4147.

14. Emily F. Boss et al., "Shared Decision Making and Choice for Elective Surgical Care: A Systematic Review," *Otolaryngology-Head and Neck Surgery* 154, no. 3 (2016): 405–20,

15. Samantha B. Meyer and Paul Russell Ward, "Do your patients trust you?: a sociological understanding of the implications of patient mistrust in healthcare professionals," *Australasian Medical Journal* 1, no. 1 (2008): 1–12, **http://hdl.handle.net/2328/26516**.

16. Wendy Levinson and Nigel Chaumeton, "Communication between surgeons and patients in routine office visits," *Surgery* 125, no. 2 (1999): 127–34, **https://doi.org/10.1016/S0039-6060(99)70255-2**.

17. Claire K. Ankuda et al., "Measuring critical deficits in shared decision making before elective surgery," *Patient Education and Counseling* 94, no. 3 (2014): 328–33, **https://doi.org/10.1016/j.pec.2013.11.013**.

18. G. Ainslie and N. Haslam, "Hyperbolic discounting," in *Choice over time*, eds. G. Loewenstein and J. Elster (Russel Sage Foundation, 1992), 57–92.

19. Neil D. Weinstein, "Unrealistic optimism about future life events." *Journal of personality and social psychology* 39, no. 5 (1980): 806–20, **https://doi.org/10.1037/0022-3514.39.5.806**.

20. Charles S. Carver, Michael F. Scheier, and Suzanne C. Segerstrom, "Optimism." *Clinical psychology review* 30, no. 7 (2010): 879–89, **https://doi.org/10.1016/j.cpr.2010.01.006**.

21. Jason S. Wrench and Melanie Booth-Butterfield, "Increasing patient satisfaction and compliance: An examination of physician humor orientation, compliance-gaining strategies, and perceived credibility." *Communication Quarterly* 51, no. 4 (2003): 482-503, **https://doi.org/10.1080/01463370309370169**.

22. Amos Tversky and Daniel Kahneman, "Prospect theory: An analysis of decision under risk," *Econometrica* 47, no. 2 (1979): 263–91.

23. Alan G. Sanfey et al., "The neural basis of economic decision-making in the ultimatum game," *Science* 300, no. 5626 (2003): 1755–8.

24. Tversky et al., "Prospect theory," 263–91.

The Butovo Firing Range: A Commemoration of the Victims of Soviet Repression

By Grace Dye '20

INTRODUCTION

During Joseph Stalin's purges, the NKVD (Stalin's secret police force) established a death camp outside of Moscow called the Butovo Firing Range or Butovo Polygon. From 1937–1938, Stalin's henchmen killed tens of thousands of innocents in a merciless string of executions. Many of those executions took place at Butovo Polygon. In Butovo's place now stands a memorial center with tributes to Stalin's victims. This heartbreaking site reflects only a fraction of the devastation Stalin wrought on his nation. Despite Butovo's momentous history, the current Russian government is slow to acknowledge the atrocity of Stalin's crimes committed here and elsewhere. Instead, it is allowing the Russian Orthodox Church to take the lead in commemorating former gulags and death camps. Notably, the Church recognizes the significance of these sites without downplaying the role of the Soviet government. Not only is Vladimir Putin's government refusing to take responsibility for crimes formerly committed by the state, it actively promotes Stalinist symbols of repression. It is vital for the truth to be preserved so the suffering of thousands does not fade into oblivion.

This research analyzes the difference in action taken by the Russian Orthodox Church in memorializing Butovo versus the Russian state's neglect of its history.

BACKGROUND

On July 30, 1937, the head of the Soviet secret police signed the most infamous order of Stalin's reign: Order #00447. This order instigated the height of Stalin's purges from August 1937 to October 1938 and fundamentally changed the world's perspective on Stalin's policies. The order was specifically designed to eradicate "once and for all" anyone who threatened the Soviet regime, whether this threat was real or simply imaginary.[1] Originally planned to last four months, the order was extended through October of the following year. Until Order #00447, most arrests were political in nature. Specifically, followers of Leon Trotsky, co-founder of the Bolshevik party and critic of Stalin, were arrested in the hundreds between 1936 and 1937.[2] However, the order authorized the NKVD to arrest practically anyone for anti-Sovietism, which included anything from a denunciation of Stalin to kinship with someone on the NKVD's arrest list.

Order #00447 divided potential victims into two categories. The first comprised *kulaks* (peasants), criminals, and "anti-Soviet elements"[3] such as Socialist-Revolutionaries.[4] They were regarded as enemies of the people. Because Stalin considered these people dangerous to society, the NKVD was authorized to arrest and execute anyone who fell under the first category. Many such executions were committed prior to a trial, with permission from local governments. If a trial was conducted, its procedure was oftentimes a farce.[5] The second category of victims included relatives and associates of perceived enemies of the people. They were sent to labor camps with sentences of up to ten years.[6] Because the victims of Butovo were considered enemies of the people, their end would be swift and brutal.

In 1934, the NKVD appropriated Butovo Polygon and equipped it as a private firing range.[7] Formerly an estate, the firing range was walled off from the public and used to test military equipment before Order #00447. After Order #00447 was given in 1937, the range was modified to an execution site and mass burial ground. The NKDV chose Butovo because it was far enough from Moscow to perform killings in secret. At the time, many Russians did not believe Stalin himself was responsible for the carnage inflicted by Order #00447, so executions were usually concealed. The firing range operated as a "special object," a code term among Stalin's secret police for a secret execution

THE CHURCH RECOGNIZES THE SIGNIFICANCE OF THESE SITES WITHOUT DOWNPLAYING THE ROLE PLAYED BY THE SOVIET GOVERNMENT.

THE RUSSIAN STATE HAS NOT BEEN AS ACTIVE IN COMMEMORATING BUTOVO VICTIMS

site.[8] Moreover, Butovo became handy as a burial site. Moscow cemeteries had run out of room to bury all the dead from Stalin's purges; however, Butovo provided plenty of space for the bodies. Because of its secrecy, later investigators of the site doubted the range was truly a burial mound. A team of archaeologists disproved this theory in 1997. Victims buried in the firing range are still there to this day, their graves undisturbed.

Butovo has a total of 13 mass graves, each about a kilometer long.[9] The well-kept lawn is dotted with square mounds of earth heaped over the graves in order to distinguish them from the rest of the area. Because the NKVD kept detailed dossiers of its victims, including photos, much has been discovered about the identities of the graves' occupants. These records detail a staggering number of bodies. Over 14 months, a recorded 20,762 individuals were shot at Butovo Polygon.[10] According to the archeologists who confirmed these burials, the actual total might exceed 40,000.[11] They further determined that the polygon was possibly used as an execution site up until Stalin's death in 1953, 15 years after Order #00447 was supposed to end. The authors of Butovo's official website have taken up the task of identifying and commemorating victims. According to the site, more than 1,000 of these victims have been identified as church figures (priests, nuns, deacons, etc.), over 300 of whom have been officially canonized by the Russian Orthodox Church.[12]

Butovo victims covered a wide demographic. Most were male peasants or members of the upper class, which consisted of civil servants, nobles, and officers of the imperial army prior to the Russian Revolution.[13] Their formerly tsarist ties were a perceived threat to Stalin and his regime. Besides peasants and

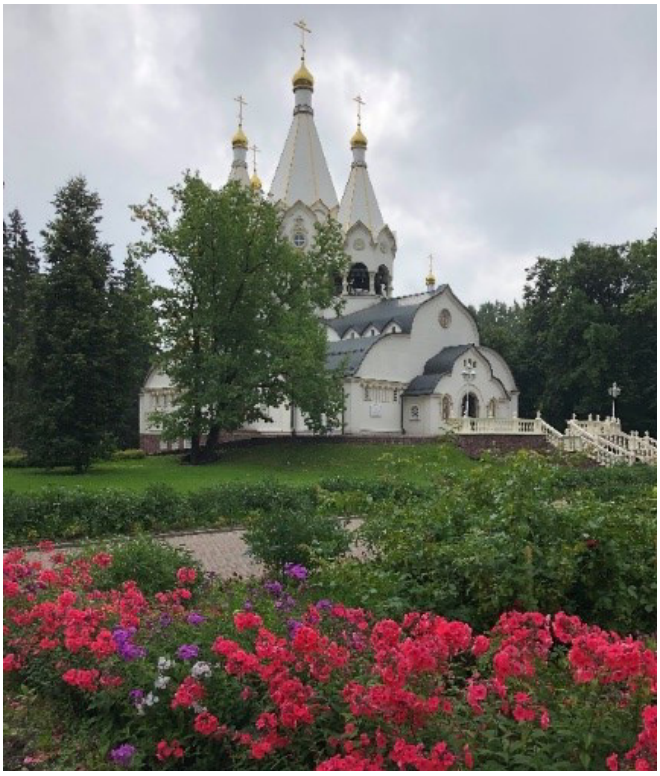


Figure 1. *Memorial Church of the Resurrection at Butovo. Photo taken by the author July 2019.*

upper-class members, the NKVD killed many foreign "spies" representing over 60 nationalities including Chinese, Germans, Italians, Latvians, Poles, and others.[14] Other victims included musicians, alpinists, circus performers, and actors. The youngest victim was 13

Figure 2. *Photo of victims and articles found at Butovo, taken by Chernyi Chelovek, June 13, 2016. https://commons.wikimedia.org/wiki/File:%D0%91%D1%83%D1%82%D0%BE%D0%B2%D1%81%D0%BA%D0%B8%D0%B9_%D0%BF%D0%BE%D0%BB%D0%B8%D0%B3%D0%BE%D0%BD_8197.jpg*

years old—the oldest over 80. On some days, no one was shot. On other days, mass executions took place, ending the lives of hundreds. The officers in charge of the executions were frequently given a bucket of vodka before the day's work. They drunkenly carried out their morbid task, shooting victims point-blank in front of the mass graves and watching them tumble in. The dead were buried right where they lay. Many of these executioners either spiraled into alcoholism, became victims of Soviet repression themselves, or committed suicide.[15]

Almost all Butovo victims were murdered without justifiable reason. The majority of them were simple peasants, newly established in life as workers in Russia's industrial sector. While peasants received the brunt of Stalin's persecution, the NKVD did not hesitate to target Russia's elite. At the time, many such victims were regarded as heroes by their countrymen, admired as effective leaders in Russian politics, religion, medicine, military, and more. We see an example of this with ecclesiastical leader Metropolitan Seraphim Chichagov. According to Cherkaeva, the Metropolitan was a remarkable example of a Russian renaissance man, serving his country as a "courageous soldier, historian . . . prophet, writer, artist, musician."[16] She comments on how he received 14 Russian and foreign distinctions for his achievements, both civil and military. Cherkaeva further mentions Chichagov's medical accomplishments: "He cured approximately 20 thousand patients using his own method based on the healing properties of plants (described in his book 'Medical Conversations')."[17] Despite such an incredible life of service, Chichagov was shot by the NKVD when he was over 80 years old.

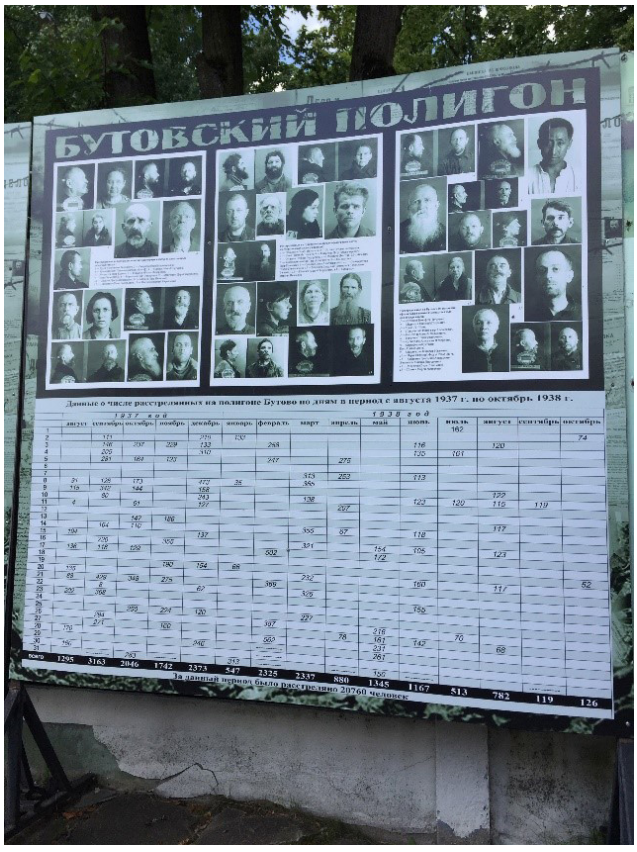


Figure 3. *Chart of Butovo casualties. Photo taken by the author July 2017.*

DISCUSSION

The Butovo memorial center is divided into several sections. Upon entering, it is easy to mistake the center for a park. The total area of the center is a bit less than 14 acres,[18] most of it filled with trees, pathways, and benches. After closer inspection, it becomes clear the center is no ordinary garden. Scattered across the site are two churches, two large monuments shaped like crosses, information boards attached to a fence, a memory garden, and a stone plaque reading, "In this zone of the Butovo Polygon, thousands of victims of political repression were secretly shot by the NKVD

Figure 4. *Photo of Butovo victim's mugshot by Andrey Zelev, March 23, 2016. http://cyclowiki.org/wiki/%D0%A4%D0%B0%D0%B9%D0%BB:Butovskij-poligon-lekarstvo-ot-kommunizma_01.jpg "Misha Shamonin was shot at the Butovo Polygon at the age of 13 years, the oldest of those shot at Butovo was over 80 years old."*

MGB in 1937-1938. Eternal memory."[19] The wooden cross and church were erected by descendants of Butovo victims. They wanted both a physical reminder of their family members who had suffered as well as a place nearby to serve the Divine Liturgy and respect their dead. Once the wooden church could no longer accommodate the growing number of parishioners, a larger stone church was constructed, its development instigated by Patriarch Alexy II of the Russian Orthodox Church.

Patriarch Alexy's goal was to remember Butovo's tragic history, an event he called Russia's "national Golgotha."[20] The stone church was consecrated as the Church of the Resurrection of Christ. Sometimes the phrase "and the New Martyrs and Confessors of Russia" is added at the end as an unofficial title. Indeed, the iconography and structure of the church support this addition. The building contains a lower and an upper church, a common feature among Russian Orthodox churches. The lower church is dedicated to the victims of Butovo. Icons of canonized Butovo saints line its walls, based off of photos from the dossiers mentioned previously.[21] Because of the circumstances surrounding these martyrs' deaths, the iconography is dark and somber out of remembrance for the dead. The upper church features icons of martyrs and saints in keeping with the theme of perishing for Christ. Because the Divine Liturgy is celebrated in the upper church, the iconography there is lighter and more joyful, a reminder to Orthodox Christians that Christ has conquered death and that the liturgy is a celebration of his resurrection.

Interestingly, the Russian state has not been as active in commemorating Butovo victims. In fact, it has been criticized for its lack of involvement at Butovo as well as other sites of Soviet repression, such as the Solovetsky Islands and Kolyma. Due to the state's reluctance in recognizing victims of these camps, the role of preserving memory has fallen to the Church. This is evident at Butovo, in part because of the large number of clergy killed there. In fact, the Church officially owns the polygon. It has a dual goal in managing the site: Butovo functions as both a shrine for the veneration of new martyrs, as well as a place of commemoration for victims of Stalinist repression, not only at

Figure 5. *Dome of the Church of the Resurrection at Butovo. Photo taken by the author July 2017.*

Butovo but everywhere in Russia.[22]

In contrast with the Church's public commemoration of these victims, the state has remained somewhat aloof in recent years. On October 30th of every year, a ceremony takes place in Moscow on Lubyanka Square in front of the Solovetsky stone to commemorate all victims of Soviet repression. 2007 was considered particularly important for this ceremony, as it marked the 70th anniversary of the 1937 Great Terror. However, Vladimir Putin chose not to participate, instead attending a smaller memorialization at Butovo. Some believed his motives for this visit were political. As Veronika Dorman notes, "Both religious and Memorial activists judged that [Putin] could not have ignored the 70th anniversary of 1937 without losing face."[23] Rather than ignore the ceremonies entirely, Putin refrained from engaging in Russia's central commemoration event, choosing instead to visit a less visible site outside of the capital. Not only did Putin avoid the high-profile Moscow ceremony in 2007, he has also ac-

tively supported the resurrection of Soviet emblems. He restored the Soviet anthem, as well as the Red Banner emblem for Russia's armed forces.[24] An organization he was formerly director of, Russia's Federal Security Service, "wanted to get rid of" facilities such as Butovo Polygon.[25] Due to lack of finances, it turned responsibility of Butovo over to local government. The Service held the site until 1995. From that point on, the Church enthusiastically prepared to commemorate Butovo, with little support from public officials. One successful politician did offer a large portion of funding for the construction of the stone Church of the Resurrection.[26]

Overall, the Russian state has remained noticeably silent not only during large-scale commemoration events, but also unofficial ones led by ordinary citizens. In 2007, a nationally organized procession took place from the Solovetsky Islands of northern Russia to Butovo. This procession traveled by canals which connected the islands to Moscow. The goal of the event was to carry a cross from one site to the other, a public tribute generating attention for victims of repression. At the Solovetsky Islands, a monastery had been converted to a labor camp in the 1930s. The islands are regarded as the ultimate symbol of Soviet repression in Russia. As such they were deemed an appropriate starting point

Figure 6. *Garden of memory. Photo taken by the author July 2019.*

Figure 7. *Garden of memory plaques. Photo taken by the author July 2019.*

for the procession, while Butovo marked the endpoint because of its significance as the largest mass grave in Moscow. Scholar Veronika Dorman explains how the symbolism of the procession was intended to commemorate the victims of Stalin, especially Christians:

> [The project] came to be seen as an opportunity to tell the story of the Solovki and Butovo, of the channels and construction sites, of the martyrs and the cross. The common theme . . . were the victims, and specifically those prisoners who followed all the "stations of the cross": imprisoned at the Solovki, exploited at the canals, and executed at Butovo. . . . In the Orthodox tradition, the cross functions as a seal of baptism, able to sanctify even physical territories of memory simply by covering them. At the Solovki, the difficult relationship between the repressive past and the commemorative present is illustrated by the massive re-erection of monumental crosses. . . . Homage is paid to the past by restoring and modifying a tradition in a way that seem to cancel out the break in chronology. The act of erecting such a cross at the Butovo firing range in order to link it to the archipelago shows that the two sites compete both in horror and in sanctity.[27]

We see from this account that great care was taken to thoughtfully and honorably remember victims of repression by blessing the territory where they suffered. Despite the event being nationally organized, it did not attract many people and ended up being only a "quasi-private" event.[28] The procession only garnered media attention as it neared Moscow. Once again, Russia's religious members took the initiative instead of state leaders who remained silent.

CONCLUSION

The tragic events of Butovo grimly exemplify the Soviet history of repression. Rather than actively commemorating this history, the state has deferred to

Figure 8. *Icon of the Martyrs of Butovo Polygon. Photo taken by author July 2017.*

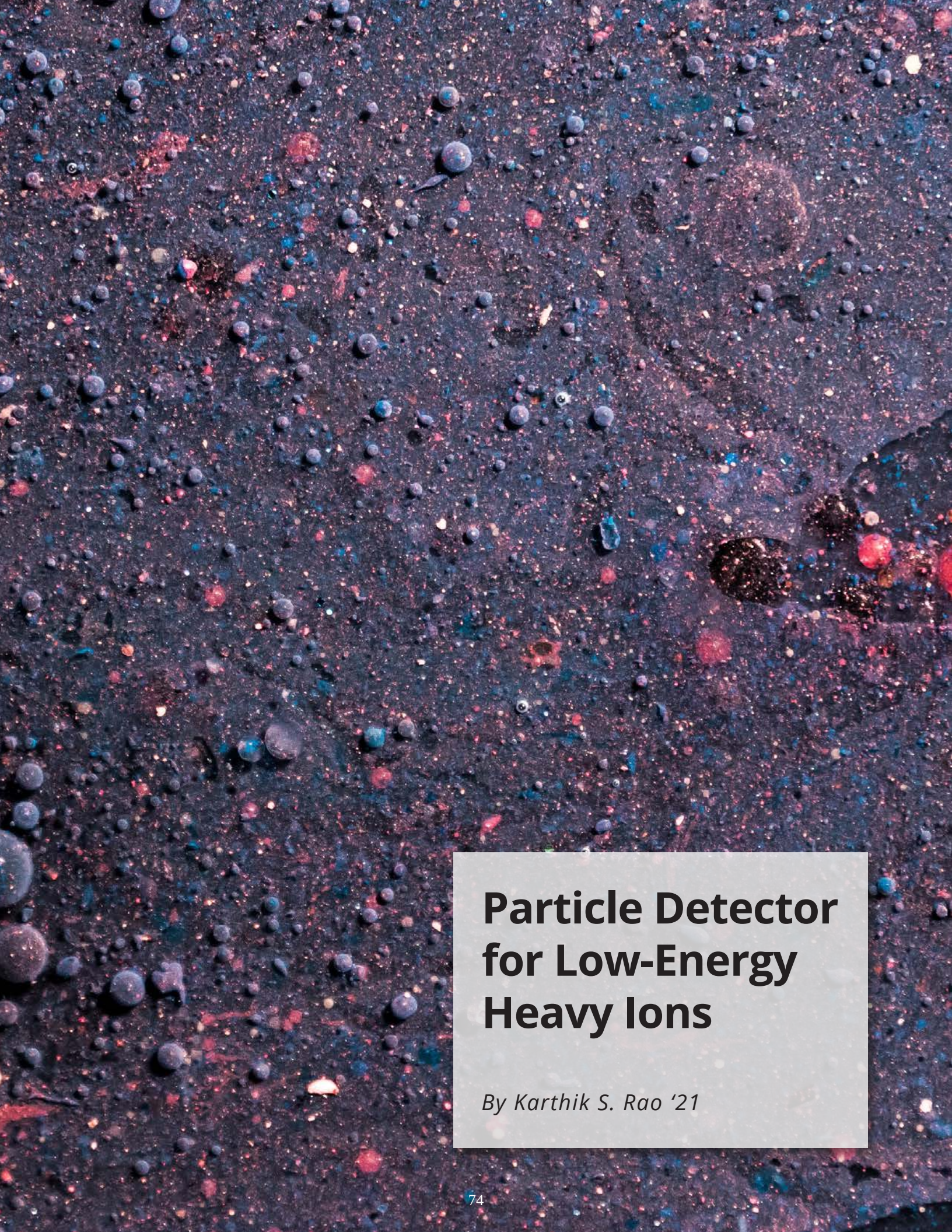
Figure 9. *Icon of the Butovo Martyrs. Photo taken by author November 2019.*

the Russian Orthodox Church in bringing memorialization to the forefront. Although the state has not explicitly rejected the Church's actions, it has not enthusiastically supported them, as seen by Vladimir Putin's resurrection of former Soviet emblems. Thanks to the

Russian Orthodox Church, Russians are able to actively remember both the victims of Butovo and a host of other victims. Sites like Butovo offer the chance to preserve historical memory, even while those in power aim to bury or ignore it.

REFERENCES

1. Nérard François-Xavier, "The Butovo Shooting Range," sciencespo.fr, Section A, February 27, 2009, **https://www.sciencespo.fr/mass-violence-war-massacre-resistance/en/document/butovo-shooting-range**.
2. Robert W. Thurston, *Life and Terror in Stalin's Russia, 1934-1941* (Connecticut: Yale University Press, 1998), 47.
3. Michael Ellman, "Regional influences on the formulation and implementation of NKVD order 00447," *Europe-Asia Studies*62, no. 6 (August 2010): 915-31, **https://doi.org/10.1080/09668136.2010.489254**.
4. François-Xavier, Section A.
5. For more information on show trials during the Stalinist purges, see George H. Hodos's *Show Trials: Stalinist Purges in Eastern Europe, 1948-1956* and Eugenia Ginzburg's *Journey Into the Whirlwind*.
6. Oleg V. Khlevniuk, *The History of the Gulag: From Collectivization to the Great Terror* (Connecticut: Yale University Press, 2004), 147.
7. Olga Cherkaeva, "Turning Sites of Massive Repression into Memorials," *Muzeológia a kultúrne dedičstvo,* vol. 6, no. 1 (2018): 71. **http://www.muzeologia.sk/index_htm_files/mkd_1_18_Cherkaeva.pdf**
8. Carleton College, "Butovo Polygon," blogs.carleton.edu, accessed June 23, 2020, **http://blogs.carleton.edu/smokeofthefatherland/butovo-polygon/**.
9. Cherkaeva, 72.
10. Ibid.
11. Karin Christensen, *The Making of the New Martyrs of Russia: Soviet Repression in Orthodox Memory* (New York: Routledge, 2018), 150.
12. "Бутовский полигон--Русская Голгофа," martyr.ru, accessed June 23, 2020, **https://martyr.ru/**.
13. Christensen, 146.
14. Ibid.
15. Ibid.
16. Cherkaeva, 73
17. Ibid., 73–4.
18. Ibid., 71.
19. Christensen, 151.
20. BBC Monitoring, "Service helps heal Russian Orthodox rift," *BBC News* online, May 15, 2004, **http://news.bbc.co.uk/2/hi/europe/3717739.stm**.
21. See Figure 4 for photo example.
22. Krzysztof Sala and Trine Stauning Willert, *Rethinking the Space for Religion: New Actors in Central and Southeast Europe on Religion, Authenticity and Belonging* (Lund, Sweden: Nordic Academic Press, 2012), 217.
23. Veronika Dorman, "From the Solovki to Butovo: How the Russian Orthodox Church Appropriates the Memory of the Repressions," *Labaratorium* vol. 2, no. 3 (2010): 434, **http://ecsocman.hse.ru/data/2010/10/21/1214790963/17_eng.pdf**.
24. Steven Lee Meyers, "Moscow Journal; Father of K.G.B. Might Return to Headquarters," *The New York Times*, September 17, 2002, **https://www.nytimes.com/2002/09/17/world/moscow-journal-father-of-kgb-might-return-to-headquarters.html**.
25. Christensen, 150.
26. Ibid., 156.
27. Dorman, 432-3.
28. Ibid., 433.



Particle Detector for Low-Energy Heavy Ions

By Karthik S. Rao '21

INTRODUCTION

DETERMINING THE RATES OF NUCLEAR REACTIONS THAT CONTRIBUTE TO THESE PROCESSES CONSTITUTES A MAJOR PART OF NUCLEAR ASTROPHYSICS.

Understanding the origin of elements in the universe is a fundamental question that presents several challenges, both theoretically and experimentally. As discussed in "The Origin of Chemical Elements,"[1] all the chemical elements in the universe were originally thought to have been created in the Big Bang explosion by neutron capture reactions brought about by the rapid expansion and cooling of primordial matter. This paper argues that the protons, subatomic particles with a positive charge, led to the formation of deuterium nuclei, which are heavier hydrogen nuclei. The nuclei collided with neutrons and merged with them, leading to the creation of heavier chemical elements. While this theory accounted for the large abundances of hydrogen and helium in the universe, it was later shown that it could not explain abundances of heavier elements.

Burbidge, Burbidge, Fowler, and Hoyle proposed another theory in their "B^2FH" paper.[2] They proposed that most of the chemical elements found in the universe were created in the interior of stars. While hydrogen, helium and lithium were formed as a result of the Big Bang, other elements were created due to nucleosynthesis processes that occurred in stellar environments. This work has since allowed scientists to understand the occurrence of elements in the universe and propose their own theoretical and experimental methods to elucidate the details of nucleosynthesis processes. Determining the rates of nuclear reactions that contribute to these processes constitutes a major part of nuclear astrophysics.[3]

Most of these nuclear reactions occur in cycles in which hydrogen burns.[4] One example of such a reaction is the Carbon-Nitrogen-Oxygen cycle, which occurs once carbon is produced in stars. This reaction produces more energy compared to the first stage of hydrogen burning reactions. This increased energy heats up the star and leads to more nuclear reactions which results in the formation of new nuclei. Unfortunately, the conditions under which these reactions occur makes it difficult to directly study the rate of reaction in laboratory conditions. For instance, these reactions occur at energies well below the Coulomb barrier, which makes their nuclear cross section too small to measure.[5] The nuclear cross section of a nuclear reaction describes the probability that the reaction will occur. The Coulomb barrier is the energy barrier due to electrostatic interaction between two nuclei. This barrier must be overcome before the nuclei can get close enough to interact. Since the reactions occur at sub-Coulomb energies in stars, but are measured at energies much higher in laboratories, significant uncertainty is present in the measurements. To overcome these experimental difficulties, indirect methods have been developed to determine the reaction rates without making direct observations.

Unique detector systems are often required to perform these studies that use indirect methods. This work contributes to the development of such systems. Specifically, the development of a new focal plane detector for magnetic spectrometers located at the Cyclotron Institute at Texas A&M University. Unique features of this detector which make it particularly useful for these nuclear astrophysics studies are its excellent 2D position resolution and its sensitivity to low energy heavy ions.

METHODS

The new focal plane detector consists of two parallel plate avalanche counters (PPACs) separated by a fixed distance. The entire volume in between them is filled with a gas, which is a mixture of nitrogen and pentane for this study. PPAC detectors are a special type of gas-filled particle detectors that are very sensitive to small energy depositions, making them position

Figure 1. *Top view of a fully assembled PPAC detector.*

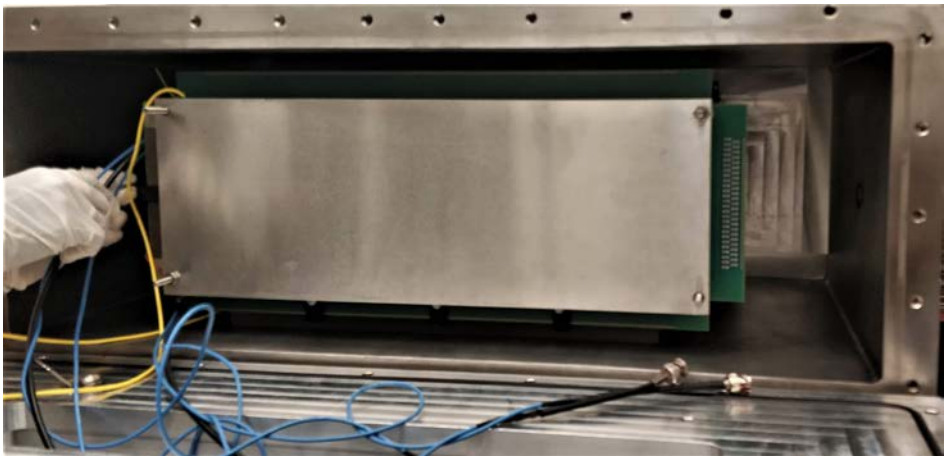


Figure 2. *Two sets of PPACs inside the steel box for testing.*

sensitive. This means that the position and energy of incoming ions can be determined with accuracy using our design choices. Each of the PPAC detectors has two cathodes and one anode. The two individual PPACs combined allow us to determine the trajectory of incoming ions as well as the time of flight. Thus, the detector can separate particles with equal magnetic rigidities, but different mass and charge ratios. Using this information, the energy of the particle can be determined. This information is then used in experiments to study the reactions that are relevant for nucleosynthesis processes in stellar environments.

A particle traveling through a PPAC detector will ionize the gas between the cathodes and anode creating electron-ion pairs. These electrons and ions will travel through the uniform electric field toward their respective electrodes. The electrons will create a *Townsend avalanche* and create many similar electron-ion pairs, providing a gas gain that amplifies the signal and makes it possible to detect a passage of a single ion through the detector. A Townsend avalanche is a gas ionization process where free electrons are accelerated by an electric field, collide with gas molecules, and free additional electrons as a result. This process repeats itself and the freed electrons are accelerated and in turn free additional electrons. This results in an avalanche multiplication that permits electrical conduction through the gas which is normally insulating. The total charge from the electrons is then collected by the detector which produces a signal. This signal lets us know that the particle has passed through the detector at a particular point. Since there are two detectors and the particle passes through both of them, we receive two separate signals, indicating two points in space. The line between these two points represents the trajectory taken by the particle, from which the distance traveled can then be determined. Using the time difference between when signals are received from the first detector and second detector, the particle's travel time is also determined, allowing us to calculate the energy of the particle.

The detector has been assembled and is currently in the testing phase. **Figure 1** shows the top view of the fully assembled PPAC detector. It is important to test the detector to find out its properties such as the energy and position resolutions. This information determines how accurately and precisely the detector can measure the position of the particle and time taken to travel, which allows us to determine the uncertainties on the energies and position.

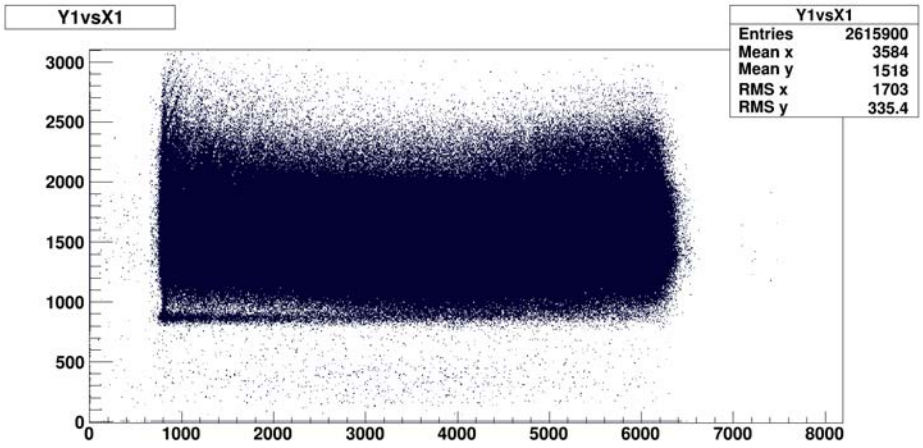


Figure 3. *Alpha particle detections made using test source.*

RESULTS

Preliminary tests conducted have shown that the detector is successfully able to detect alpha particles using the testing source with an acceptable amount of noise. **Figure 2** displays the testing setup with the two PPACs inside a steel box.

Due to unforeseen events surrounding the COVID-19 virus in the spring of 2020, complete data is unavailable at the time of publication of this article. **Figure 3** displays the result of one of the tests performed, in which alpha particles from the test source were allowed to pass through the entire area of detection. Since the area of detection is rectangular, and the particles are not constrained in any direction, it is expected that the graph showing these detections in the XY plane is rectangular as well. This can be seen in **Figure 3**, where there is a high concentration of detection in a rectangular area and low concentration outside this area. The number of entries corresponds to the number of ions that have generated signals on the cathode. The mean of x and y corresponds to the average position of the detected ions in the x-axis and y-axis, respectively. Similarly, the RMS of x and y is the root mean square of the position of detected ions along the x-axis and y-axis, respectively. Further testing needs to be done to eliminate false detections from noise to determine position and energy resolution of the new detector system. Once testing is complete, the properties of the detector such as energy and time resolution will be determined. After determining these properties, the detector can be used to conduct experiments in nuclear astrophysics involving indirect methods. If the properties determined do not allow for the accuracy and precision required to conduct experiments, parts of the detector such as the foil used in the anode will be replaced with materials that allow us to achieve the accuracy needed. It is expected based on preliminary tests that the detector is capable of producing results within the needed uncertainty.

CONCLUSION

In this research project, we built, assembled, and tested a particle detector that consisted of two parallel plate avalanche counters (PPACs). Theoretically, this detector possesses high 2D position resolution and the ability to detect low-energy heavy ions. It is expected that the detector can separate particles with equal magnetic rigidities and different mass to charge ratios, measure the time of flight for particles as they move from one end of the detector to the other, and locate, with sufficient precision, the coordinates of the particle inside the detector so that the actual path a particle takes can be determined. Currently, work is still ongoing as the particle detector is being tested to find out its various properties such as timing and energy

THEORETICALLY, THIS DETECTOR POSSESSES HIGH 2D POSITION RESOLUTION AND THE ABILITY TO DETECT LOW-ENERGY HEAVY IONS...

THESE EXPERIMENTS WILL GIVE US FURTHER UNDERSTANDING INTO THE ORIGIN OF ELEMENTS AFTER THE BIG BANG.

resolution. The result of these tests will help determine how accurate the detector is and if any changes need to be made in order to improve its accuracy. Once these properties have been determined and found to be within acceptable range of accuracy, the detector will be used in magnetic spectrometers at the Cyclotron Institute for nuclear astrophysics related experiments that utilize indirect methods. Based on tests conducted so far, it is expected that the detector is accurate enough to be used in these experiments. This will allow us to conduct research involving low-energy heavy ions. These experiments will give us further understanding into the origin of elements after the Big Bang.

ACKNOWLEDGMENTS

I would like to thank my research group at the Cyclotron Institute at Texas A&M University. Specifically, I would like to thank Dr. Grigory Rogachev, Dr. Heshani Jayatissa and Dr. Greg Chubaryan for their invaluable help. This project is funded by the Department of Energy, Office of Science under grant number #DE-FG02-93ER40773.

REFERENCES

1. R. A. Alpher, H. Bethe, and G. Gamow, "The Origin of Chemical Elements," *Physical Review* 73, no. 7 (January 1948): 803–4, **https://doi.org/10.1103/physrev.73.803**.

2. E. Margaret Burbidge, G. R. Burbidge, William A. Fowler, and F. Hoyle, "Synthesis of the Elements in Stars," *Reviews of Modern Physics, American Physical Society*, (October 1, 1957), **https://doi.org/10.1103/RevModPhys.29.547**.

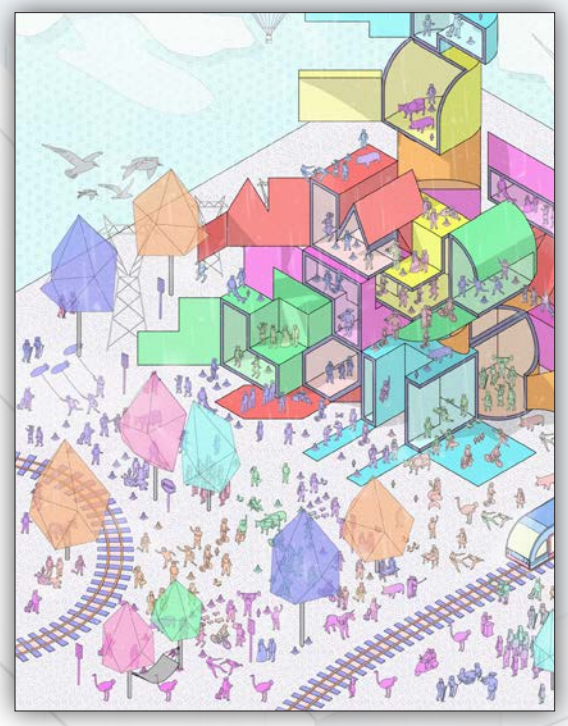
3. R. E. Tribble, C. A. Bertulani, M. La Cognata, A. M. Mukhamedzhanov, and C. Spitaleri, "Indirect Techniques in Nuclear Astrophysics: a Review," *Reports on Progress in Physics* 77, no. 10 (January 2014): 106901, **https://doi.org/10.1088/0034-4885/77/10/106901**.

4. Claus E. Rolfs and William S. Rodney, *Cauldrons in the Cosmos: Nuclear Astrophysics* (Chicago, IL: University of Chicago Press, 2005).

5. Tribble, "Indirect Techniques in Nuclear Astrophysics: a Review," **https://doi.org/10.1088/0034-4885/77/10/106901**.

The Populated Dreamworld

By Francisco Anaya '21



The subject matter that the artwork addresses is the drawing aspect of architecture. This drawing extracts elements from the traditional architectural drawing and uses the same tools and techniques to create a new drawing style.

This drawing directly engages with the architecture field by exploring a new paradigm shift of populated drawings. The entourage (human figures) have traditionally only been used to convey scale in architecture drawings; however, this art piece argues that the entourage can be used in order to tell a story and create a dialogue that will go beyond their traditional mundane use.

The artwork started with a piece of paper and a pen as quick sketches. Once an idea was mature it was processed in a 3D modeling software in which the scene was completely 3D modeled. The 3D geometry was then translated into 2D line vectors. The vector lines were then post-processed by adding color, shadows, and changing line weights. This process is extremely powerful because it is the same process that used to make traditional architecture drawings but now makes an unorthodox drawing about architecture.

The drawings demonstrate the power that architectural designers have through the medium of drawing. The objective of this project will be to curate populated drawings though the entourage in order to exhibit the authorship of architects in creating new realities and expressing their ideas through a visual language. The drawing partakes in a new architectural convention of the populated drawing through the usage of the entourage. It will exhibit the implication of the entourage to our society by redefining the entourage in order to further the narrative of a drawing. And giving a new power to drawing through the vehicle of the entourage. The drawing does not have one specific interpretation it instead invites the viewer to interpret the drawing how they see fit and create a dialogue from it. This reflects the power of the visual language and the authorship of architects and artists when curating a drawing.

This is an original piece that was made from scratch specifically for the *Explorations* Journal cover artwork.

AUTHOR BIOGRAPHIES

ELIZABETH J. ABRAHAM ‘20

Elizabeth Abraham '20 is a chemical engineering major at the Texas A&M Qatar campus from Kerala, India. Elizabeth has great interest in the field of optimization and sustainability, which led to her work as an Undergraduate Research Scholar utilizing process integration techniques to achieve sustainability through optimization. Elizabeth plans to continue exploring her research interests through graduate school and is pursuing a career in academia where she hopes to find solutions to achieve sustainability.

KRISTEN AKIN ‘20

Kristen Akin ‘20 is a psychology major with a minor in chemistry from College Station, Texas who went to A&M Consolidated High School. Kristen’s inspiration for this project came from her interest in how inmates put in solitary confinement cope with the accompanying boredom. Kristen is pursuing her master’s degree in forensic psychology in the fall of 2020 and plans to pursue a Ph.D. in the future.

FRANCISCO ANAYA ‘21

Francisco Anaya '21 is an environmental design major with a minor in Digital fabrication and product design from Houston, Texas. Francisco attended Energy Institute High School 2013-2017 before attending Texas A&M University. The research motivation stems from an interest in architectural drawings and attempting to produce something out of the norm while exploring the agency behind the architectural entourage. Francisco plans to attend graduate school for a master's in architecture after receiving his undergraduate degree.

NATALIE COLEMAN ’20

Natalie Coleman ’20 is a civil engineering honors student with a minor in Hispanic studies and a certificate in international engineering. Since the spring of 2018, Natalie has been an undergraduate researcher in the Urban Resilience Lab where she has investigated the social impacts of infrastructure service disruptions caused by natural hazards. She has also participated in the Undergraduate Research Scholars program and served as an Undergraduate Research Ambassador. Natalie will be attending the civil engineering Ph.D. program at Texas A&M University.

MADELEINE DARDEAU ‘20

Madeleine Dardeau '20 is a dance science major from Bastrop, Texas. After graduation, Madeleine plans to continue her studies of dance science and eventually work in a university teaching anatomy and physiology to dance students. In this career, Madeleine hopes to increase the longevity of dancers' careers by combining the art of dance with science.

AUTHOR BIOGRAPHIES

GRACE DYE ‘20

Grace Dye '20 is a double major in Russian and history from College Station, Texas. She began her research in order to display little-known elements of Russia's captivating history. After graduation, Grace hopes to earn her Ph.D. in Slavic studies and teach in higher education. Her ultimate goal is to help open Russian culture to Americans and create a better understanding of Russia as a whole, the way her teachers did for her.

MIGUEL ESPARZA ‘20

Miguel Esparza '20 is a civil engineering major with a focus in structural engineering and a minor in Hispanic studies for community engagement from Cypress, Texas. Miguel was inspired to join the Urban Resilience Lab directed by Dr. Ali Mostafavi after participating in a program that highlighted the social disparities of a natural disaster. He plans to continue studying structural engineering and conducting research with the Urban Resilience Lab as a master’s student at Texas A&M.

DANIEL ANDRES GARZA ‘20

Daniel Andres Garza '20 is a biomedical sciences major with a certificate in cultural competency and communication in Spanish from Roma, Texas. Daniel completed this research under the supervision of Dr. Timothy Herrman and Dr. Kyung-Min Lee. Daniel’s motivation for this research came from his interest in spectroscopic techniques, specifically in Raman spectroscopy in animal feed. Daniel’s goal is to earn his Doctor of Medicine degree and perform epidemiological research in the medical field.

AMY HARBOURNE ‘20

Amy Harbourne ‘20 is an English major from Brownsville, Texas. The motivation behind her research was to investigate the connection to past societies via parallel cultural nuances. She plans to continue her education in rhetorical discourse and teach others about the deep connection between rhetoric and everyday life.

AUTHOR BIOGRAPHIES

MADELYN KLUMB ‘20

Madelyn Klumb ‘20 is a dance science major from Jourdanton, Texas. She plans to continue her education by receiving a Master of Fine Arts degree at Sam Houston State University so she can reach her dream of becoming a dance teacher at a collegiate level. She hopes to help future students reach their dreams by providing a safe and creative learning space for them.

TAHA O. KUBBAR ‘20

Taha Kubbar '20 is a chemical engineering major at the Texas A&M Qatar campus. He is a Libyan-Canadian who enjoys performing research to increase his knowledge on the topic of study. Taha plans to pursue a master's degree and Ph.D. in chemical engineering.

FARAH O. RAMADAN ‘21

Farah Ramadan '21 is a chemical engineering major with minors in mathematics and chemistry at the Texas A&M Qatar campus. Farah is from Barja, Lebanon and attended the Bahrain Bayan School before moving to Qatar to attend college. As an undergraduate student, Farah joined a research team where she primarily studies process integration and system optimization. Farah plans to continue her research during her senior year and complete a master’s program after graduation.

KARTHIK S. RAO ‘21

Karthik Rao '21 is a physics and computer science double major with minors in mathematics and cybersecurity from Mumbai, India. Karthik has performed undergraduate research since his freshman year, working on various topics ranging from molecular gyroscopes to particle detectors. After graduating, Karthik hopes to attend graduate school to pursue a Ph.D. in physics.

AUTHOR BIOGRAPHIES

ZACHARY J. SKREHOT ‘21

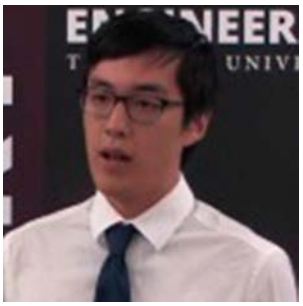
Zachary J. Skrehot '21 is an accounting major with minors in psychology and economics from Spring, Texas who went to Klein Collins High School. After undergoing a series of spinal procedures, Zachary became interested in pain perception and disparities, and eventually started as a research assistant in the Mathur Lab at Texas A&M in April of 2019. Zachary plans to continue exploring research opportunities on topics surrounding surgery and health outcomes during his senior year and after graduation.

LUKE SULLIVAN ‘21

Luke Sullivan '21 is an economics major with a minor in business from Fair Oaks Ranch, Texas. Luke’s research began as a class assignment but was quickly expanded upon due to his interest in politics and the relevance of the election year. Luke was recently accepted to be a research assistant in the Texas A&M Department of Economics and will be assisting master’s students with their thesis. Luke plans to attend law school upon completion of his undergraduate degree.

WILLIAM WALLACE ‘21

William Wallace '21 is an economics major with a concentration in financial econometrics from Austin, Texas. William has always been deeply interested in American politics and political power, which inspired him to write this paper. For the past year, William has worked at the Texas A&M Public Policy Research Institute, and he plans to become a university professor. William is also pursuing a Master of Science degree in economics.



IAN GUANG XIA ‘21

Ian Guang Xia '21 is a biomedical engineering major with a minor in electrical engineering from San Antonio, Texas. Ian started conducting academic research at Claudia Taylor Johnson High School for his AP chemistry teacher during senior year, and carried that interest in academic research into his undergraduate studies. Ian plans to work in the software industry and possibly conduct research on current questions and issues he encounters there.

BOARD BIOGRAPHIES

AASHISH ANANTHANARAYAN ‘21

Aashish Ananthanarayan is a senior computer science major from Mumbai, India. Aashish moved to the United States in 2017. His areas of interest are Deep Learning and Cybersecurity and he loves working on challenging and exciting projects in these areas.

MACK CLEVELAND ‘23

Mack Cleveland is a freshman chemical engineering major from Bedford, Texas. His interests range from chemistry and mathematics to philosophy and classics. Mack passionate about interdisciplinary learning, and Is excited by research because it offers an amazing opportunity to advance the boundaries of human knowledge.

ADEETA DONGRE '21

Adeeta Dongre is a senior biomedical sciences major who plans to become a veterinarian. Research and writing have been a huge part of her academic career, and most of her research thus far has been concentrated on animals (entomology) and chemistry (organic).

JILES FINCH ‘21

Jiles Finch is a senior biomedical sciences major from Midland, Texas. Jiles is a pre-med student that is also involved in the Biomedical Research Certificate Program. After graduation, Jiles plans to get a master’s in biomedical science or microbiology and then continue to medical school.

BOARD BIOGRAPHIES

DOUGLAS FLETCHER ‘20

Doug Fletcher is a recent statistics graduate from Clear Lake TX. He has since begun work as a health services researcher at RTI International. While at A&M, Doug was a member of the Academy of Undergraduate Researchers across Texas, an Undergraduate Research Scholar, graduated as an Honors Fellow, and was a member of the *Explorations* board throughout all of his undergraduate education.

THAO HO ‘22

Thao Ho is a junior bioinformatics major. Thao’s passion revolves around research and medicine and she wishes to one day pursue an M.D./Ph.D. program. Thao is a highly curious individual; therefore she loves learning and experiencing new things.

CATHERINE JOHNSON ‘23

Catherine Johnson is a freshman mathematics major from Nashville, Tennessee. Catherine has a special love in my heart for the more abstract problems in number theory, as well as the great unsolved conjectures in the mathematical field. After undergraduate, Catherine hopes to complete a M.S. Business through Mays Business School.

BRIAN LOWE ‘23

Brian Lowe is a junior aerospace engineering major from Weslaco, Texas. Brian plans to attend graduate school after graduation, however, his main passion is music. Having been a member of the Crossmen Drum Corps, Texas A&M's own engineering choir, and the Hullabaloo Pep Band, Brian wishes to bring a multidisciplinary background to his studies.

BOARD BIOGRAPHIES

ANDREA MEIER ‘21

Andrea Meier is a senior civil engineering major from Allen, Texas. Her interest in civil engineering is focused in water resources, and she intends to work in the water infrastructure planning field after graduation. Throughout her time at Texas A&M, she has had the chance to explore many interests through involvement in organizations.

URENNA ORAZULIKE ‘20

Urenna Orazulike is a senior pre-med public health major from Philadelphia, Pennsylvania. Urenna moved to Nigeria where she spent a huge part of her childhood. She returned to the U.S. in 2015 and completed her high school education in Erie, Pennsylvania, graduating with thirteen other students under completion of the International Baccalaureate Diploma.

REAGAN SPEXARTH ‘20

Reagan Spexarth is a recent political science graduate from The Woodlands, Texas. Reagan joined Explorations her freshman year, and was an active member of both the editorial board and the marketing and design team ever since. Reagan is passionate about research and worked as an undergraduate researcher at The Bush School of Government and Public Service where she studied government stabilization efforts in Kosovo.

AVERY TRAVIS ‘20

Avery Travis is a recent statistics graduate with a minor in mathematics. Avery joined Explorations with the belief that publishing research done by our students will not only help increase the prestige of our school, but also provide inspiration to those who may not know where to start in their own pursuit for research. Avery aspires to combine the skills she gained while on the board with her expertise in STEM to help connect people of all backgrounds in the scientific community.

BOARD BIOGRAPHIES

ANDREA VAN RAVENSWAAY ‘23

Andrea “Andie” van Ravenswaay is a junior applied math major with a double minor in art history and economics from Houston, Texas. Andie loves to travel whenever she can and is an aspiring actuary, who hopes to work in underwriting for art insurance.

REBECCA ZIVLEY ‘23

Rebecca Zivley is a freshman general engineering student from Houston, Texas. Rebecca is passionate about research and learning, and these interests led her to Explorations. It is her goal to become an engineering professor so that she can continue researching and sharing knowledge as part of her professional career.

LAUNCH

UNDERGRADUATE RESEARCH

Explorations: The Texas A&M Undergraduate Journal
114 Henderson Hall, 4233 TAMU
College Station, Texas, 77843-4233
United States of America

ISSN 2668-7525 (print)
ISSN 2688-7533 (online)

explorations.tamu.edu