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FROM OUR FACULTY

I was privileged to teach Aggies from incoming freshmen to graduating seniors and graduate students from the beginning to end of their degree programs. While graduate students were receptive, responses of undergraduates elicited by the word research continued to range from anxiety or something to avoid to a challenging and interesting opportunity. My B.S. degree in Nutrition from the University of Wisconsin included the use of sources beyond a textbook. Without copy machines or Internet, a lot of time was spent finding and reading peer-reviewed journal articles in the UW main and medical libraries. A few years later I was back in a library (Mississippi State) making copies of journal articles for my master's thesis on Hunger in America and then, after more years, in TAMU libraries for my dissertation. The value of published research in peer-reviewed journals to the researcher is and to the reader can be immeasurable. I also learned to enjoy reading research articles.

Peer-reviewed journal articles are fascinating because usually the authors are also the discoverers of the new knowledge presented in that paper. They are sharing what they found with us. Developing an appreciation of this wonderful resource in students was an unfaltering goal of mine during my career at Texas A&M. Students also learned about research. My courses became notorious for essay exams and all of those required journal articles. During the semester, students expressed their change in view of journal articles, from enigmas to valuable sources of information and, in comparison to textbooks, fun to read. Essay exams also became the preferred format because they could express their understanding of the issue on the exam while learning how to write about science.

Research relies on creativity to develop an original research idea, critical thinking to decide on the need for and practicality of the idea and evaluation of the results, and problem-solving because problems are plentiful with every research project. Then comes the need to document this research in the form of an abstract and presentation at a research conference or class and maybe even an article in a peer-reviewed journal. The ability to be involved in research at the undergraduate level at Texas A&M takes many forms but exists for students who are willing to invest the time and effort required because research also requires perseverance.

For more than a decade Texas A&M has offered something else, as well, a peer-reviewed journal for research by undergraduates only. Thus a student with an interest in learning through research can be involved in the entire process from research hypothesis and study design to data analysis and formulation of conclusions in a paper that just might be published in *Explorations*. This is outstanding experience in written communication. This journal showcases high-level research conducted by Texas A&M undergraduates with their faculty mentors. A source of pride for the university as a whole, its breadth of topics also is a means of broadcasting the opportunity to be included in this journal to all students on campus, not just those in STEM majors.

Graduates with research experience at any level have told me how valuable that experience has been for their careers and their future, whether that included graduate study, professional school, professional internships, or other careers. Graduates who have participated in, if not led, the effort to have their papers published in a journal like *Explorations* are even more prepared to succeed in their careers because of the ability to communicate in writing and accept criticism on their writing. Of interest is the fact that often the most enthusiastic about their undergraduate research experience are those who have gone into non-research careers, such as practicing medicine, educating children/teens, and working for a corporation.

Undergraduate research in whatever form and writing about one's involvement in research with the possible paper in a peer-reviewed journal, including of course, Explorations, are experiences that can promote success in future endeavors. That might be deciding on investments, assessing treatment modalities for patients, designing a forum on public health, or buying a car. Research and the ability to write and speak well make a profound difference.

This letter ends my career at Texas A&M University.

What a great way to go!

Dr. Karen Kubena
Professor, Nutrition and Food Science

CONTENTS

InNervate VR: Can Virtual Reality Teach Anatomy?

By Amber May Ackley and Karla I. Chang Gonzalez

Figure 1. 2-D anatomical diagrams do not support a 3-D understanding of anatomical structures nor allow for the observation of motion.

Motivation

Cadaver dissections, plasticized models, two-dimensional (2-D) diagrams, and didactic lectures—these are the primary tools of traditional anatomy education. However, these methods have many limitations and are not always enough to help students build a visual-spatial understanding of anatomical structures. For example, 2-D diagrams lose an entire dimension in detail and do not allow for the observation of the motion of muscles and nerves in a three-dimensional (3-D) space **(Figure 1)**.

Virtual reality (VR) applications for supplemental anatomy education have been one of several new trends to emerge in education technology.[1] VR is a strong 3-D platform for students to practice direct manipulation of complex anatomical structures.[2] In addition, VR provides a highly motivational learning environment while supporting the learning of those with lower visuospatial ability.[3] To fill a gap in traditional anatomy education and build on VR as education technology, our research explores the efficacy of VR as a platform for anatomy education.

Visualizing the routes of neuronal signaling through 3-D space is particularly difficult to present through the use of traditional teaching methods.[4] The relationship between nerves and muscles is complex, and nerve severance produces varied effects on the mechanics of a leg depending on where a nerve is damaged. Currently, the field of veterinary medicine is limited to understanding the underlying mechanics of muscle systems rather than observing the nerves and their muscles in motion.

For our creative research project, we built "InNervate VR," a VR program that allows a user to

Figure 2. Diagram depicting user interaction. InNervate VR allows a user to view a healthy animation on a canine thoracic limb. The user is able to sever five different nerves along any point. The resulting animation illustrates the change in the limb's range of motion. A different animation is played based on where and which nerve was severed.

interact with and innervate (supply nerves to) a canine thoracic limb. The user is able to sever certain nerves on a canine thoracic limb and view how the nerve damage affects the leg's range of motion. This tool will explore the possibilities of VR and seek to improve upon existing methods of higher-level anatomy education.

Background

Since its invention, VR has been noted for its potential in education and training purposes. There have been many case studies which test the usability of VR specifically for anatomy education. VR can provide engaging and intuitive environments for learning visually and spatially complex topics such as human anatomy, biochemistry, and molecular biology. One of the key reasons VR can surpass traditional methods of instruction is that VR enables users to move beyond "real-world" experiences by interacting with or altering virtual objects in ways that would otherwise be difficult or impossible.[5,6]

While there is much evidence supporting VR as a viable supplement of anatomy education, most studies evaluating the feasibility of VR educational tools conclude that it is not yet ready to replace traditional methods of teaching.[7] Some of the downsides of VR for training and education purposes include cost, acceptance

in the medical community, and limitations of technology including achieving realism. Furthermore, many studies comparing traditional methods of education versus new media-based methods conclude that while users who tested out new media methods had overall positive feedback on the experiences, they did not score significantly higher on evaluation exams than the users who followed traditional education methods.[8] Most VR anatomy programs take advantage of the medium's 3-D spatialization of anatomical structures, but their interaction is limited to switching visibility, adding and subtracting layers, manipulating the translation of organs, bones, muscles and structures, and viewing labels to learn about the spatial relationships of the anatomical structure.[9,10,11,12]

A literature review of the existing studies on VR teaching tools shows that the most successful VR programs are those which take advantage of the

SINCE ITS INVENTION, VR HAS BEEN NOTED FOR ITS POTENTIAL IN EDUCATION AND TRAINING PURPOSES

medium's unique capabilities to illuminate a difficult topic to teach using traditional methods. Through our research, we seek to increase the level of dynamic interaction than what previous VR anatomy applications permitted by allowing the user to change the animation and movement of the 3-D models in their environment **(Figure 2)**.

Exhibition

Our creative work exhibition demonstrated a user's experience in two distinct environments—the external environment and the internal environment **(Figure 3)**.

The first component of our exhibit, **the external environment**, is everything a user sees when they enter the Visualization Immersion Reality Lab (VIRL) at Texas A&M University. This stage of our exhibit is purely functional and includes all the necessary systems and components to utilize VR:

- HTC Vive headset, sensors, and controllers
- Structure built around the system delineating the area in which the user can move freely
- PC and associated systems that run the application on the headset

The second component of our exhibit, **the internal environment**, is the appearance of the exhibit through the lens of the HTC Vive headset. When using a VR application, the user's physical world is completely replaced with a rendered, computer-graphics generated scene. Due to the computer-generated nature of VR, we had complete agency in designing the user's experience of their environment within the application. The main focus of our application exhibit is the interaction between the user and the thoracic limb model, and we based our design decisions to facilitate this user interaction.

The application's environment is a simple room that is generally void of defining features. This simple layout reduces distractions commonly associated with the newness of VR to some users. In order to direct the user's attention to the learning target, the canine forelimb has the most saturated colors within the environment and is situated atop a visually unique pedestal structure in the center of the room. During

the interaction, our user is able to move around the space and view the model about the pedestal's full circumference. In addition to the physical components of our virtual environment, a user interface is needed to aid the user in understanding the different ways one can interact with the environment around them.

User Interface

We present our User Interface (UI) on two floating panels situated on the left and right sides of the leg, pushed slightly further back in space than the leg. This way, the user never loses sight of the leg when utilizing the interface. The most essential interaction within our program is the user's ability to define a location along a nerve, sever the nerve at said location, and observe how this nerve damage affects the leg's range of movement. Our solution to facilitating this interaction is to provide the user with a "Play Animation" button, paired alongside a "Reset" button. When pressed, the "Play animation" button will activate the thoracic limb to move in its full, healthy range of motion and come to a stop after two cycles. Each time the user damages a nerve, they can press "Play Animation" to view the resulting motion. If they would like to undo all damages and return their leg to a healthy state, they can press the "Reset" button. To cut a nerve, the user simply needs to point at a spot along a nerve and press the trigger of their hand controller. To better aid the user in understanding the results of their interactions, we have implemented visual feedback which turns the nerves and affected

Figure 3. External environment "VIRL" (left) and internal virtual environment "InNervate VR" (right).

muscles red when damaged.

We provide the user with a third UI element: a menu list of possible nerves. Each possible selection will show small markers along the nerve models, revealing to the user where cuts can be made along the nerve. Another key UI element is a slider that gives the user the ability to reduce or increase the opacity of the leg's muscle models, which will allow for a better view of any of the canine nerves obscured within muscles.

AR Findings

Collaborative research between the Department of Veterinary Medicine and Biomedical Sciences and the Department of Visualization is an ongoing endeavor and tools such as our InNervate VR fall under the umbrella of creative works known as Creative Anatomy. Within this sphere of development, InNervate VR has a related prototype augmented reality application, InNervate AR. Augmented reality is technology which superimposes computer-generated images over the user's view of the real world. AR typically utilizes hand-held devices such as phones to show imagery, unlike the less accessible headsets used by VR. A frequent critique of InNervate AR was the application's limited ability to compare a damaged limb from a healthy limb with a full range of motion. This feedback led us to create an option for the user to toggle on or off a second limb in InNervate VR that always plays the animation for a healthy range of motion. This toggle allows a user to view the

damaged limb side-by-side a healthy limb animation for comparison. Another way in which the prior AR work impacted our planned interaction is rotation features in the user interface. Even though a user is free to move around our thoracic limb asset while in the VR application, the AR application found that many users prefer to remain relatively stationary. By providing users with the option to rotate the leg, we can ensure that the users may view the limb in a 3D capacity even if they choose to stand in place. Both the previous AR work and our InNervate VR applications seek to fulfill a similar educational deficit in anatomy education. Their comparison may influence future work research under creative anatomy.

Reflection

During our public presentation of InNervate VR, users agreed that we did not include a sufficient introduction to our virtual environment. Users who were less familiar with VR platforms did not know what to

> **EVEN THOUGH A USER IS FREE TO MOVE AROUND...MANY USERS PREFER TO REMAIN RELATIVELY STATIONARY.**

do upon entering the environment; they almost always needed verbal instructions from us explaining the interactions they could do in our environment. Similarly, users who were unfamiliar with anatomy were unsure of what exactly they were observing on the canine leg.

To remedy both issues, we implemented a tutorial section to our VR application. The tutorial introduces the users to the space by encouraging them to click on certain buttons in a pre-defined order. This not only reveals to the user the interactions possible in InNervate VR but also allows non-VR users to become comfortable using the Steam VR hand controller systems. Our tutorial also includes a labeling section where we provided the names of each muscle, bone, and nerve on our canine thoracic limb. We hope this labeling module will serve as a teaching tool to non-anatomy students as well as a refresher to students with some anatomy experience. Most major changes we implemented after receiving feedback were related to user interaction. If we were to modify our VR program, we would solidify our desired user interaction at an earlier stage of development. Because the user interaction is critical to the success of VR, it would have benefitted us to pinpoint potential interaction problems, such as minimal introduction to the virtual environment, earlier.

We believe InNervate VR is a promising addition to the higher-level anatomy classroom. Ideally, it will be implemented as a lab activity where students receive traditional lectures covering the topics of innervation in the canine thoracic limb. Afterward, they enter our Virtual Environment and truly visualize the complex concept of innervation. Not only will the students' interaction with the canine limb solidify their understanding of their anatomy lectures, but our application allows them to view innervation in its true 3-D form. InNervate VR will help students better understand concepts for their exams, as well as reinforce anatomy students' overall holistic understanding of innervation, which will carry on to support them in their professions.

Feedback from both anatomy professors and students supports that InNervate VR does illustrate

a topic that is traditionally challenging for students to comprehend. These experts also indicated that we achieved our goal of accurately representing the movement and texture of the muscles that make up our limb. As demand for visualization tools for the medical community increases, and as technology becomes more affordable and accessible, InNervate VR and any ongoing InNervate projects resulting from it will greatly enhance the teaching of innervation and other spatially-complex topics.

Acknowledgments

References

1. C. Moro, Z. Štromberga, A. Raikos, and A. Stirling, "The effectiveness of virtual and augmented reality in health sciences and medical anatomy," Anatomical Sciences Education 10, no. 6 (2017), https://doi.org/10.1002/ase.1696.

2. S. Jang, J. M. Vitale, R. W. Jyung, and J. B. Black, "Direct manipulation is better than passive viewing for learning anatomy in a three-dimensional virtual reality environment." Computers and Education 106, (2017): 150–65, https://doi.org/10.1016/j.compedu.2016.12.009.

3. K. Stepan, J. Zeiger, S. Hanchuk, A. Del Signore, R. Shrivastava, S. Govindaraj, and A. Iloreta, "Immersive virtual reality as a teaching tool for neuroanatomy," International Forum of Allergy and Rhinology 7 no. 10 (2017): 1006–13, https://doi.org/10.1002/alr.21986.

4. N. Heise, H. A. Hall, B. A. Garbe, C. M. Eitel, and T. R. Clapp, "A Virtual Learning Modality for Neuroanatomical Education," The FASEB Journal (April 20, 2018).

5. Helene Hoffman and Dzung Vu, "Virtual Reality: Teaching Tool of the Twenty-First Century?" Academic Medicine 72, no. 12, (1997): 1076–81.

IDEALLY, [INNERVATE VR] WILL BE IMPLEMENTED AS A LAB ACTIVITY WHERE STUDENTS RECEIVE TRADITIONAL LECTURES

6. H. S. Maresky, A. Oikonomou, I. Ali, N. Ditkofsky, M. Pakkal, and B. Ballyk, "Virtual reality and cardiac anatomy: Exploring immersive three-dimensional cardiac imaging, a pilot study in undergraduate medical anatomy education." *Clinical Anatomy* 32, no. 2 (March 2019): 238–243, https://doi.org/10.1002/ca.23292.

7. S. A. Azer and S. Azer, "3D Anatomy Models and Impact on Learning: A Review of the Quality of the Literature," *Health Professions Education* 2, no. 2 (2016): 80–98, https://doi.org/10.1016/j.hpe.2016.05.002.

8. Anthony M. Codd and Choudhurt Bipasha, "Virtual Reality Anatomy: Is It Comparable with Traditional Methods in the Teaching of Human Forearm Musculoskeletal Anatomy?" *Anatomical Sciences Education* 4, no. 3 (2011): 119–25.

9. M. Fairén, M. Farrés, J. Moyés, and E. Insa, "Virtual Reality to Teach Anatomy," *EUROGRAPHICS* (2017).

10. Stepan, "Immersive virtual reality as a teaching tool," 1006–13.

11. Jang, "Direct manipulation," 150–65.

12. D. T. Nicholson, C. Chalk, W. R. J. Funnell, and S. J. Daniel, "Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model," *Medical Education,* 40, no. 11 (2006): 1081–8, https://doi.org/10.1111/j.1365-2929.2006.02611.x.

Amber May Ackley '19

Amber May Ackley '19 is a Visualization major with a minor in Computer Science from Plano, Texas, who went to Liberty High School. Amber's passion for art and computer graphics has lead her to pursue new media projects such as the educational anatomy application InNervate VR as an Undergraduate Research Scholar. After graduation, she is pursuing a career as a Rigging Artist in order to further explore biological motion and performance in CG characters.

Karla I. Chang Gonzalez '19

Karla I. Chang Gonzalez '19 is a Visualization major from El Paso, Texas. As a Visualization major, Karla has a passion for storytelling and technical problem solving. During her undergraduate career, Karla served as President for TAMU ACM SIGGRAPH and volunteered at two national SIGGRAPH conferences. She also worked as a graphic designer and editor for *Explorations* during her freshman year of college. Karla's long-term career goal is to work on animated feature films.

The Human Intestine in a Test Tube

By Rachel Elizabeth Stading

Introduction

Probiotics are a new trend in healthcare, but some people may not understand the role probiotics play in impacting the human body. Probiotics essentially exchange "bad" bacteria for "good" bacteria in the intestines. Human intestines contain a microenvironment of bacteria that breaks down indigestible carbohydrates, releases acids and gases, and synthesizes key vitamins. However, the overall health effects from the interactions between the bacteria living in human intestines and the rest of the body are still greatly unknown. The desire to understand more about the bacteria colonizing our intestines has recently grown due to an increased interest in probiotics in the health industry as well as groundbreaking discoveries linking intestinal bacteria to various brain conditions, such as Parkinson's disease and Autism. Often, these bacteria play crucial roles in nutrient and drug absorption in the digestion process. In order to know more, we must investigate the microscopic world of the human intestinal tract. The question then becomes: How do we run experiments to accurately test the interactions between bacteria and the human body?

Preliminary testing of drugs and chemicals on humans is far too dangerous and variable to be a viable option for experimentation. Animal drug testing can also be inaccurate, because most animals have different microbiological systems than humans. Because of these barriers, scientists have turned to testing through *in vitro* models. These *in vitro* models allow scientists to simulate the human intestinal tract without the use of living organisms for safer and more controllable experimentation. Simply removing a piece of live human intestines for testing is dangerous and costly. The objective of our research is to create an *in vitro* human intestinal model that will accurately simulate the interaction between bacteria and the human intestine. Essentially, we are striving to create a human intestine in a test tube.

IN VITRO MODELS... SIMULATE THE HUMAN INTESTINAL TRACT WITHOUT THE USE OF LIVING ORGANISMS

The human intestine is made up of several different types of cells. The goal of this experiment was to create a particular subset of human intestinal cells called an epithelial microfold (M) cell. These cells have the special characteristic of being able to transport microorganisms and macromolecules from inside the intestines to the connective tissue in the body where immune cells reside. M cells are known to be a part of the immune response, because they will often uptake antigens and present them to immune cells to react against foreign invaders and induce tolerance to beneficial bacteria.[1]

It was recently discovered that M-like epithelial cells could be created *in vitro* through the interactions between a type of human enterocyte cell-line, known as Caco-2, and a lymphocyte cell-line, known as Raji. Growing two different cell-lines together is known as a coculture. Both of these cell-lines are long-lasting and well characterized, allowing for proper experimentation. The purpose of this experiment was to determine whether M cells would become more differentiated through direct or indirect interactions between Caco-2 and Raji cells. Differentiation means that the interactions between Caco-2 and Raji cells have caused the formation of M cells.

To obtain M cells, Caco-2 and Raji cells must be cocultured in a format that allows for nutrient exchange and cell-cell interaction to promote the overall growth of the cells. Here, two coculture formats are evaluated: a direct one, in which the two cell types are allowed to be in close contact, and an indirect format, in which the

two cells types are physically separated by a porous membrane that allows for nutrient exchange. After three weeks of coculture, the amount of M-cell induction was evaluated for each coculture format. It was found that direct interaction between Caco-2 and Raji cells induced Caco-2 differentiation into M-cell to a greater extent than indirect interaction. Being able to obtain M-cells using the efficient and replicable technique of direct interaction will bring the scientific community one step closer to creating an accurate replica of the human intestine. Overall, an *in vitro* model promises to be an important tool in studying phenomena like bacterial invasion and immune activation in the human intestine.

Methods

Caco-2 and Raji cells were routinely grown separately following protocols from the American Type Culture Collection (ATCC). For the direct coculture model, Caco-2 and Raji cells were well mixed at a 1:1 ratio and allowed to settle for 2 hours at 37°C.[2] Then, the cell suspension was placed onto a permeable polyester membrane as shown in **Figure 1**. For the indirect coculture model, the Caco-2 cells were seeded onto a membrane and were allowed to propagate for 2 weeks.[3] Then, Raji cells were placed on the opposite side of the membrane to allow only for indirect interaction via chemical signals, which can also be seen in **Figure 1**. The control for the experiment was a culture of Caco-2 cells (monoculture) seeded onto the top side of a membrane, which was not expected to differentiate into M cells. All seeded membranes were incubated at 37°C with growth nutrient replacement every other day. Experiments were performed in quadruplicate. After incubating three weeks, the cultures were evaluated for M cell differentiation.

In order to evaluate the presence of M cells, three separate tests were performed.[4] The first test was a transepithelial electrical resistance (TEER) test. A TEER value measures the electrical resistance across the layer formed by the cells on the membrane. The more cells on the membrane means the higher the resistance measured. However, because M cells transport particles across the layer of cells and increase its permeability, more M cells

would be expected to cause a lower resistance across the membrane. For this experiment, the TEER values were measured for the monoculture, direct coculture, and indirect coculture models in order to gauge which of the three had more M cells.

The second test performed was a nanoparticle transport study. For this test, fluorescent nanoparticles were placed on the top side of each membrane. Because M cells transport particles like bacteria, a higher number of M cells would result in greater transportation of the fluorescent nanoparticles across the membrane. The number of fluorescent nanoparticles transported from the top to the bottom side of the membrane was measured by spectrophotometry, which measures the amount of light detected from the fluorescent nanoparticles.

The third test performed was a microvillus staining test. Microvilli are hair-like structures that project from many cells in the human intestine to aid in nutrient absorption. M cells, however, do not have microvilli. This test stains any cells that have microvilli; therefore, more M cells on the membrane would yield a greater number of unstained areas (e.g., dark spots) present on an image of the layer of cells. Statistical significance of the data obtained was evaluated with a significance of 0.05.

Figure 1. Experimental setup of the monoculture, direct coculture, and indirect coculture.

Results

The TEER values for the control monoculture, direct coculture, and indirect coculture can be seen in **Figure 2**. According to **Figure 2**, the monoculture had the highest TEER values. This result is expected, because the monoculture cannot differentiate into M cells. The indirect coculture had significantly lower TEER values, suggesting that M cells were present on the membrane, causing less resistance between the top and bottom sides of the membranes. The direct coculture

Figure 2. TEER values for the control, indirect coculture, and direct coculture membranes with respect to the control. *denotes significant difference with respect to control (p-value < 0.05).

Figure 3. Results for the nanoparticle transport study of the monoculture, indirect coculture, and direct coculture.

showed the least resistance across the membrane, suggesting the presence of the greatest portion of M cells out of the three cultures.

The nanoparticle transport study measured the amount of fluorescence transported across the membrane. The results of this study can be seen in **Figure 3**. Based on these values, the monoculture and indirect coculture did not show a significant difference in the number of fluorescent nanoparticles transported across the membrane. However, the direct coculture showed a much higher number of nanoparticles transported than either the monoculture or the indirect coculture, suggesting a much higher presence of M cells.

The microvilli staining experiment tested to see if there were any cells that did not contain microvilli (a characteristic of M cells). **Figure 4** displays the results from this staining experiment. As seen in these images, the monoculture is almost completely stained with very

few dark spots. The indirect coculture contains a few more unstained regions. The direct coculture shows a large amount of very dark spots where the stain did not adhere. Therefore, the staining images suggest that the direct coculture contains the greatest amount of M cells without microvilli because the stain did not adhere.

Conclusion

The results from the three tests confirm that the coculture of Caco-2 and Raji cells directly interacting with one another had a higher differentiation of M cells than the coculture of indirect interaction. The direct coculture had the lowest TEER values, the highest number of fluorescent nanoparticle transportation, and the greatest number of unstained regions for the microvilli staining. All of these results indicate the largest presence of M cells.

Based on the experimental results, a direct coculture model should be chosen over indirect coculture to differentiate M cells from interacting Caco-2 and Raji cells. Increasing the number of differentiated M cells allows for a more accurate creation of an *in vitro* human intestinal environment. The efficiency and simplicity of using the direct coculture model instead of the indirect coculture model will save time and energy for future scientists when obtaining M cells—an important subset of cells in the human intestines—for experimentation. This experiment signifies that direct interaction is a proven *in vitro* method for procuring M cells, which brings us closer to creating an accurate replica of the human intestine in a test tube.

Because of the success of this experiment, the next step for this research is to add other key human intestinal cells to the *in vitro* environment in order

Figure 4. The microvilli staining images of the monoculture, indirect coculture, and direct coculture. Light coloring denotes adherence of stain and dark coloring denotes lack of stain. Images are each 1200x900 mm.

THIS EXPERIMENT... BRINGS US CLOSER TO CREATING AN ACCURATE REPLICA OF THE HUMAN INTESTINE

to build a more representative model of the human intestinal tract. Furthermore, we plan to run experiments with M cells that incorporate different types of immune cells to study their joint immune response when presented with harmful bacteria and pathogens.

Creating an accurate and controllable *in vitro* model of the human intestinal tract is essential for exploring the relationship between the bacteria in human intestines and the overall health of the human body. With this more comprehensive *in vitro* model, intestinal bacteria's effect on infections, brain conditions, drug administration, and nutrient absorption can be tested and better understood by the medical community. The ultimate goal of this research would be that probiotics could one day be specifically designed to cater to the specialized needs of the individual.

Acknowledgments

REFERENCES

1. A. Gebert, H. J. Rothkotter, and R. Pabst, "M cells in Peyer's patches of the intestine," *International Review of Cytology* 167, (1996): 91–159.

2. P. Chaikhumwang, D. Nilubol, A. Tantituvanont, and P. Chanvorachote, "A new cell-to-cell interaction model for epithelial microfold cell formation and the enhancing effect of epidermal growth factor," *European Journal of Pharmaceutical Sciences* 106 (2017): 49–61.

3. A. des Rieux, E. Ragnarsson, E. Gullberg, V. Préat, Y. J. Schneider, and P. Artursson, "Transport of nanoparticles across an in vitro model of the human intestinal follicle associated epithelium," *European Journal of Pharmaceutical Sciences* 25, no.4-5 (2005): 455–65.

4. A. Beloqui, D. J. Brayden, P. Artursson, V. Préat, and A. des Rieux, "A human intestinal M-cell-like model for investigating particle, antigen and microorganism translocation," *Nature Protocols* 12 (2017): 1387–99.

Rachel Elizabeth Stading '19

Rachel Elizabeth Stading '19 is a chemical engineering major from Katy, Texas. Rachel began her research in order to explore the unknown questions pertaining to the human body. Rachel hopes to attend medical school to become a doctor so that she may pursue a life-long passion of exploring and studying the human body and helping others.

Are Wild Sea Turtles Feeding During Nesting?

By Nicole Guentzel

TRADITIONAL METHODS FOR ASSESSING NUTRIENT INTAKE IN WILD TURTLES HAVE SERIOUS LIMITATIONS

Introduction

Olive ridley sea turtles (*Lepidochelys olivacea*) are a vulnerable species with declining wild populations.[1] One reason for this decline is habitat loss, which can lead to decreased food availability. Poor nutrition in turn can lead to reproductive consequences such as skipped breeding years and fewer eggs.[2,3] If undernourished turtles are producing fewer eggs, hatchling numbers will decline, making species recovery more difficult. Therefore, assessing nutrient storage and utilization would also be helpful to better understand how environmental disturbances are impacting turtles' ability to fuel the energetically expensive physiological process of reproduction.

Traditional methods for assessing nutrient intake in wild turtles have serious limitations. One traditional technique called stomach flushing consists of prying a turtle's mouth open, inserting tubes down the esophagus, and pumping salt water through to force the stomach contents up a retrieval tube. This is a highly invasive process that can harm the turtle and only provides information about what a turtle has eaten immediately prior to capture, providing little information on long term food intake.[4] In an effort to develop less invasive means to assess nutritional state, the feasibility of applying two recently-developed, less invasive techniques to turtles in the wild were evaluated.

The first method is ultrasonography of subcutaneous fat, the tissue layer below the epidermis and dermis. Using ultrasonography to measure subcutaneous fat has been validated with necropsy in leatherback sea turtles but not in other sea turtle species. If a turtle is not eating this layer should thin as fat is redistributed to other tissues for energy. Well nourished, consistently eating turtles should therefore have thicker layers of subcutaneous fat than poorly nourished turtles.[5] Subcutaneous fat measurement may thus provide information about a turtle's long-term access to food. The second method is blood β-hydroxybutyrate (BHB) measurement. BHB is a ketone body that is produced from stored fat in the liver during fasting as an alternative energy source to glucose.[6] Price et al. conducted a feeding study in captive juvenile green sea turtles and concluded that BHB is an effective indicator of fasting status in this particular species since levels of BHB increased rapidly during fasting. BHB levels may therefore reflect mobilization of fat in fasting turtles. The first objective of my project was to determine whether subcutaneous fat and blood BHB measurement could also be applied as assessment methods for fat storage and mobilization in other sea turtle species like olive ridleys. To evaluate the applicability of these techniques in non-captive turtles, wild reproducing olive ridleys were used in this study. Whereas ultrasonography of subcutaneous fat may provide information about nutrient storage in this species, BHB may serve as a fasting indicator.

Understanding differences in fat storage and utilization between sexes would also be helpful for assessing the energetic and nutritional strategies used to maximize reproductive output of olive ridleys. The second objective of my project was to determine whether there were differences in subcutaneous fat and blood BHB between sexes. Female sea turtles are capital

Figure 1. A blood sample is taken from the dorsal cervical sinus of a wild olive ridley sea turtle. The turtle's head is covered with a wet black cloth to keep the turtle calm and the head is extended downwards to prevent injury.

breeders who fast during reproduction.[7] Capital breeders build up energy reserves at foraging grounds, cease feeding, and then migrate to nesting beaches, fueled by fat stores.[8] During this migration, females deposit yolk in their eggs. These eggs are contained in ovarian follicles. At nesting beaches, olive ridley females mate and lay multiple nests over a four-month period either during monthly mass-nesting events or solitarily. After a female has laid her last nest for her nesting season the remaining unfertilized eggs are absorbed in a process called follicular atresia.[9] This reproductive strategy suggests females will retain substantial fat stores at the beginning of their respective nesting seasons which they subsequently draw upon to fuel the energetic demands of nesting. Males are not as commonly studied as females, but in contrast, they typically do not fast during migration. Therefore,

> **FEMALES…ARE EXPECTED TO HAVE THINNER SUBCUTANEOUS FAT LAYERS AND HIGHER BHB LEVELS THAN MALES**

females utilizing a capital breeding strategy are expected to have thinner subcutaneous fat layers and higher BHB levels than males when they arrive at nesting beaches and post-mating (i.e. immediately after mating).

Methods

Sampling was conducted at Ostional Wildlife Refuge in Ostional, Costa Rica from June to September in the years 2016 through 2018. Ostional Beach is a unique site where thousands of olive ridleys migrate to mate and nest. Mating olive ridleys float on the surface of the ocean making sampling of both males and females possible. After copulation males and females were separated by our team and brought onboard a boat for sampling. A 10 mL blood sample was taken from the turtle's dorsal cervical sinus within five minutes of capture and placed immediately on ice to maintain integrity of the sample **(Figure 1)**. Blood samples were later centrifuged at the field station to separate out the plasma, which was immediately frozen to prevent sample degradation.

In addition to blood sampling, three ultrasound images were taken in the dorsal shoulder region of the subcutaneous fat using the shoulder joint as a landmark to keep the measurements consistent. Images were taken in this region because a turtle's shell blocks the ultrasound signal, limiting measurements to soft tissue regions. This location also consistently yielded the clearest images of tissue layers with multiple ultrasound measurements in leatherbacks.[10] ImageJ software was then used to measure the depth of the subcutaneous fat from sonogram images collected in the field. The three measurements were averaged for total fat depth **(Figure 2)**.

Figure 2. A representative sonogram of the dorsal shoulder region used for measurement. The subcutaneous fat is the anechoic (black) region between the echoic (white) regions of the epidermis/dermis and the skeletal muscle.

Figure 3. (A) Mean (± standard error) subcutaneous fat measurements by sex (B) and for early vs. late season females. (C) Mean (± standard error) BHB concentrations by sex (D) and for early vs. late season females. No comparisons were significantly different.

To categorize females based on reproductive state, females were placed on their shell in a car tire and gonadal ultrasounds were taken. Females with follicles were categorized as early season females and females in atresia were categorized as late season females. Gonadal ultrasounds were also used to detect if the intestines contained food. Intestines were only discernible in the sonograms if they were full.[11] Ultrasounds were not taken of the males.

Blood samples were returned to Texas A&M University where BHB was measured with a commercial BHB kit (Sigma Aldrich, St. Louis, MO) and read using a microplate spectrophotometer at 450 nm. The BHB standard curve provided with the commercial kit measured a range of concentrations from 0–10 mM. Because undiluted blood BHB concentrations exceeded this range, olive ridley blood samples were first diluted to 1:16 to allow them to be measured with the kit.

For the statistical analysis, two-way analyses of variance (ANOVAs) were used to compared means of subcutaneous fat and BHB between 26 females and 16 males. Next, the same series of ANOVAs was run contrasting 12 early versus 14 late season females. Lastly, a two-sample t-test was run assuming unequal variances for visible intestines and BHB to determine the relationship between intestinal state and BHB levels. The BHB concentrations of nine turtles with no visible intestines and of 17 turtles with visible intestines were compared in the t-test.

Results

Subcutaneous fat was distinguishable from surrounding tissues in sonograms **(Figure 2)** and easily measurable using image analysis software. There was no significant difference in subcutaneous fat between the sexes or in early versus late season females **(Figure 3)**. A 1:16 dilution of blood gave measurable concentrations of BHB, which likewise did not differ between the sexes or over time **(Figure 3)**. There was a significant difference in the comparison between BHB levels and intestinal state (P < 0.001). Turtles with no visible intestines had a BHB average of 98.3 (±18.5) mM and turtles with visible intestines had a BHB average of 85.7

(±5.7) mM, suggesting that BHB levels are elevated in fasting animals.

NEW CONSERVATION POLICIES... SHOULD BE CONSIDERED TO INCREASE FOOD AVAILABILITY

Conclusions

The results of this study indicate that subcutaneous fat and blood BHB are measurable in wild olive ridleys; therefore, ultrasonography and blood BHB measurement appear to be practical non-invasive techniques worth further analysis. In future studies, however, ultrasonography measurements of subcutaneous fat will need to be validated by comparing fat layers in olive ridleys at necropsy to ultrasonographic measurement of subcutaneous fat in the dorsal shoulder region as was done in leatherbacks.[12] Additionally, further studies should monitor how subcutaneous fat and blood BHB levels change during the four-month nesting period. Females are expected to be fasting during this period, so blood BHB is expected to increase as subcutaneous fat decreases.[13,14] Additional blood samples and ultrasounds can be taken from females previously sampled at post-mating during the monthly mass-nesting events to track changes in nutrient storage and utilization.

Ultrasonography was also used to detect intestinal contents in sonograms of females, a technique not previously described. BHB was elevated when intestines were empty and was lower when intestines were full. This result matched expectations that BHB should increase during fasting, a period when the intestines should be empty. The result also suggests that BHB may be functioning as an energy source in sea turtles in the same capacity as in mammals.

In comparing subcutaneous fat and BHB between sexes, females were expected to have thinner subcutaneous fat layers and higher BHB concentrations; however, there was no difference between sexes in either of these categories. If females are fasting, a difference is expected in these measurements because females should be fueling the deposition of yolk in eggs with fat reserves while males are fueling reproductive effort with food intake before arrival at nesting beaches.[15] Therefore, results suggest that females may be feeding at mating grounds. To further test this possibility, these same parameters were compared in early and late season females at post-mating. If females are fasting during the reproductive season, late season females should have thinner subcutaneous fat layers and higher BHB concentrations than early season females. However, there was no difference between early and late season females in any of these categories, providing further support for the possibility of females fueling reproductive costs with food intake at mating and nesting grounds.

Once fully validated, ultrasonography of subcutaneous fat and blood BHB measurement will provide less invasive and potentially more informative methods for assessing sea turtle feeding than stomach flushing. Expanding the application of these novel techniques to other sea turtle species should help us understand how food availability and nutrition impact sea turtle reproduction, as well as the physiological differences between males and females during reproduction. It will be particularly important to determine if both sexes have access to the nutrients needed to maximize egg production and population recovery. Currently, there are no sea turtle prey monitoring or management conservation policies in place in Costa Rica, which hosts two mass-nesting beaches and several solitary nesting beaches. If females are feeding during the reproductive season as our results suggest, new conservation policies, including monitoring and management of sea turtle prey species, should be considered to increase food availability, nutritional health, and reproductive output of sea turtles, thus helping to sustain these sea turtle populations for many years to come.

Acknowledgments

References

1. Jeffrey D. Miller, "Reproduction in Sea Turtles," in *The Biology of Sea Turtles*, ed. Peter L. Lutz and John A. Musick (Boca Raton: CRC Press, 1997) 51–81.

2. Annette C. Broderick, Brendan J. Godley, and Graeme C. Hays, "Trophic Status Drives Interannual Variability in Nesting Numbers of Marine Turtles," *Proceedings of the Royal Society B* 268, no. 1475 (July 2001): 1481–87, http://doi.org/10.1098/rspb.2001.1695.

3. Andrew R. Solow, Karen A. Bjorndal, and Alan B. Bolten, "Annual Variation in Nesting Numbers of Marine Turtles: The Effect of Sea Surface Temperature on Re-Migration Intervals," *Ecology Letters* 5, no. 6 (November 2002): 742–46, https://doi.org/10.1046/j.1461-0248.2002.00374.x.

4. Gregory A. Forbes and Colin J. Limpus, "A Non-Lethal Method for Retrieving Stomach Contents from Sea Turtles," *Wildlife Research* 20, no. 3 (1993): 339–43, https://doi.org/10.1071/WR9930339.

5. Heather S. Harris et al., "Validation of Ultrasound as a Noninvasive Tool to Measure Subcutaneous Fat Depth in Leatherback Sea Turtles (*Dermochelys coriacea*)," *Journal of Zoo and Wildlife Medicine* 47, no. 1 (February 2016): 275-79, https://doi.org/10.1638/2015-0023.1.

6. Edwin R. Price et al., "Serum Triglycerides and b-Hydroxybutyrate Predict Feeding Status in Green Turtles (*Chelonia mydas*): Evaluating a Single Blood Sample Method for Assessing Feeding/Fasting in Reptiles," *Journal of Experimental Marine Biology and Ecology* 439 (January 2013): 176–80, https://doi.org/10.1016/j.jembe.2012.11.005.

7. Miller, "Reproduction in Sea Turtles," 51–81.

8. Virginie Plot et al., "Leatherback Turtles Are Capital Breeders: Morphometric and Physiological Evidence from Longitudinal Monitoring," *Physiological and Biochemical Zoology* 86, no. 4 (2013): 385–97, https://doi.org/10.1086/671127.

9. David Wm. Owens, "The Comparative Reproductive Physiology of Sea Turtles," *American Zoologist* 20, no. 3 (1980): 549–63, https://doi.org/10.1093/icb/20.3.549.

10. Harris et al., "Validation of," 275–79.

11. A. L. Valente et al., "Ultrasonographic Imaging of Loggerhead Sea Turtles (Caretta caretta)," *Veterinary Record* 161, no. 7 (2007): 226–32, http://dx.doi.org/10.1136/vr.161.7.226.

12. Harris et al., "Validation of," 275–79.

13. Harris et al., "Validation of," 275–79.

14. Edwin R. Price et al., "Serum Triglycerides and b-Hydroxybutyrate," 176–80.

15. Miller, "Reproduction in Sea Turtles," 51–81.

Nicole Guentzel '19

Nicole Guentzel '19 is a graduating senior Biology major with a minor in Spanish from Baytown, Texas. Nicole participated in the 2018–2019 class of the Undergraduate Research Scholars where she completed her thesis, which culminated in this article, under the guidance of Dr. Duncan MacKenzie. After graduation, she hopes to pursue an advanced degree and encourage other students to do undergraduate research.

Influential Factors of Undergraduate Migration

By Sara Adnan AlBanna

Introduction

As means of mobility become increasingly widespread, globalization has led to the increase of international migration for education. In 2016, UNESCO found that the net flow of internationally mobile students bound for the US was 898,727[1] with approximately 970,000 inbound and 72,000 outbound.[2] The large quantity of students migrating to pursue higher education is a curious phenomenon, leaving many to wonder what inspires the decision. In 2013, there were 784,427[3] inbound students to the US with 67,153[4] from the Gulf Cooperation Council (GCC) countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates), constituting 8.56% of inbound international undergraduate students. At Texas A&M University, College Station (Texas A&M) the total percentage of international undergraduate students was only 1.60%.[5] Comparing national percentages to those at Texas A&M, we uncover a contrast; despite the large international student body across the US, only a small percentage choose to study at Texas A&M. It is crucial to understand the motives and factors that influence tertiary education migration trends and how they can be mediated.

One framework for understanding this form of migration is the push and pull hypothesis which considers the decision-making factors of high school graduates as attractive (pull) or repulsive (push). Push factors are conditions of the initial, country of residence that encourage graduates to study abroad due to the standard of living, economic, safety, or social factors that limit education potential. Pull factors refer to the advantages of choosing the destination country or institution that could be related to political, personal, monetary, geographic, or degree standard.

A previous study that attempted to analyze these factors considered variables of: quality of degree, convenience, and cost of the institution.[6] However, it overlooked the contribution an individual's upbringing, background, and personal virtues hold in the decision-making process, therefore limiting the decision of

where to pursue an undergraduate degree to a product purchase. This perspective does not explore how personal factors of preference such as family influence, political circumstances, and community strength affect outcomes.

In this study, personally motivated factors and their weights among students traveling to and from the GCC countries were analyzed to understand the increasing international undergraduate migration movement. Through this study, we can learn to better tailor the undergraduate system to enhance an institution's ability to satisfy student expectations, whether locally or abroad, increase attractive elements, and reduce the repulsion from academic institutions.

This analysis clarifies what factors may influence the trends of the international student body at Texas A&M. As a resident of Qatar and an undergraduate student at Texas A&M University at Qatar (Texas A&M at Qatar), I chose not to migrate for my undergraduate degree, but at least three quarters of the 120 students of my high school graduating class migrated to countries abroad. I hope to also use this study to understand what influenced so many of my peers to migrate outwards, and what could have potentially changed their decision.

Literature Review

Studies claim that it is crucial to know how a high school graduate decides whether or not to migrate.[5] They take the decision making process of high school graduates as the purchase or usage of services, which limits the consideration of other factors that contribute to the decision to migrate for a higher education.

The previously noted study[7] started with several non-hierarchical factors that could explain high school graduates' migration decisions. These factors included quality of study, academic reputation, educational offers, cost, location, employability rates, and external influences. The conducted research revealed the main motivation to travel abroad was "seeking an international experience for a personal, academic, and professional development," with the second strongest motivator as "academic reputation and quality." However, it is important to note that particular research study was broad, having been conducted on a pool of students whose only commonality was having attended a public university in North Portugal.

In contrast, my research aims to analyze the GCC as countries of origin and destination for undergraduate students. Having the GCC as the base reference allows the creation of generalizations that apply to students that have not participated in my study but did migrate from or to the GCC. To aid in attaining more focused data, research was conducted in the form of interviews and a survey.

Methods

Case Study

To understand and sample the local community and to extract the most influential factors of its decision making process, data collection was conducted with in-person first hand interviews at Texas A&M at Qatar. Two interviews were conducted. Both interviews were with current Texas A&M at Qatar Bachelor of Science students, one of whom we denote as "K," a Kuwaiti national freshman studying chemical engineering, the other denoted "AB," a Yemeni national junior in the petroleum engineering department. The names of both interviewees are left anonymous throughout the report.

Survey

To widen the scope of the study and increase diversity in collected data, a survey was released following the case studies. The survey was put together as an online Qualtrics survey and distributed on November 14, 2018 to undergraduate students at Texas A&M at Qatar by this project's faculty mentor. To collect information from students abroad, the survey was forwarded to individuals through snowball sampling.

The survey questions were as follows:

1. Gender
2. Nationality
3. Did you seek a higher education (BS/BA degree right after high school? If not, why?
4. What year did you enter an institution for a BS/BA degree?
5. What country did you reside in before your BS/BA?
6. If the country is different, what country did you travel to for a higher education (BS/BA degree)?
7. Rank the following according to their importance in your decision making process

(Options)

1. Independence
2. Close proximity to family
3. Reputation of institution
4. Availability of desired major
5. Cost of study
6. General safety level of the area
7. Familiar cultural/way of life
8. Future employment opportunities

8. Who was the most supportive of your decision?
9. Who was the least supportive of your decision?
10. Prior to beginning the BS/BA studies, what was the longest period you spent apart from your direct family? Pick the closest period. (never - one week - three months - six months - one year - >one year)
11. If you are willing to participate in an interview for further data collection, please insert your email below.

Limitations

This study had a few limitations in its design. The seventh question had eight options from which an individual can rank the important factors that play into their decision. These options were based upon previous research[8] and insight uncovered during the interviews. However, there potentially could be reasons not listed that rank higher on the scale of importance for different individuals. The line of research has not been restricted by the year at which members of the community entered an institution for higher education. The analyzed pool is considerably broad in that aspect as they range from 2010–2018, to ensure a variation in the findings and to connect why these respective decisions (migration) have been made. However, this could lead to variation in motive as the factors that caused a disadvantage previously may not exist today and vice versa.

THE "AVAILABILITY OF THE DESIRED MAJOR" WAS THE MOST IMPORTANT FACTOR

Results

Interview Results

The first interviewee, AB, stated that "I always knew I'm going to have to study in a university outside Yemen. Since my father knows that the education level [university level] is very bad in Yemen he wouldn't let us study there." Due to the local education level, political and economic instability, as well as the encouragement of his older siblings, who had each migrated for their undergraduate degrees, migration was not a question for AB, but more a matter of where to go. This concern was answered by the consideration to remain geographically close to family as he said, "I always had someone [family member] with me, and most often I had my mom there" emphasizing his wish for this to remain unchanged; moreover at the time of the interview, his brother, who encouraged him to study in Qatar, lived in Qatar.

The second interviewee, K, clarified that while his home country, Kuwait, had excellent educational opportunities, they were not as renowned for his desired major. K stated, "the university for petroleum engineering is exceptionally strong there [Kuwait], but I wanted to study something a little wider, less specialized and decided on chemical engineering." While exploring

his options for a well-respected certificate in chemical engineering, K recalled, "My dad was coming to Qatar for his work and decided to take me with him and told me to go and see what the University [Texas A&M at Qatar] was like. I agreed and together we came, and I decided to submit my application when I was doing my comparison." Another factor in K's decision lay in his increased proximity to family and to home as he said, "My mom was definitely the most supportive in my decision to come to Qatar. The least supportive would be my little brother since he didn't want me to leave and wanted me to stay in Kuwait, and it helps that I am now studying what I enjoy and still continue to be close to home."

Interview Analysis

The two case studies confirmed that students have different motives to migrate, but a generalization can be constructed: Migration, if not obstructed by unfortunate circumstances, is in search of the institution best known for the students chosen major with considerably increased proximity to family. The strength of this generalization was tested against a wider survey to further understand the extent of its application.

Thus far, four variables have been suggested to affect the decision of migration:

- Availability and quality of the institution and the desired degree
- Proximity to family and familiar environments
- Regional conflict
- Future plans and employment options

Furthermore, referencing the push and pull scheme, it appeared that K had shown more of a pull to Texas A&M at Qatar due to the degree standard being more promising than the one in his home country. AB presented a pull towards Texas A&M at Qatar for its attractive and promising study catalogue and the greater proximity to his brother. He also presented a push from his home country due to political instability and the general level of education.

Survey Results

The survey had a total of 60 respondents, aiding in

Figure 1. Question 7: Unfiltered responses

	Avg. importance	1-3 %	4-6 %	7-8 %
4. Availability of desired major	2.70	71.67	23.33	5.00
3. Reputation of Institution	3.17	65.00	30.00	5.00
8. Future employment opportunities	3.98	45.00	41.67	13.33
5. Cost of study	4.50	41.67	25.00	33.33
2. Close proximity to family	4.53	35.00	40.00	25.00
6. General safety level	5.17	23.33	45.00	31.67
1. Independence	5.48	11.67	60.00	28.33
7. Familiar cultural/ way of life	6.47	6.67	35.00	58.33

Table 1. Question 7: Data averaged table - 60 respondents

	Avg. importance	1-3 %	4-6 %	7-8 %
4. Availability of desired major	2.66	71.43	21.43	5.36
3. Reputation of Institution	3.18	60.71	32.14	5.36
8. Future employment opportunities	3.82	45.00	37.50	14.29
2. Close proximity to family	4.45	35.71	37.50	25.00
5. Cost of study	4.57	37.50	26.79	33.93
6. General safety level	5.04	23.33	44.64	30.36
1. Independence	5.36	12.50	58.93	26.79
7. Familiar cultural/ way of life	6.29	6.67	35.71	55.36

Table 2. Question 7: Averaged "From GCC" - 56 respondents

	Avg. importance	1-3 %	4-6 %	7-8 %
4. Availability of desired major	2.36	80.00	20.00	0.00
3. Reputation of Institution	2.88	76.00	20.00	4.00
5. Cost of study	4.36	40.00	32.00	28.00
8. Future employment opportunities	4.44	36.00	40.00	24.00
2. Close proximity to family	4.80	32.00	36.00	32.00
1. Independence	5.00	20.00	56.00	24.00
6. General safety level	5.32	12.00	68.00	20.00
7. Familiar cultural/ way of life	6.84	4.00	28.00	68.00

Table 3. Question 7: Averaged "To GCC" - 25 respondents

uncovering a general trend presented by the accumulated total responses.

Figure 1 shows how many times each option was ranked under a certain level of importance. With the data from the survey, **Table 1** was constructed highlighting the importance scale, the average, and the percentage under which each of the eight presented factors numbered in the seventh question fell.

From **Table 1**, the three most important factors in descending order by average are:

• Availability of desired major
• Reputation of Institution
• Future employment opportunities

The findings of **Table 1** reinforce the initial conclusion based off of the interviews. The "availability of the desired major" was the most important factor with over 71% of respondents placing it in their top three in ranking of importance. This was followed by "reputation of the institution," and "future employment opportunities." These results are an overview of the responses collected from individuals that entered university for a bachelor's degree between 2011 and

2018 without any restraints on the country of origin or destination. The second phase of the study consisted of analyzing data by comparing individuals migrating to vs. from the GCC.

A similar table to that made for the overall respondents was created for respondents that migrated from the GCC as well to the GCC.

The first thing to compare between the groups is the percentage of importance and the average importance of the top three factors.

Table 2 shows the most important factors of migrating from the GCC as:

• Availability of desired major
• Reputation of institution
• Future employment opportunities
• Close proximity to family

Table 3 shows the most important factors of migrating to the GCC as:

• Availability of desired major
• Reputation of institution
• Cost of study
• Future employment opportunities

Conclusion

In both cases "availability of desired major" is the leading response from the students surveyed. It is mutually followed by the "reputation of the institution." Thus far, there appears to be no discrepancy in the importance of these two factors regardless of the community of origin or destination. This finding hints that these two factors are the leading contributors to the decision making process of high school graduates choosing to migrate. This in part supports the generalization that: "Migration, if not obstructed by unfortunate circumstances, is in search of the institution best known for the students' chosen major with considerably increased proximity to family." However, the results start to diverge on the third ranked influential factor.

Graduates migrating from GCC countries held future employment opportunities as the third most influential, while students migrating to the GCC held future employment as the fourth most important factor. Additionally, the survey indicated that the increased proximity to family is more important to students migrating from the GCC than to the GCC. The second

ACKNOWLEDGING AND UNDERSTANDING DIFFERENT CULTURES CAN PREPARE AGGIES TO CONTRIBUTE TO THE INTERNATIONAL COMMUNITY

half of the generalization was made following the interviews conducted with students migrating both from the GCC to the GCC, which noted the importance of increased proximity to family. The importance this factor holds with students migrating from the GCC could indicate strong family influence or a community oriented-mentality.

With the push and pull hypothesis as an explanatory framework and considering the decision making process, it can be concluded that for students originating from the GCC, proximity to family is important. For institutions like Texas A&M with an increasingly diverse student population, it is critical to help international students create communities of diverse backgrounds and experiences. Taking the first step to create an inviting space for multiculturalism can encourage families to consider international institutions such as Texas A&M as not only a source for an undergraduate degree, but also as a welcoming community for students and their families. Creating diverse and inclusive communities pushes both the local and the migrating students out of their comfort zone to widen their perspectives and increase their Aggie experiences. In a world with increasing globalization, acknowledging and understanding different cultures can prepare Aggies to contribute to the international community.

References

1. "Education: Net flow of internationally mobile students," UNESCO Institute for Statistics, (March 20, 2019), http://data.uis.unesco.org/.

2. "Global Flow of Tertiary-Level Student," UNESCO Institute for Statistics, (2019), http://uis.unesco.org/en/uis-student-flow#slideoutmenu.

3. "Education" (March 20, 2019).

4. Laura Bridgestock, "Middle Eastern Students Abroad: In Numbers," www.topuniversities.com (April 10, 2015), https://www.topuniversities.com/blog/middle-eastern-students-abroad-numbers.

5. Texas A&M University Data and Research Services, *Enrollment Profile Spring 2017,* (February 23, 2017), https://dars.tamu.edu/Data-and-Reports/Student/files/EPSP17.aspx..

6. Diana Branco Oliveira and Ana Maria Soares, "Studying abroad: developing a model for the decision process of international students," www.tandfonline.com, (February 23, 2016), https://doi.org/10.1080/1360080X.2016.1150234.

7. Oliveira et al., "Studying abroad."

8. A&M, *Enrollment Profile*.

Sara Adnan AlBanna '22

Sara Adnan AlBanna '22 is a Petroleum Engineering major with a minor in geology studying at Texas A&M at Qatar. Sara is proudly the first female engineer of her family and looks forward to setting many more firsts in her career. With prospects to expand her studies into Renewable Energy Engineering she is keen to aid her local and international communities in finding collaborative ways to reduce our collective carbon footprint.

Designing Better Glucose Sensors for Diabetes Patients

By Christopher Wright

Introduction

Millions of people worldwide are affected by diabetes mellitus, a leading cause of death in the United States. This disease develops as a result of either disrupted insulin production (type 1) or altered insulin absorption (type 2), leading to increased blood glucose levels over long periods of time. To combat this disease, patients must closely monitor their blood glucose (BG) levels. Change in glucose levels can cause severe complications, such as cardiovascular damage, nerve degeneration, and vision damage, if left uncontrolled. Therefore, each patient requires access to reliable sensors to collect data to determine BG levels at any given time. While commercial sensors are widely available, they are quite expensive due to their high production cost, expensive glucose sensing materials, and the materials used to hide the sensor from the immune system. As more patients are diagnosed with conditions requiring access to reliable glucose sensors, the need for less expensive sensors dramatically increases.

The goal of this project is to explore different ways of creating low cost and reliable sensors. Most diabetes patients use one of two categories of sensors: single use test strips or continuous glucose monitors (CGMs). Both types of sensor are explored and improved upon with affordability being the central goal of this project. Furthermore, a standard metric for identifying if the sensor would be applicable for real patient use was identified as "within 15% of reference value if $\geq$ 100 mg/dL or 15 mg/dL of reference value if $\leq$ 100 mg/dL."[1]

Glucose Enzyme Molecule

Nearly all glucose sensors on the market employ the same technology for sensing glucose levels in a sample; the sensors use an enzyme to convert the concentration of glucose into an electrical signal **(Figure 1)** that is interpreted by standard electronics. The electronics used range from simple devices that measure the resistance of the sensor to more complicated ones that characterize the relationship between voltage and current applied to the sensor. The enzyme turns the glucose molecule and an oxygen (O_2) molecule into gluconic acid and hydrogen peroxide (H_2O_2).

Instead of using the typical oxygen, commercial sensors utilize electrons in this reaction. As more electrons are consumed, the electrical resistance of the material increases. Therefore, a simple resistance measurement can determine the glucose concentration in the solution.

This enzyme is an apt tool for determining the BG levels in patients. However, it is very difficult to use in integrated sensors. The difficulty lies in binding the enzyme to a solid material from which charges can be donated, since the enzyme most commonly exists in liquid solutions. The process of embedding enzymes in a conductive material is called immobilization. Developing new methods for immobilization is a primary research topic for developing glucose sensors that are lower cost, more accurate, or generating novel

Glucose → Gluconic acid

Oxygen → H_2O_2

Figure 1. Glucose sensing enzyme reaction.

Figure 2. Visual Explanation of Molecular Imprinting (MIP).[3]

ideas altogether due to the high level of difficulty of embedding enzymes.

Molecular Imprinting Technology

Molecular imprinting (MIP) is a technique that can potentially mimic the glucose binding site in the enzyme. The theory is that while a polymer is forming from the building of monomer groups, another molecule can be embedded in the polymer solution. Afterwards, the molecules that were on the surface of the polymer can be removed, forming a binding site that is the exact shape of the molecule used.[2] Therefore, this molecule is referred to as the template molecule.

This technology and process can also be used for glucose sensing **(Figure 2)**. Glucose can be used as the template molecule for molecular imprinting, but the correct polymer must be used. To sense glucose levels, a conductive polymer is needed because the electrical characteristics change when glucose binds to the surface. Polyaniline (PANI) was chosen as it is a conductive polymer that can be easily synthesized for a low cost. Therefore, a glucose sensor could be created using polyaniline as the polymer and glucose as the template molecule.

Reusable MIP Test Strips

In this research project, MIP is used to create low-cost test strips for measuring the glucose concentration of a solution. The challenge of this research is creating a method which measures glucose precisely in a wide linear range. The range at which a patient with diabetes mellitus might measure their BG is between 40-500 mg/dL or 2-30 mmol/L. Designing a sensor which linearly represents this range is a significant challenge due to decreased accuracy at extremely low and high glucose levels.

One problem with using PANI is that the material is not physically stable when its dimensions are small. When the sensor is fabricated, only a very thin film of polyaniline is synthesized. Therefore, our process is modified to include the addition of small paper strips to

the solution. The polyaniline solution is soaked into the paper substrate, giving it increased physical stability while maintaining similar electrical characteristics. Then to measure the concentration of glucose, electrodes can be connected on either side of the PANI soaked paper to measure the conductivity of the material.

GOx Ink Continuous Glucose Monitor

In addition to the test strips, we developed a flexible ink to sense blood glucose levels; interestingly, this can also be used in a variety of applications like smart tattoos.

To create this ink, the fabrication process of the test strip sensor is modified. Instead of adding glucose as a template molecule, the aforementioned enzyme is added to be immobilized in the PANI solution. Paper strips are not added as a substrate for the material because the PANI will be either embedded in the skin or deposited on a material. The ink could also be soaked into another substrate if desired.

The challenge with creating the ink is that the PANI should not fully form until it is ready to be deposited on another surface; once the monomers are linked together and the enzyme is embedded, it cannot be dissolved again. So, the ink must be stored for long periods of time in a simple, monomer form. Then, when ready to use, the monomers would knit together to create the final glucose sensing. The hydrogen peroxide product from the enzyme's reaction can be used to build the polymer. This allows the ink monomers to be linked together by simply soaking in a glucose solution. After the ink is saturated, the sensor is ready to react to glucose solutions.

Methods

MIP Sensor Fabrication

Fabricating the MIP sensor requires three groups of steps. The first and second are the preparation of

> MIP IS USED TO CREATE LOW-COST TEST STRIPS FOR MEASURING THE GLUCOSE CONCENTRATION OF A SOLUTION

Figure 3. Test strip creation process.

Figure 4. Figure demonstrating how the ink is fabricated.

the aniline solution and the oxidant solution. The third step is the combination of the two solutions, and the preparation of the strips **(Figure 3)**.

Hydrochloric acid (HCl) and Ammonium Persulfate (APS) are used in the reaction to bind the monomers together.

Glucose Sensing Ink Fabrication

Creating the ink is quite similar to creating the test strips. The main difference is that instead of imprinting the polymer with glucose, the enzyme is immobilized in the polymer due to its large size. In addition, HCl and APS are not used because the ink should lie dormant until it is ready to be used.

First, similar to the test strip fabrication process, the aniline monomer solution is created with the addition of the enzyme, instead of glucose as used in strip fabrication. Unlike the fabrication of the test strip, no oxidant solution is created because the hydrogen peroxide from the enzyme reaction is used. However, we create a solution that is 20% saturated with glucose

for use in the enzyme. Next, after depositing the monomer solution onto a surface such as the skin, the glucose solution is added to the surface. After several hours, the monomers will be fully linked and the sensor is ready. **Figure 4** gives a visual representation of how this process works.

Results

Glucose Test Strips

The test strips were very successful in correctly identifying the glucose solution. **Figure 5** shows that a linear range is observed with increasing resistance as more glucose is added. The R^2 value of the results indicates the linearity of the data. The closer the number is to 1, the better. In our case, this indicates great linearity.

Glucose Sensing Ink

Testing is still in progress for the ink, although some challenges have been identified. One of these being that the enzyme used to sense the glucose levels is very sensitive to pH and temperature levels. This affects the rate at which hydrogen peroxide is produced. The significance of this finding is that polyaniline synthesis is highly dependent on the rate of production, so the pH and temperature of the solution should be optimized.

THIS IS A GOOD STEP TOWARD ACHIEVING NONINVASIVE GLUCOSE MEASUREMENT

Figure 5. Data graph of the glucose test strips.

Using a fully formed polymer and breaking it apart might allow the enzyme to become immobilized.

A successful experiment was done that proves the process described above can work to synthesize polyaniline. However, experiments on ink performance in response to glucose are still in progress.

Conclusion

There is a large potential for usage of the improved MIP glucose test strips. Because of the very high linearity of the test strips, this shows the viability for replacing the current commercial strips. As a result, this could lead to huge savings in cost for patients. Because these strips also do not use the expensive enzyme, this leads to a much longer shelf life and greater ease of use in a variety of climate conditions.

As for the glucose sensing ink, this is a good step toward achieving noninvasive glucose measurement, a milestone goal for diabetes patients. This project demonstrates the large potential that this solution has and proves that the concept could work if more research is conducted on the ink's performance.

Acknowledgments

References

1. David C. Klonoff, MD, FACP, FRCP, and Bbb. "BLOOD GLUCOSE MONITORING SYSTEM SURVEILLANCE PROGRAM," *Diabetes Technology Society*, (June 23, 2017), https://www.diabetestechnology.org/surveillance.shtml.

2. Mohammad Masoudi Farid, et al., "Molecular Imprinting Method for Fabricating Novel Glucose Sensor: Polyvinyl Acetate Electrode Reinforced by MnO2/CuO Loaded on Graphene Oxide Nanoparticles," *Food Chemistry, Elsevier*, (July 29, 2015), www.sciencedirect.com/science/article/pii/S0308814615011620.

3. Satanaka, *Molecular Imprinting*, 2006, 1,159 x 449 pixels, https://commons.wikimedia.org/wiki/File:Molecular_imprinting.png.

Christopher Evan Wright '19

Christopher Evan Wright '19 is an electrical engineering major with a minor in mathematics from Katy, Texas. Christopher's research project was conducted in the 2018–2019 Undergraduate Research Scholar's program under the guidance of Dr. Jun Kameoka. Christopher hopes to attend graduate school a few years after working in industry. Afterwards, he hopes to continue to develop medical devices to help patients lead happier, healthier lives.

Thinking in Three Dimensions: Investigating Cell Mechanotransduction in 3D-Printed Scaffolds

By Darby Jane Ballard and Erica Michelle Huebner

Introduction

Between 2011 and 2018, the tissue engineering industry reported over $9 billion in sales of tissue engineering related products. Biomaterials-based companies are generating over 99% of this income, with cell-oriented companies accounting for the remaining sales. Perhaps more interesting is that the tissue engineering industry also reported over $35 billion in spending, with approximately $10.9 billion representing investment in research and development.[1]

Tissue engineering treatments use scaffolds, cells, and biologically active molecules to develop tissues that can replace damaged or diseased parts of the body. Regenerative medicine, a branch of tissue engineering, focuses on the concept of self-healing and allowing the body, with the help of medical therapies, to regenerate damaged tissues and organs.[2] Despite the substantial financial investments and research effort in this area, tissue engineering therapies play a relatively small role in patient treatment. Most research activity has been focused on biologic and immunologic factors, which are vital to the potential success of a tissue-engineered therapy. However, failures of tissue engineering therapies may also be related to mechanical factors. For example, complications may arise as a direct consequence of compliance mismatch, which occurs when there is a sudden discontinuity in mechanical properties. This can happen when dissimilar materials are bonded together and can result in premature failure. Problems may also be indirectly related to mechanical factors. For example, failure to maintain a physiologically relevant mechanical environment may result in aberrant mechanical cues adversely affecting cellular processes driven by mechanical factors. While considerable research has been performed on the materials involved in tissue engineering applications, the effects of mechanical factors on integration of engineered tissue grafts requires more investigation. Our research aims to fill this gap in knowledge and optimize the design of tissue engineered scaffolds to improve the development of functional tissues. These tissues can then be used to replace damaged and diseased tissues in clinical settings.

Cells are mechanotransducers, meaning they respond to external mechanical forces biochemically through gene expression and protein production. Therefore, the mechanical environment in which they grow affects how they develop and differentiate.[3] Most healthy, growing cells produce an extracellular

Figure 1. Scaffold degradation process.

matrix (ECM), which provides mechanical support for cells and is the primary structural component of most tissues. The ECM also contains important cues that influence how cells differentiate and grow. There are numerous strategies for producing engineered tissue grafts, though there are common elements in each. In one approach, cells are seeded, or chemically attached, onto a biodegradable synthetic scaffold, which is then implanted in a patient. After implantation, the cells begin their normal activity which includes production of ECM.[4] Ultimately, the synthetic scaffold completely degrades, and the ECM remains as a biologic scaffold to support the tissue. Alternatively, the graft can be grown in vitro or outside of the patient. The process is similar with the exception being that the cells used to produce the ECM are removed from the scaffold and replaced with autologous cells, i.e. cells from the patient, prior to implant **(Figure 1)**. Different scaffolds can be constructed by varying parameters such as material, porosity, surface properties, mechanical properties, etc. Because of the cells' mechanotransductive properties, which dictate their behavior based on their mechanical surroundings, the mechanical design of the scaffold influences how the cells grow and what biochemical signals they produce. To explore this phenomenon on both 2D and 3D structures, we 3D-printed scaffolds, tested their mechanical properties, seeded cells onto them, and analyzed the cellular response to mechanical stimulation.

Methods

Our study thus far has been divided into four main components: scaffold printing, mechanical analysis, cell culture, and mechanical stimulation. Initially, 3D-printed silicone scaffolds were printed using an envisionTEC®3D-Bioplotter™. Silicone (polydimethyl siloxane, PDMS) was selected for its printability and biocompatibility, meaning that it could safely be used in cell culture. By using a pressure-based extrusion printer and adjusting factors such as printing needle diameter, extrusion pressure, print speed, and strand spacing, the scaffold dimensions could easily be altered, creating a variety of microarchitectures to test. In particular, scaffolds of various structures were printed, including a 90-degree grid pattern, a 60-degree grid pattern, and a wave pattern **(Figure 2)**. We anticipate that scaffolds of varying architectures and dimensions will produce different mechanical environments in which cells

Figure 3. Eulerian strain calculated with Ncorr.

would grow, allowing us to better direct the way cells will behave once implanted in the body. Through later testing, we will gain an understanding of which scaffold features induce which cell behaviors, allowing us to better direct cell-to-tissue development.

The stretch characteristics of each scaffold design were characterized using uniaxial tensile testing **(Figure 3)**. This method utilizes a device that clamps the scaffold on both ends, then stretches the material in one direction at a specified rate. To observe the scaffold responses, we used Ncorr

Figure 2. Scaffold print patterns.

digital image correlation (DIC) MATLAB software, an optical measurement technique for quantifying local displacements and strains from imaging data. Each scaffold was stretched, increasing one percent in length per second, with photos for DIC taken at one-second intervals, until the scaffold had doubled in length. Using this data, we can calculate the localized strains on the scaffold at any point in time.

Cells were then cultured onto the 3D scaffolds we had printed, along with 2D PDMS (silicone) membranes. These membranes were used to acquire a baseline understanding of the scaffolds by characterizing simpler, single-layered versions of the 3D membranes. Both the scaffolds and membranes were treated with surface protein to encourage cell adhesion. Scaffolds were treated with either 2%-gelatin, 4%-gelatin, or fibronectin, and membranes were treated with fibronectin only. All surfaces were introduced to 3T3 fibroblasts, a line of mouse connective tissue cells, which were incubated to confluence, when they successfully cover the surface of the structure. The 3D scaffolds were analyzed through phase contrast imaging and the 2D membranes through staining and fluorescence microscopy. Both analyses allowed us to visualize cell morphology, or physical shape, and detect the presence of key features.

Finally, stretched cell microscopy was performed to examine cell physical behavior in response to a mechanical stimulus. In this process, cell-seeded 2D membranes were loaded into a bioreactor for mechanical testing. This bioreactor contained clamps to hold the membrane sample in place and was filled with cell media that enabled cell survival throughout the mechanical testing process. A stepper motor attached to the bioreactor was used to induce a cyclic load on the membranes that would repeatedly stretch and relax samples. The membranes were stretched for six hours under a sinusoidal stretch to ten percent strain at a frequency of 1 Hz. After a second incubation period, the membranes were fixed and stained through the aforementioned process. Performing fluorescent microscopy on the mechanically stimulated membranes as well allowed us to compare changes between membranes with and without loading in the nuclei and F-actin fibers.

Results

Fibroblasts cultured on both the 2D PDMS membranes and the 3D scaffolds successfully grew to confluence, covering a wide area of each surface and maintaining healthy morphology. Our results pertaining to the 3D scaffolds provide initial insight on the viability of our testing methods and will inform future experiments. The ability to culture fibroblasts onto these surfaces shows the potential for 3D bioprinting to provide a stable environment for cellular development. After cells on the membranes were fixed and stained with 4′,6-diamidino-2-phenylindole (DAPI) to show nuclei[5] and rhodamine phalloidin to indicate F-actin protein fibers, observation under a fluorescent microscope revealed the presence of both nuclei and F-actin fibers **(Figure 4)**.

Because these key cell structures appeared, we verified that PDMS membranes are a viable option for future cell culture tests. Additionally, analysis of the

Figure 4. Fibroblasts on 2D membrane stained to show presence of cell nuclei (blue) and F-actin fibers (red).

Figure 5. Enlarged phase contrast image of untreated, Bioplotter-produced 3D structure seeded with fibroblasts.

cell-seeded 3D scaffolds under phase contrast imaging revealed that the cells adhered best to the untreated scaffolds, independent of any other factors. This surprising result will require further investigation and will help us to better understand the conditions that promote cell growth **(Figure 5)**. Lastly, staining and imaging the membranes subjected to mechanical loading revealed that the F-actin fibers aligned in a uniform direction when stretched **(Figure 6)**. This supported our hypothesis that physically manipulating the scaffolds affects the physicochemical properties of the cells. Further understanding of how different mechanical factors affect cell behavior will allow us to better predict how they may differentiate or what tissues they may form (e.g., muscle, bone, skin). This will aid us in being able to properly characterize the specific effects that the scaffold microarchitectures have on cell development.

Figure 6. Fluorescent images of F-actin with and without loading.

With our experimentation, we successfully developed a protocol for testing various scaffold designs and analyzing the response within the cells. This can be used in future trials to validate and verify the accuracy of our data. Through our study, we demonstrated that varying the structures of 2D and 3D scaffolds could provide feasible ways to induce changes in the physicochemical properties of the cells. This knowledge will enable us to create higher-performing engineered tissues in the future. Better engineered tissues allow for a higher degree of specificity in patient treatments, and subsequently a greater likelihood of treatment success.

Future Directions & Conclusion

In the future, we plan to produce more complicated scaffold structures, potentially using soluble support structures and different materials like collagen. Here, we could alter grid angles to explore different microarchitectures, which would affect the surface area to which cells could adhere.[6] Additionally, printing new geometric structures would modify the scaffold mechanical properties, providing different mechanical environments in which cells would develop **(Figure 7)**. Different cell types will be seeded onto the various scaffold designs then observed and tested as they differentiate. We will also begin using RT-PCR, reverse transcriptase polymerase chain reaction, to measure the type and quantity of genes that the cells are expressing. By identifying what chemicals the cells are releasing, we will be able to better investigate the effects induced by the mechanical environments on cells.

Figure 7. Future scaffold pattern.

Tissue engineering technologies could potentially address many of the diseases and injuries that are difficult to treat with the limits of current methods, particularly because replacement tissues may offer a better alternative to some current medical solutions. For instance, engineered tissues could be used to enhance hernia repair or skin regeneration techniques. In a greater context, our research could contribute to advancing the medical field to be capable of solving a greater variety of medical problems through highly-personalized solutions.

ENGINEERED TISSUES COULD BE USED TO ENHANCE HERNIA REPAIR OR SKIN REGENERATION TECHNIQUES

Acknowledgments

REFERENCES

1. Y. S. KIM, M. M. SMOAK, A. J. MELCHIORRI, AND A.G. MIKOS, "AN OVERVIEW OF THE TISSUE ENGINEERING MARKET IN THE UNITED STATES FROM 2011 TO 2018," *TISSUE ENGINEERING PART A* 25, NO. 1–2 (2019), DOI:10.1089/TEN.TEA.2018.0138.

2. M RAO, "THE NIH AND THE REGENERATIVE MEDICINE FIELD," *REGENERATIVE MEDICINE* 7, NO. 2 (2012): 129–31, DOI:10.2217/RME.12.8.

3. B. ENYEDI AND P. NIETHAMMER, "A CASE FOR THE NUCLEAR MEMBRANE AS A MECHANOTRANSDUCER," *CELLULAR AND MOLECULAR BIOENGINEERING* 9, NO. 2 (2016): 247–51, DOI:10.1007/S12195-016-0430-2.

4. K. M. KENNEDY, A. BHAW-LUXIMON, AND D. JHURRY, "CELL-MATRIX MECHANICAL INTERACTION IN ELECTROSPUN POLYMERIC SCAFFOLDS FOR TISSUE ENGINEERING: IMPLICATIONS FOR SCAFFOLD DESIGN AND PERFORMANCE." *ACTA BIOMATERIALIA* 50, (2017): 41–55, DOI:10.1016/J.ACTBIO.2016.12.034.

5. *DAPI (4',6-DIAMIDINO-2-PHENYLINDOLE)*, HTTPS://WWW.THERMOFISHER.COM/US/EN/HOME/LIFE-SCIENCE/CELL-ANALYSIS/FLUOROPHORES/DAPI-STAIN.HTML.

6. L. PHILLIP AND S. RAMILLE, "3D-PRINTED GELATIN SCAFFOLDS OF DIFFERING PORE SIZE AND GEOMETRY MODULATE HEPATOCYTE FUNCTION AND GENE EXPRESSION," *FRONTIERS IN BIOENGINEERING AND BIOTECHNOLOGY* 4, (2016), DOI:10.3389/CONF.FBIOE.2016.01.01756.

Darby Jane Ballard '20

Darby Jane Ballard '20 is a senior biomedical engineering major from Del Rio, Texas. Ballard has conducted research in the Biomechanical Environments Laboratory at Texas A&M and plans to pursue her interest in autoimmune disease therapies at the graduate level once she receives her undergraduate degree.

Erica Michelle Huebner '20

Erica Michelle Huebner '20 is a senior biomedical engineering major with a minor in mathematics from Seabrook, Texas. Erica has been a part of the Biomechanical Environments Laboratory working under Dr. Michael Moreno since summer 2018 and continued her research through the Undergraduate Summer Research Grant Program in 2019. Upon graduation, Erica hopes to attend graduate school and eventually pursue a career researching tissue engineering and stem cell therapies.

Utilization of Violence and Human Sacrifice among the Moche

By Richard Dally

Introduction

The essence and comprehension of human sacrifice performed by ancient cultures across the world are proven in the archaeological record, and in some cases, continue to remain open for discussion. Human sacrifice is customarily defined as an act of killing a person as a propitiatory offering or as a retainer sacrifice to a divine figure, and it has a large cultural significance in the history of Peru. The scope of this research focuses on the Moche culture that flourished before the Incan and Chimu empires of ancient Peru. Through the review of relevant literature, iconographic interpretation, and archaeological and osteological analysis, this research explores how the Moche elite and priests utilized human sacrifice to affirm and advance their religious and political polities to maintain order over internal and neighboring rival polities.

The Moche, or Mochica, were named after the Moche river valley in the North Coast of Peru. As written records do not exist, archaeology and anthropology provide a better understanding of the Moche's cultural identity through analyzation of material culture, archaeological sites, and iconography. The Moche dominated the majority of the North Coast of Peru during the Early Intermediate Period (200–850 CE). Their influence and material culture ranges from the far north Piura valley to as far south as the Huarmey valley.[1]

The Moche utilized the craftsmanship, sociopolitical structure, and technology from pioneering Peruvian cultures to make themselves culturally distinct in the pre-Columbian world. Although they lived in an arid coastal environment, the Moche thrived by incorporating maritime resources and advanced agriculture through a system of irrigation canals. The

> THE MOCHE UTILIZED THE CRAFTSMANSHIP, SOCIOPOLITICAL STRUCTURE, AND TECHNOLOGY FROM PIONEERING PERUVIAN CULTURES TO MAKE THEMSELVES CULTURALLY DISTINCT

Moche channeled rivers from the Andes to cultivate and augment agriculture potential. They were specialists in sophisticated metallurgy, textiles, and ceramics, as well as in constructing adobe temples, pyramids, and palaces known as huacas.[2]

Literature Review

Our comprehension of the Moche's political and social organization has changed throughout decades of archaeological research and interpretation. Rafael Larco Hoyle, a pioneering Peruvian archaeologist, categorized the Moche by developing a five-stage chronology through analysis and interpretation of Moche art style and ceramic vessels. Larco's chronology allowed future scholars to divide the Moche into three phases: Early Moche, Middle Moche, and Late Moche. The huacas suggest the Moche were a highly stratified political and religious hierarchy that expanded their range of influence through militaristic behavior as a state-like society.[3] However, it is now widely acknowledged that there were two spheres, northern and southern, of Moche influence. The north is "characterized as a loose confederation of culturally similar polities" and the south, as a militaristic and expansionist state society.[4] Understanding Moche's sociopolitical structure

Figure 1. Rollout drawing of a large combat scene by Donna McClelland. Image Courtesy of the Christopher B. Donnan and Donna McClelland Moche Archive, Image Collections and Fieldwork Archives, Dumbarton Oaks, Trustees for Harvard University, Washington, D.C.

Figure 2. Rollout drawing of combat between two pairs of warriors by Donna McClelland. Image Courtesy of the Christopher B. Donnan and Donna McClelland Moche Archive, Image Collections and Fieldwork Archives, Dumbarton Oaks, Trustees for Harvard University, Washington, D.C.

provides further insight into their elite's motives for human sacrifice and warfare.

The purpose of Moche warfare and human sacrifice depicted in iconography continues to be a topic of debate. Sutter and Cortez addressed three competing models, primarily derived from ethnohistoric analogies and iconographic interpretations that potentially offer clarification for Moche human sacrifice and warfare. Model A suggests the Moche performed staged ritual one-on-one combat amongst the local elite within their society. Model B proposes combat with non-Moche polities through traditional militaristic state expansion. Model C posits the Moche were engaging in warfare with conflicting independent Moche polities in neighboring valleys.[5] Mortuary samples gathered from Moche archaeological sites provide insight to the origins of sacrificial victims. Biological analyses help determine

biodistance and oxygen isotope compositions of dental samples gathered from skeletal remains of sacrificed and non-sacrificed individuals.[6,7,8] This allows researchers to identify the origins of the sacrificial victims at Huaca de la Luna and apply them to the competing models.

Moche Iconographic Scenes of Violence and Sacrifice

Warfare is easily recognizable in Moche iconography, with frequent scenes of one-on-one combat found on ceramic vessels and murals located in temples **(Figures 1, 2)**. Combat is depicted through the phases of the Moche but most commonly found on Middle and Late Moche ceramics. The interpretations of combat scenes can be categorized using the three models mentioned above.

Figure 3. Rollout drawing of warriors leading nude prisoners by a rope by Donna McClelland. Image Courtesy of the Christopher B. Donnan and Donna McClelland Moche Archive, Image Collections and Fieldwork Archives, Dumbarton Oaks, Trustees for Harvard University, Washington, D.C.

Figure 4. Rollout drawing of the Sacrifice Ceremony, or Presentation Theme, by Donna McClelland. Image Courtesy of the Christopher B. Donnan and Donna McClelland Moche Archive, Image Collections and Fieldwork Archives, Dumbarton Oaks, Trustees for Harvard University, Washington, D.C.

Model A was favored by Moche scholars due to the recognition of the warriors' Moche style apparel and weapons in combat scenes, indicating that the Moche warriors were fighting against other warriors from their population. The scholars assert that the primary objective of these ritual battles was not to kill opponents, but to wound and defeat them in battle. Defeated warriors were taken as captives, stripped of their regalia and clothing, and paraded to a religious power center for a sanguineous ceremony **(Figures 3, 4)**.[9] Proponents of Model A assert that the Moche's representation of the combat scenes parallels tinkus, ethnohistoric Andean highland ritual battles. However the comparison is problematic and archaeological evidence is not consistent with the tinkus.[10]

Model B focuses on combat with non-Moche polities (e.g. Recuay and Gallinazo).[11] This model is unlikely due to a lack of foreigners represented in these scenes; however, opinions differ on whether foreigners are depicted in Moche iconography.[12] Model C posits that the Moche were engaging in religious or secular combat with Moche polities in neighboring valleys,[13] which explains the similarities between the Moche combatants depicted in iconography and supports the idea of ritual one-on-one combat posited in Model A. Knocking off an opponent's helmet or grabbing the foe's hair is a sign of capture or a "visual metaphor for a military victory over an enemy or competing polity," which has also been documented in other cultures **(Figure 2)**.[14] Placing Model C in the greater context of the Moche's sociopolitical organization supports the northern and southern spheres of Moche influence.

The most iconic religious ceremony depicted in Moche iconography is the Sacrifice Ceremony, or the Presentation Theme, that represents a sanguineous religious ceremony **(Figure 4)**. In the lower portion of this scene, two bound captives' throats are slit for exsanguination by ceremony participants who collect the captives' blood in goblets. The upper portion reveals the Warrior Priest, receiving a goblet presumably filled with blood, from the Bird Priest, followed by other prominent figures participating in the ceremony. Originally, the Sacrifice Ceremony was interpreted as a mythical scene, however, excavations of Moche power centers in the Lambayeque and Jequetepeque Valleys revealed elaborate tombs of elite individuals adorned in regalia similar to the figures in the Sacrifice Ceremony.[15] These tombs indicate the Moche, or at least the elite, participated in these religious sacrificial ceremonies. A ceremonial goblet that contained human blood antigens was excavated from a tomb, perhaps to be consumed by the attendants of the ceremony.[16]

These archaeological discoveries offer a better understanding of Moche religious ideology and organization. The regalia of recognizable characters depicted in the ceremony found in tombs were real, or at least they participated in a guise of supernatural figures and deities, confirming the Moche conducted ceremonies requiring the sacrifice of captives.[17] These ritual roles were passed down, as indicated by multiple, non-contemporaneous burials of similar fashion. The Sacrifice Ceremony was enacted in numerous sites throughout many valleys. Huaca El Brujo in the Chicama Valley houses painted friezes of prisoners and supernatural spider decapitators with a human femur from a fleshed body integrated into the friezes, suggesting that the decapitator scenes and prisoner display are not metaphorical.[18] Several portrayals of the decapitator god (e.g., fish, spider, and birds of prey) are presented in Moche iconography, and evidence of sacrificial decapitation was found at Huaca Dos Cabezas in the Jequetepeque Valley.

Moche Human Sacrifice at Huaca de la Luna

Huaca de la Luna in the Moche Valley is well-known for containing sacrificial victims, especially at Plazas 3A and 3C. Excavations conducted at Plaza 3C revealed it was enclosed with adobes preceding the erection of Plaza 3A, supporting the idea that the plazas were "not in use at the same time, but date to different construction phases."[19] Radiocarbon-dated samples revealed that nearly all human sacrifices in

Plaza 3C were buried over several centuries in eolian sediment (i.e., windblown sand) during typical weather associated with the arid environment. Thin and few layers of fluvial sediment in the stratigraphy is evidence of infrequent rainfall over time, which revealed no signs of correlation between rainfall and number of victims. The earliest evidence of human sacrifice dates to the beginning construction stages of Huaca de la Luna. These early sacrifices did not take place in Plaza 3A, as it was rapidly built due to threatening El Niño flooding. Excavations at Plaza 3A uncovered roughly seventy-five individuals that likely died in six distinct events. Some of the victims in Plaza 3A were embedded in colluvial and alluvial sediment (i.e. mud) and some eolian sediment, which implies that they were sacrificed during and after torrential flooding caused by at least two El Niño episodes.[20] Data from high-resolution ice-cores indicates that there was frequent torrential flooding around the same time Plaza 3A was in use.[21] Environmental and sociopolitical disruptions, caused by torrential flooding, likely spawned local skirmishes among rival Moche polities which ultimately led to the human sacrifices at Plaza 3A.

The individuals sacrificed in both plazas were young, healthy males showing signs of injuries, especially parry fractures, which is a defensive fracture of the ulna at midshaft. These injuries are consistent with combat, indicating that they were professional warriors with experience. Fracture wounds were found in "the early stages of healing at the time of death: apparently wounds sustained in combat or following capture."[22] This suggests that several weeks has passed between when they were captured and sacrificed. The victims were seated and bound before being sacrificed, as represented in Moche iconography, supporting all three models **(Figure 3)**. The sacrificial remains at Plaza 3C are usually articulated while most of the remains in Plaza 3A are disarticulated and unbound.[23,24] The disarticulation of the skeletal remains in Plaza 3A may be a result of vulture scavenging, which has also been seen in Moche iconography.[25]

Osteological analysis of the remains in both plazas indicates that the majority of the victims had their throats

slit, as indicated by nicks across the cervical vertebrae and few "unequivocal cases of decapitation" **(Figure 4)**.[26,27,28] There is evidence of skull fractures associated with eight victims at Plazas 3A and one from 3C that were perimortem. The reason some of the victims were clubbed remains ambiguous. Although Moche warriors were depicted in iconography striking captives to induce nose bleeding, scenes of victims being bludgeoned to death are unknown. Further analysis reveals that some of the victims with skull fractures, whose cervical vertebrae are still attached, also show cut marks of a standard throat slice that is common with majority of the victims.[29] Hence, the practice of bludgeoning victims was not an alternate modus operandi of human sacrifice, "but perhaps an embellishment reserved for a select few," or victims who resisted being sacrificed. Nonetheless, the evidence does not support Model A because if it were staged ritual combat the victims would have been willingly sacrificed by traditional throat slitting. These examples of bludgeoning can also be interpreted as capital punishment, yet the end result of capital punishment is indistinguishable from human sacrifice.

The sacrificial ritual did not end with the death of the victims; sacrificed individuals were left out to decompose under natural elements and reveal signs of intentional postmortem flaying of fleshed bodies and disarticulation of skeletons. In contrast, the elite and some commoners were typically interred with grave goods in a supine position.[30,31] The tortured victims "would have been transgressors of the ancestral order"[32] so they were displayed out in the elements to deprive them "funerary rites that would have assured the circulation of vital force between life and death."[33] Sacrificial expiation was intended to placate the deities and ancestors of the Moche. Additionally, shattered ceramic vessels of seated prisoners with ropes tied around their neck were found in situ with the unburied sacrificial remains, which can be interpreted as a form of harassment instead of physical torture.[34] This treatment of the victims supports Models B and C.

Conceptualizing the Origins of the Huaca de la Luna Human Sacrifices

One study tested the three models to the Plaza 3A victims by examining the archaeological context and "biodistance data on genetically influenced dental traits" gathered from samples within the same and nearby valleys; allowing further insight into reconstructing "genetic relations among both prehistoric and living populations."[35] The researchers compared the dental traits of the sacrificial victims at Plaza 3A to the non-sacrificial mortuary samples and concluded that the victims from Plaza 3A originated from valley populations outside of the local Moche valley population.[36] The same study was applied to the Plaza 3C victims, who were found to be closely related to the local Moche valley population.[37] Although the researchers were unable to determine the exact origins of the sacrificed individuals, they concluded that their data does not support Model A.[38,39]

Another study tested individuals from urban tombs of the elite and sacrificial victims at Huaca de la Luna using "phosphate oxygen isotope compositions of tooth enamel and bone."[40] Phosphate oxygen isotope values vary considerably with the highest values found at low altitudes near a coast, and they decrease the farther one travels from a coast and when moving up elevation. These values become fixed during childhood in tooth enamel, however, the values in bones changes throughout an individual's life. By comparing the local values to the values in tooth enamel and bone remains, it can be determined if an individual had lifelong residence at a site; were born elsewhere and moved to a site, and even if they were born at a site, left for an extended period, then returned. Elite males from urban tombs had values consistent with lifelong residence whereas females had values consistent with later arrivals, suggesting wives were chosen from outside Huaca de la Luna "to unify social and political alliances."[41] The earlier victims from Plaza 3C were from Huaca de la Luna while the later victims from Plaza 3A were both locals and non-locals, suggesting a change in the sacrificial ritual. The research utilized the regional baseline water sources from the north coast of Peru to elucidate the human oxygen isotope values.[42] Some of the individuals from Plaza 3A may have relocated to Huaca de la Luna, although the dental morphology and oxygen isotope values reveal non-local origins. One possibility is that the victims were captured for several years from distant valleys as "controlled labor" or as slaves.[43]

Conclusion

When applied to Model C, the characteristics of the sacrificial victims from Plazas 3A and 3C are consistent with the current knowledge of the militaristic and expansionist southern Moche polity and a loose confederation of northern Moche polities of similar cultural and ideological beliefs.[44,45] The archaeology of Huacas de Moche affirms a "significant chronological shift in power from religious specialists to more overt

secular-like political control."[46] The southern Moche's expansion of territory did not transpire over a single campaign but alternatively in several campaigns over hundreds of years, utilizing both non-military and military tactics that most likely included alliance formation between the south and north.[47,48] Undoubtedly, the Moche heavily engaged in the four sources of power identified by Mann: military, economic, political and ideology.[49] However, the Moche utilized ideology as their primary strategy and source of power through the investment in resources, as seen in the construction of Moche temples, production of religious objects, and performance of religious ceremonies.[50] I believe Moche iconography can be interpreted as a form of propaganda to spread religious and sociopolitical ideologies through different expressions of material culture.

It is important to understand how archaic cultures in Peru, such as the Moche, responded to times of social and environmental crisis (e.g., El Niño flooding or drought) that resulted in warfare and human sacrifice. Labeling human sacrifice as purely religious is too narrow of an interpretation. For some cultures, modern and prehistoric, religion is used as a sociopolitical tool to affirm one's own power and legitimacy. Human sacrifice could very well have been used to inflict fear and assert power in order to prevent local skirmishes and insurgency from rival polities. This is seen with the Moche using human sacrifice as a religious mechanism to affirm their religious and political ideologies from competing Moche polities, as well as affirming the elite's supremacy.

REFERENCES

1. Luis J. Castillo Butters and Santiago U. Castillo, "The Mochicas," in Handbook of South American Archaeology, ed. Helaine Silverman and William Isbell (New York: Springer, 2008), 707–29, https://doi.org/10.1007/978-0-387-74907-5.

2. Butters et. al, "The Mochicas," 707–29.

3. Butters et. al, "The Mochicas," 707–29.

4. Richard C. Sutter and John W. Verano, "Biodistance Analysis of the Moche Sacrificial Victims from Huaca de la Luna Plaza 3C: Matrix Method Test of their Origins," American Journal of Physical Anthropology 132, no. 2 (November 2006): 193–206, https://doi.org/10.1002/ajpa.20514.

5. Richard C. Sutter and Rosa J. Cortez, "The Nature of Moche Human Sacrifice: A Bio-Archaeological Perspective," Current Anthropology 46,

no. 4 (August 2005): 521–49, https://doi.org/10.1086/431527.

6. Sutter et. al, "Moche Human Sacrifice," 521–49.

7. Sutter et. al, "Biodistance Analysis," 193–206.

8. J. Marla Toyne et al., "Residential Histories of Elites and Sacrificial Victims at Huacas de Moche, Peru, as Reconstructed from Oxygen Isotopes," Journal of Archaeological Science 42, no. 1 (February 2014): 15–28, https://doi.org/10.1016/j.jas.2013.10.036.

9. Sutter et. al, "Moche Human Sacrifice," 521–49.

10. John W. Verano, "Warfare and Captive Sacrifice in the Moche Culture: The Battle Continues," in Embattled Bodies, Embattled Places: War in Pre-Columbian Mesoamerica and the Andes, ed. Andrew K. Scherer and John W. Verano (Washington D.C.: Dumbarton Oaks Pre-Columbian Symposia and Colloquia, 2014), 283–310.

11. Sutter et. al, "Moche Human Sacrifice," 521–49.

12. Verano, "Warfare and Captive Sacrifice," 283–310.

13. Sutter et. al, "Moche Human Sacrifice," 521–49.

14. Verano, "Warfare and Captive Sacrifice," 283–310.

15. Sutter et. al, "Moche Human Sacrifice," 521–49.

16. John W. Verano, "War and Death in the Moche World: Osteological Evidence and Visual Discourse," in Moche Art and Archaeology in Ancient Peru, ed. Joanne Pillsbury (New Haven: Yale University Press, 2002), 111–26.

17. Verano, "War and Death," 111–26.

18. Verano, "War and Death," 111–26.

19. John W. Verano, "Communality and Diversity in Moche Human Sacrifice," in The Art and Archaeology of the Moche: An Ancient Andean Society of the Peruvian North Coast, ed. Steve

IT IS IMPORTANT TO UNDERSTAND HOW ARCHAIC CULTURES IN PERU, SUCH AS THE MOCHE, RESPONDED TO TIMES OF SOCIAL AND ENVIRONMENTAL CRISIS

BOURGET AND KIMBERLY L. JONES (AUSTIN: UNIVERSITY OF TEXAS PRESS, 2008), 23–42.

20. VERANO, "COMMUNALITY," 23–42.

21. VERANO, "WARFARE AND CAPTIVE SACRIFICE," 283–310.

22. SUTTER ET. AL, "BIODISTANCE ANALYSIS," 193–206.

23. VERANO, "WARFARE AND CAPTIVE SACRIFICE," 283–310.

24. VERANO, "COMMUNALITY," 23–42.

25. VERANO, "WARFARE AND CAPTIVE SACRIFICE," 283–310.

26. JOHN W. VERANO, "THE PHYSICAL EVIDENCE OF HUMAN SACRIFICE IN ANCIENT PERU," IN *RITUAL SACRIFICE IN ANCIENT PERU*, ED. ELIZABETH P. BENSON AND ANITA G. COOK (AUSTIN: UNIVERSITY OF TEXAS PRESS, 2001), 165–84.

27. VERANO, "WAR AND DEATH," 111–26.

28. VERANO, "COMMUNALITY," 23–42.

29. VERANO, "COMMUNALITY," 23–42.

30. VERANO, "PHYSICAL EVIDENCE," 165–84.

31. VERANO, "WAR AND DEATH," 111–26.

32. ANNE-MARIE HOCQUENGHEM, "SACRIFICES AND CEREMONIAL CALENDARS IN SOCIETIES OF THE CENTRAL ANDES: A RECONSIDERATION," IN *THE ART AND ARCHAEOLOGY OF THE MOCHE: AN ANCIENT ANDEAN SOCIETY OF THE PERUVIAN NORTH COAST*, ED. STEVE BOURGET AND KIMBERLY L. JONES (AUSTIN: UNIVERSITY OF TEXAS PRESS), 23–42.

33. HOCQUENGHEM, "SACRIFICES AND CEREMONIAL CALENDARS," 23–42.

34. HOCQUENGHEM, "SACRIFICES AND CEREMONIAL CALENDARS," 23–42.

35. VERANO, "WARFARE AND CAPTIVE SACRIFICE," 283–310.

36. VERANO, "WARFARE AND CAPTIVE SACRIFICE," 283–310.

37. SUTTER ET. AL, "BIODISTANCE ANALYSIS," 193–206.

38. VERANO, "WARFARE AND CAPTIVE SACRIFICE," 283–310.

39. SUTTER ET. AL, "BIODISTANCE ANALYSIS," 193–206.

40. MARLA TOYNE ET AL., "RESIDENTIAL HISTORIES OF ELITES AND SACRIFICIAL VICTIMS AT HUACAS DE MOCHE, PERU, AS RECONSTRUCTED FROM OXYGEN ISOTOPES," *JOURNAL OF ARCHAEOLOGICAL SCIENCE* 42, NO. 1 (FEBRUARY 2014): 15–28, HTTPS://DOI.ORG/10.1016/J.JAS.2013.10.036.

41. TOYNE ET AL., "RESIDENTIAL HISTORIES," 15–28.

42. TOYNE ET AL., "RESIDENTIAL HISTORIES," 15–28.

43. TOYNE ET AL., "RESIDENTIAL HISTORIES," 15–28.

44. VERANO, "WARFARE AND CAPTIVE SACRIFICE," 283–310.

45. SUTTER ET. AL, "BIODISTANCE ANALYSIS," 193–206.

46. TOYNE ET AL., "RESIDENTIAL HISTORIES," 15–28.

47. SUTTER ET. AL, "BIODISTANCE ANALYSIS," 193–206.

48. TOYNE ET AL., "RESIDENTIAL HISTORIES," 15–28.

49. MICHAEL MANN, T*HE SOURCES OF SOCIAL POWER: VOLUME I, A HISTORY OF POWER FROM THE BEGINNING TO A.D. 1760* (CAMBRIDGE: CAMBRIDGE UNIVERSITY PRESS, 1986), 11–27.

50. BUTTERS ET. AL, "THE MOCHICAS," 707–29.

Richard Alexander Dally '19

Richard Alexander Dally '19 attended Texas A&M University at Galveston as a Maritime Studies major with a double minor in Anthropology and English from Waxahachie, Texas. Richard completed his research in the 2018–2019 class of the Undergraduate Research Scholars under the guidance of Dr. DiGeorgio-Lutz and Dr. Mark. Richard plans to pursue a Master's in Marine Resources Management at Texas A&M University at Galveston.

Shining Light on Tuberculosis

By Camella J. Carlson

Introduction

Mycobacterium tuberculosis, a dangerous bacterium typically affecting the lungs, has proved challenging to treat and cure. Tuberculosis (TB) is one of the top 10 causes of death worldwide. About one-fourth of the world population is infected with latent TB. In 2017 alone, there were an estimated 10 million new active TB cases and 1.3 million deaths attributed to TB.[1] In fact, deaths caused by TB just recently surpassed those by HIV, making it the leading infectious disease killer. Individuals with suppressed immune systems, for example, those living with HIV, are particularly susceptible to developing active TB. Tuberculosis usually affects the lungs, but it can also present as extrapulmonary TB infecting other areas of the body.

TB's rapidly evolving strains present a particularly formidable problem. Many strains become drug resistant and even multidrug resistant (MDR), a problem worsened by patients carrying out their treatment regimen incorrectly.[2] The worldwide strategy to combat this disease is multifaceted; efforts include increasing healthcare access and education in areas affected by TB, developing more accurate diagnostic methods, and improving drug research for more powerful treatments. Globally, the TB incidence rate is falling by 2% each year. However, this rate needs to increase in order to meet the goals of the World Health Organization's End TB Strategy.

Expedited drug development methods are necessary to adequately address TB, particularly MDR-TB.[3] Treating these strains increases the complexity of the treatment, adding time and cost. An average treatment could last at least 20 months. Our project aims to establish a faster and more cost-effective drug development process. Drug development typically requires longitudinal animal studies to assess effectiveness. These studies involve monitoring a new TB drug in animal subjects; they require many animals in order to sacrifice a few animals and analyze TB progression at multiple time points throughout the study. The Maitland lab proposes utilizing an optical detection method to simplify these studies and to require fewer animal subjects. This method would be more statistically relevant because the same animal could be measured at multiple points in time, resulting in studies with more scientific rigor. Additionally, a more sensitive analysis method could detect changes in the amount of TB sooner, providing quicker feedback about the likelihood of success for a treatment candidate.

Background

The optical detection of TB would employ a technology called reporter enzyme fluorescence.[4] Reporter enzyme fluorescence uses a molecule that is cleaved only when it contacts a specific bacterial enzyme in Mycobacterium tuberculosis. After the fluorescent portion of the molecule is freed from the quenching portion, the molecule can be excited by light. Excitation causes the molecule to emit light at a wavelength longer than that of excitation. This light can be detected, and the amount of signal corresponds to the number of bacteria. This method provides a faster alternative to the current standard of analyzing the growth of bacteria on an agar plate; optical detection can deliver results in a matter of hours whereas culture takes 6 to 8 weeks.

Our system design is tailored to monitor TB in a mouse model, because mice are commonly used to

assess potential drugs. We are utilizing both computer simulations of light transport and physical models of mouse lungs in order to optimize the system setup and further enhance its performance.

The specific scope of this project is to investigate how mouse lungs can be accurately modeled by an optical tissue phantom. Essentially, an optical tissue phantom is a plastic model that interacts with light in the same way as the biological tissue—sharing both similar shape and optical properties. Phantoms are commonly used to evaluate and calibrate imaging systems. Most are made of one or two materials with rather simplistic geometry. Adding complexity by replicating complicated anatomy, adding texture, or using more materials can mimic tissue with greater accuracy. Our phantom will both validate the computer simulation and test potential system configurations without requiring further animal studies.

Methods

Because our main application is pulmonary TB, the phantom was made with particular attention to the properties and structure of the lungs. The airways, the lung tissue, and the surfactant, a mucus-like substance that coats the airways, were the three primary components depicted in the model because light interacts with each differently. Optical properties characterizing how light interacts with a specific medium were considered when picking the representative materials. Air was selected for the airways; a polymer, polydimethylsiloane (PDMS), for the lung tissue; and glass for the surfactant **(Table 1)**. These materials all had a similar refractive index, which describe the speed and path of light passing through, to the biological tissue.

Lung airways branch out ending in tiny air sacs called alveoli **(Figure 1)**. The alveoli are coated in surfactant and compose the majority of the lung volume. This geometry must also be represented in the model. Molds were fabricated to recreate the lung and airway shapes. Spherical glass microbubbles—small, round, thin glass shells filled with air—were

employed to replicate the alveoli structures. Varying amounts of microbubbles were used to represent different points throughout the respiratory cycle, because the lung has different optical properties depending on the volume of air inside.[5]

Figure 1. Simplified lung geometry depicting the airways and alveoli.

Sample phantoms were created and characterized to confirm their ability to model the alveoli. Prior to phantom fabrication, the microbubbles were sieved to narrow their diameter size distribution to 45–100 μm, an approximation of mouse alveoli size. First, the PDMS was measured and mixed. Next, the microbubbles were added and dispersed evenly throughout the mixture. The amounts of microbubbles were calculated based on average microbubble size and density to represent 30%, 40%, 50%, and 60% volume ratios. The phantoms required degassing to remove any air bubbles left from mixing. Then, they were solidified by curing in an oven.

Thick and thin phantom samples were made in order to be analyzed by two different methods: The thick samples were fabricated in petri dishes and removed once cured **(Figure 2)**. They included a fluorescent chemical for viewing with a confocal microscope which captures an image by scanning a laser over the sample. Images were taken from the center of each phantom. The resulting images were used to verify the volume ratio and confirm successful removal of unwanted air

> **MICROBUBBLES WERE USED TO REPRESENT DIFFERENT POINTS THROUGHOUT THE RESPIRATORY CYCLE**

Biological Tissue	Refractive Index	Phantom Material	Refractive Index
Airways *(trachea and bronchi)*	1.0	Air *(empty space in mold)*	1.0
Lung Tissue	1.4	PDMS	1.4

Table 1. Summary of corresponding lung and phantom composition.

Figure 2. Cured thick phantoms shown in order of increasing volume ratio (30%, 40%, 50%, 60%).

Figure 3. Thin phantoms were cured between microscope slides shown in order of increasing volume ratio (30%, 40%, 50%, 60%).

Figure 4. Confocal microscope images: 30% (a) and 50% (b) volume ratios.

bubbles.

For the thin phantoms, I used an integrating sphere to measure the transmittance and reflectance of light through each sample **(Figure 3)**. Transmittance measures the amount of light that passes through a sample, and reflectance measures the amount of light reflected off of the sample surface. Measurements were taken at multiple points on the sample and averaged. These values were then used to calculate the absorption and scattering coefficients using inverse adding-doubling software.[6] Both describe how light interacts with a specific material. Absorption measured how likely light is to get absorbed, and scattering how likely to get scattered instead of passing straight through.

Results

The confocal microscope images validated that the intended volume percentages for each thick phantom was achieved **(Figure 4)** by comparing the area inside the bubbles to the entire field of view.

For each thin phantom, the scattering coefficient was consistent across the spectrum of visible light, so it could be approximated as a constant value for each volume percentage **(Figure 5)**. The scattering showed a linear relationship to the volume of air bubbles **(Figure 6)**. This trend corresponded to, and thus, validated the light transport computer simulation.[7] Additionally, these phantoms successfully represented different points throughout the respiratory cycle.

Discussion

These microbubble compositions can now be incorporated in molds replicating the mouse lung geometry. These phantoms can be used not only to optimize our system for improved TB detection, but also in a broader context. Because this research provides further insight into how light interacts with the complex geometry and materials composing the lung, it could aid in advancing diagnostic and treatment technologies for other pulmonary pathologies.

Optical tissue phantoms can be used to calibrate, optimize, and validate imaging systems. A phantom offers a greater advantage over an animal because it has known characteristics, whereas animals have unknown and varying

Figure 5. Scattering of microbubbles in PDMS across the visible light spectrum.

Figure 6. Comparing the scattering of the computer simulation and optical phantoms as it relates to microbubble volume.

> A PHANTOM OFFERS A GREATER ADVANTAGE OVER AN ANIMAL BECAUSE IT HAS KNOWN CHARACTERISTICS

properties. By increasing the complexity of the phantom, we are further developing means to minimize animal testing and carry out research responsibly.

Acknowledgments

REFERENCES

1. World Health Organization, *Global Tuberculosis Report* 2018 (Geneva: World Health Organization, 2018): 1-4.

2. Nazir Ismail et al., "Drug Resistant Tuberculosis in Africa: Current Status, Gaps and Opportunities," *African Journal of Laboratory Medicine* 7, no. 2 (December 2018): 781, https://doi.org/10.4102/ajlm.v7i2.781.

3. Mahesh S. Vasava et al., "Drug Development Against Tuberculosis: Past, Present and Future," *Indian Journal of Tuberculosis* 64, no. 4 (October 2017): 252–75, https://doi.org/10.1016/j.ijtb.2017.03.002.

4. Ying Kong and Jeffrey D. Cirillo, "Reporter Enzyme Fluorescence (REF) Imaging and Quantification of Tuberculosis in Live Animals," *Virulence* 1, no. 6 (November 2010): 558–62, https://doi.org/10.4161/viru.1.6.13901.

5. Johan F. Beek et al., "The Optical Properties of Lung as a Function of Respiration," *Physics in Medicine and Biology* 42, no. 11 (December 1997): 2263–72, https://doi.org/10.1088/0031-9155/42/11/018.

6. Prahl SA, et al., "Determining the optical properties of turbid media by using the adding-doubling method," *Applied Optics* 32, no. 1 (1993): 559–68.

7. Durkee MS, et al., "Light scattering by pulmonary alveoli and airway surface liquid using a concentric sphere model," *Optics Letters* 43, no. 20 (2018): 5001–5004.

Camella J. Carlson '20

Camella J. Carlson '20 is a biomedical engineering major from Olathe, Kansas. Camella performed this research under the guidance of Dr. Kristen Maitland out of a desire to further understand the role of research in the medical field and to contribute to a meaningful project. She plans to pursue further education as preparation to conduct translational medical research at a research hospital.

Second Life as a Synchronous E-Learning Tool

By Taylor Bell

Introduction

This research project explored how to increase learner engagement in E-learning courses using an immersive synchronous component (ISC). ISCs are class activities in which learners participate fully in a virtual environment together in real time. A learner engagement gap was originally identified in Philip Stott's article showing that a lack of engagement posed risks to both the learner and their instructors.[1] Keeping in mind that higher education institutions are increasing the number of online courses offered,[2] it is imperative that the quality of education be maintained even as the delivery method of instruction changes. This link between learner engagement and final performance, identified by Calvo and Rio, allowed us to introduce a synchronous component to an online course with the hope of improving learner engagement and, by extension, final performance in that course.[3]

> **THERE ARE OVER 200 DOCUMENTED HIGHER EDUCATION INSTITUTIONS MAINTAINING PROPERTY IN SL**

Our specific research project investigated whether Second Life (SL), a free online immersive virtual environment (OLIVE) created by Linden Labs, could be used as a tool to introduce an ISC into an online course. By introducing SL as a synchronous component to an E-learning course, it was hypothesized that learner engagement would increase in that course. Texas A&M University currently maintains an active campus in SL which is used by multiple groups within the University including the veterinary school, the chemistry and

Figure 1. Academic Building & Sully Statue, part of Texas A&M's Virtual SL Campus.

biology departments, and biomedical sciences. The Texas A&M campus, pictured in **Figure 1**, was the main site used for the course's group activities and our research. The ultimate goal of this research was to provide higher education instructors with a new tool that could be used to encourage learners to become more engaged with course content and to facilitate higher learner performance in the E-learning environment.

At any one point in time, there are approximately 50,000 to 65,000 people logged on to SL, and there are over 200 documented higher education institutions maintaining property in SL.[4] SL users interact with each other and the shared virtual environment in real time by using avatars, voice, chat functions, and shared notecards. SL allows learners to actively engage in real-life scenarios in a way that fosters decision making and high-level thinking, while simultaneously allowing for the transfer of information from the classroom into the real world.[5] SL also offers the ability for learners to practice academic skills within a low-pressure environment. We based our research on Michael G. Moore's theoretical framework of transactional distance ,which explained how the distance between the structure and dialogue of an online course rather than the geographical distance, had an impact on the learner's educational experience.[6]

Second Life Integration with a Human Resource (HR) Course

Our project was a quasi-experimental study (participants were not randomly selected) that employed two groups of learners (fall 2018 and spring 2019) who took the online version of EHRD 315, Applied HR in the Workplace.

Fall 2018 learners completed the course and three group assignments without the use of SL while spring 2019 learners completed the course and the same three group assignments using SL. The spring 2019 semester was the first time this course was implemented using this new structure. Learners participating in the SL activities received detailed online training.

The fall 2018 learners used common non-immersive technology such as Google Hangouts, Skype, and Google Docs to complete the group assignments, whereas spring 2019 learners used interactive

> **SL ALLOWS FOR LEARNERS TO ACTIVELY ENGAGE IN REAL-LIFE SCENARIOS IN A WAY THAT FOSTERS DECISION MAKING AND HIGH-LEVEL THINKING**

Figure 2. Learners participating in a simulation in SL for EHRD 315.

simulations in SL monitored by facilitators to complete the group assignments. All other aspects of the courses were identical. Pictured in **Figure 2** is an example of a spring 2019 group gathering in SL and participating in one of the three simulations with a facilitator present.

For the spring 2019 class, the first interactive simulation required learners to analyze five different case studies that possibly violated different employment-related laws focusing on discrimination, to determine which (if any) legal statutes applied to the cases, and then discuss what the participants believed the outcome should have been based on their course material. The second simulation centered around the learners redesigning the job of a sales associate to be more satisfying and motivating using the Job Characteristics Model from their course materials. The third simulation required learners to analyze three potential candidates for a job and decide which candidate should be hired. In each simulation, the professor or a researcher was present and acted as a facilitator whose role was to observe, listen, answer questions, and pose questions to encourage further class discussion. After completion of the third activity, students in both groups were asked to complete a voluntary survey.

Methods

We used the Online Student Engagement Scale (OSE) Survey which measures learners' engagement in an online course.[7] The OSE survey contained 19 statements that asked learners to identify the different behaviors, thoughts, and feelings on a scale from 1 representing 'not at all characteristic of me' to 5 representing 'very characteristic of me.' The OSE posed statements like 'listening/reading carefully,' 'participating actively in small group discussion forums,' and 'getting to know other students in the class' for learners to self-reflect upon and rate themselves accordingly. We re-created the survey using Qualtrics, a software used for collecting and analyzing survey data. We then emailed the professor of the course a summary of the project, the Qualtrics survey link, and a request for student participation. The professor forwarded the researcher's email to her students at the completion of the three required activities. Once the learners received the forwarded email, they were given one week to complete the survey. Participation was voluntary, anonymous, and no identifiable information of participants. Two rounds of data were collected from the EHRD 315 students; one at the end of the fall semester for the fall 2018 class, and one at the end of the spring semester for the spring 2019 class.

> ## IN EACH SIMULATION, THE PROFESSOR OR A RESEARCHER WAS PRESENT AND ACTED AS A FACILITATOR

Results

The results of the two surveys were compiled and descriptive statistics were used to compare the fall and spring results. As listed in the table above, spring 2019 learners were found to have a higher average engagement score than fall 2018. With the exception of questions 8, 9, 13, 15, and 16, every other individual question on the OSE indicated average increased engagement. The standard deviation decreased for every question except for question 15.

Questions 8 and 9 asked if the course material applied to the learner's life and if the learners found ways to make the material relevant to their lives. Question 13 asked learners if they actively participated in small group discussion; however, this result could be explained by the fact that there were fewer forums and more discussion and simulation-based activities in the spring than in the fall so learners did not have as many opportunities to engage in forums.

Question 15 inquired if it was characteristic of the learner to get a good grade lending to the conclusion that future research needs to be conducted to determine if this was due to chance or directly related to the implementation of SL. Question 16 asked if the learners were doing well on the tests and quizzes and the decrease could be attributed to course quizzes not including specific information from the SL simulations.

The survey questions related to engaging in conversations online (+.42), getting to know other learners (+.52), looking over class notes between getting online to ensure material understanding (+.64), and having fun in online chats/discussions (+.71) all increased, further showing that the addition of SL simulations into an online course increased learner engagement with their peers, instructor, and course materials.

Conclusion

Based on the results of this study, we concluded that the use of SL as a synchronous learning tool in an E-learning environment increased learner engagement in the online section of EHRD 315 in the spring 2019

Fall 2018 vs. Spring 2019 Comparison			
	Fall 2018 (S)	**Spring 2019 (S)**	**Change (+/)**
Total OSE Score	3.26 (1.11)	3.73 (8.3)	0.47
Question 8	3.77(.89)	3.71(.76)	0.06
Question 9	3.73(.87)	3.68(.68)	0.09
Question 13	3.63(1.13)	3.44(.75)	0.19
Question 15	4.47(.57)	4.38(.65)	0.19
Question 16	4.37(.74)	4.09(.67)	0.18

Table 1. Comparison between fall 2018 and spring 2019 semesters.

semester. The overall average of OSE scores increased by half a point from the fall to the spring semester which showed that when learners were using SL to complete activities with their peers, they were more engaged in the course material. Even with the five questions containing an average engagement decrease, the other fourteen questions, and the survey total, showed an overall increase in learner engagement. In fact, when learners reflected on their experiences in SL, they viewed SL positively writing, "this week, Second Life surprised me. It is a cool way to meet up without having to put effort into my appearance after a long day" and that "it was nice being able to have this level of interaction with my peers and professor for this class being an 'online course.' I will admit, I was nervous at first, but it was neat seeing how applicable and interactive technology can be."

Student Responses

In the free-response portion of the survey, which was separate from the OSE Survey, learners were asked to reflect on their experiences in SL and how the activities completed using SL impacted their views on the course and their future career aspirations. There was an initial pushback from the students in regard to the SL training. One student said: "[I] found that I really do not use half of the features [the training] discussed." Overall, the students tended to view the training as intense and time-consuming. While a student said that the "training adequately prepared me for our case study assignments in this class," this student was in the minority. Based on the results of the survey, the students felt that while they learned the needed material for them to be successful in the course, the training included too much unnecessary information. This initial negative impression of SL could have been attributed to some learners' dislike and immediate rebuff of the SL activities.

Once the students were participating in the SL activities, there was an overall positive response. One student stated that "Second Life helped [him/her] learn how to communicate better through just talking since I was not able to see my group members in person." Most learners stated that they enjoyed the activity and thought SL helped their learning within the context of EHRD 315. However, SL required a learning curve that previous iterations of the course had not had, which forced the spring 2019 learners to put in more time and effort than previous semesters as they learned how to use a new tool which lead to more resistance from the learners.

While the free response section indicated that the majority of students did not see the benefit of using SL as an educational tool, the quantitative portion of the survey showed higher learner engagement. This meant that while the training could have been improved to be more concise and the SL learning curve appeared difficult to overcome to the learners, it increased learner engagement in the course despite the learners' personal statements. For future research, this experiment could be done again to adjust the SL training to be a better fit to the specific needs of the students and the course. If the training was adjusted to reduce the initial pushback from the students, then more improvement might be seen in the learners' engagement as well as their personal perspectives from the course.

Future Research

This study was an attempt at closing the gap between learners' poorer engagement in E-learning courses compared to face-to-face courses using SL as a synchronous component in an E-learning course in order to provide higher education instructors with a tool for enhancing engagement in their E-learning courses. As institutions move toward online courses, there are more opportunities to study the effects of SL as an E-learning tool that expand on this study. First, the course used in this experiment was relatively small, lending to a sample

ONCE THE STUDENTS WERE PARTICIPATING IN THE SL ACTIVITIES, THERE WAS AN OVERALL POSITIVE RESPONSE

of 64 learners. Increasing the sample size would allow for generalizations to be drawn to a larger population of learners. Second, this project was confined by a strict timeline of two semesters. Continuing to monitor the engagement levels for the EHRD 315 course would lend evidence to the impact of the SL integration. Third, the study could be expanded to include other courses aside from EHRD 315. This could start small by including other online HRD courses and then expand to other disciplines at Texas A&M. Fourth, because this study included two completely different groups of learners, adding a longitudinal aspect to this study following a group of learners through all of their E-learning courses during their time at Texas A&M or surveying EHRD 315 OSE engagement scores for each semester would also lend depth to this topic.

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References

1. P. Stott, "The perils of a Lack of Student Engagement: Reflections of a 'Lonely, Brave, and Rather Exposed' Online Instructor," British Journal of Educational Technology 47, no. 1 (2016): 51–64, doi: 0.1111/bjet.12215.

2. G. Wilson and E. Stacey, "Online interaction impacts on learning: Teaching the teachers to teach online," Australian Journal of Educational Technology 21, no. 1 (2004): 33–48.

3. L. C. Calvo and T. Reio, "The relationship between engagement and knowledge attainment in a computer-based training game and job performance of travel agents," Journal of Management Development 37 no. 5, (2018): 374–384. doi:https://doi-org.ezproxy.library.tamu.edu/10.1108/JMD-03-2017-0063.

4. K. Reinsmith-Jones, S. Kibbe, T. Crayton, and E Campbell, "Use of second life in social work education: Virtual world experiences and their effect on students," Journal Of Social Work Education 51, no. 1 (2015): 90–108, doi:10.1080/10437797.2015.977167.

5. Reinsmith-Jones et al., "Use of second life," 90–108.

6. M. Moore, "Three Types of Interaction," The American Journal of Distance Education, (1989), http://aris.teluq.uquebec.ca/portals/598/t3_moore1989.pdf.

7. M. Dixson, "Measuring student engagement in the online course: The online student engagement scale (OSE)," Online Learning 19, no. 4, (2015): 143–158.

Taylor Bell '20

Taylor Bell '20 is a senior human resource development major from Coppell, TX. Taylor completed her research while participating in the 2018–2019 Undergraduate Research Scholars Program under the guidance of Dr. Christine Mark. She will be attending SMU's Dedman School of Law in Fall 2019, where she will pursue her passion for law and business by specializing in mergers and acquisitions.

Binomial Rhapsody: Turning Math into Music

By Ritika Bhattacharjee

I WAS ABLE TO MARRY THE TECHNICAL ASPECTS OF MATHEMATICS WITH THE CREATIVE ASPECT OF MUSIC

Introduction

People passing through the engineering quad on the Texas A&M University College Station campus will undoubtedly notice an art installation by Olafur Eliasson. The polished steel structure presents a type of optical illusion: despite being only a collection of cubes, composed of sharp edges and defined vertices, the sculpture appears as a sphere, a seamless figure with no definite beginning or end. The two ideas seem incompatible—the former represents that which is definite and the latter, the infinite—and yet when these cubes are superimposed so as to leave cutouts of negative space in between, viewers perceive the resulting shape to be a sphere. This work of art, like many others by Eliasson, draws inspiration from the principles of mathematics.

As the previous example illustrates, there exists the potential for a deeper study of the relationships between mathematics and the arts. One could argue that this is particularly so where music is concerned. The twentieth century was characterized in part by the growth of Contemporary and Expressionist styles in music, allowing for greater compositional development through the use of atonality, a non-traditional musical structure (i.e. the composition does not use any identifiable scale form and is often comprised of notes that "clash," or are too close in frequency to exhibit waveform harmonics). Compositions based in atonality—regarded as "the first significant advance in this trend toward serialism in music"[1]—employed all twelve chromatic notes of western classical music, which were each assigned a value of one through twelve at the composer's discretion. The numbers were then randomly ordered by the roll of a twelve-sided die, and music would be composed using the newly generated series of notes. No pitch could be repeated until all twelve tones had already been chosen once.[2] This method created a form of music composition based solely on mathematics, specifically on discrete mathematics, which "[deals] with objects that can assume only distinct, separated values."[3]

The connection established between mathematics and music through atonality invites us to think about ways in which we might expand the relationship to relevant physics and engineering equations in order to turn them into musical compositions. Specifically, we turn from equations that operate under discrete mathematics to those under the jurisdiction of continuous mathematics such as recurring decimals, fractions, and irrational numbers to discover if there is a real relationship between continuous math and music.

Binomial Rhapsody, a project under the ENGR[X] program at Texas A&M University, was the avenue by which I was able to marry the technical aspects of mathematics with the creative aspect of music and more concretely pinpoint the influence mathematics has on musical composition. The project began as an open-ended challenge proposed by Professor Shayla Rivera to the students of the engineering college: compose music from one (or more) of the 40 mathematical and scientific equations printed on the bricks of the walkway around the Zachry Engineering Education Complex. To do this, it was necessary to form a process by which I could translate the numerical output from an equation model of a continuous function into musical notes which, when assigned whole number values from one to twelve, would represent a set of discrete numbers.

Mathematical Methods and Composition Techniques

I selected an equation that only had two variables contributing to a single output: $F = m*a$, or Newton's Second Law of Motion. The purpose of picking an

Mass	Accel	Force	Numeric Conversion	Notes	Changes?	Chord Construction
22	1	22	22 - (12*1) = 10, 10 = A, 1 = C	A, C		A min, transition on D
22	2	44	44 - (12*3) = 8, 8 = G, 3 = D	G, D		G add #4 & 7
22	3	66	66 - (12*5) = 6, 6 = F, 5 = E	F, E		d min, add scale degree 2
22	4	88	88 - (12*7) = 4, 4 = D#, 7 = F#	D#, F#	D# = Eb, F# = Gb	eb minor
22	5	110	110 - (12*9) = 2, 2 = C#, 9 = G#,	C#, G#	C# = Db, G# = Ab	Db Major
22	6	132	132 - (12*11) = 0, 11 = A#,	Bb	A# = Bb	Bb min
22	7	154	154 - (12*12) = 10, 10 = A, 12 = B	A, B	Lower one half step	Ab Major
22	8	176	176 - (12*14) = 8, 8 = G, 14 - (12*1) = 2, 2 = C#	G, C#		G Major, add raised 4th and the 7th
22	9	198	198 - (12*16) = 6, 6 = F, 16 - (12*1) = 4, 4 = Eb	F, Eb	Lower Eb one half step	d min, add scale degree 2
22	10	220	220 - (12*18) = 4, 4 = Eb, 18 - (12*1) = 6, 6 = F	F, Eb	Lower Eb one half step	d min, add scale degree 2
22	11	242	242 - (12*20) = 2, 2 = C#, 20 - (12*1) = 8, 8 = G	G, C#		G Major, add raised 4th and the 7th
22	12	264	264 - (12*22) = 0, 22 - (12*1) = 10, 10 = A	A		A min

Figure 1. The table shows the calculations performed to obtain notes from our numbers. The numeric conversion was done in the second column, after which we used the keyboard **(Figure 2)** to assign notes. Changes were made to fit the flow of the piece during the compositional process. The three movements of the piece are color-coded in the right-most column.

equation with three variables was to set one of the variables as a constant and manipulate a second variable to obtain a singular, unique output with each manipulation. Fewer variables in the chosen equation allow for greater compositional freedom, as only those notes representing few numeric variables need to be played at once. After choosing the equation, I initially set the acceleration to be a constant 1 m/s2, but realized that as I varied the value of mass, our output (the force variable) would be the same as our input (the mass variable), and our equation would simply generate a chromatic scale[4]) when I assigned individual notes numeric values. To avoid the dull predictability of the chromatic scale, I decided to set the acceleration to an arbitrary value of 22 m/s2, a nod to the expected graduation year of all members of my performance ensemble. I then multiplied this value with the mass, which I varied from 1–12.

Using Google Sheets, I multiplied each combination of numbers defined by my process to obtain an output for the force **(Figure 1)**. Because there are only twelve distinct musical notes in Western classical music (C, C#, D, D#, E, F, F#, G, G#, A, A#, and B), I then converted each of the numbers to a base-twelve system so that each output would correspond to one unique note. During the conversion, I retained the values of both the whole number quotient (the number multiplied by 12, the product of which was subtracted from the original numerical output for force) and the remainder (what was leftover from the whole number division); this was done to form chords. If both the remainder and the quotient had not been kept, the output would only be a single number, therefore yielding only a single note to play, resulting in a lack of harmony and only a solo melodic line. To avoid this problem and instead generate harmonic musical context, I kept both the remainder with the whole number quotient for nearly all calculations, and for the quotients that did not have remainders I used 12, the divisor, as part of the final note output. For cases in which the whole number quotient (regardless of whether there was a remainder) was divisible by 12, I divided the quotient by 12 and kept all notes obtained from this operation and its resulting remainders. While this process generated more musical output (because there were more numbers available), its primary purpose was to break down large numbers into numbers that I could translate into notes, ranging only from 1–12. I assigned each note a value **(Figure 2)**, notes are labeled in red and orange and the assigned numerical values are labeled in green and blue) and chose to begin the labeling system at C because "middle C" is the approximate center of the eighty-eight key piano, and the C Major scale—played on only the white keys—is typically the first scale learned because of its simplicity. To more plainly illustrate how the process worked, take the output of 264, or 22*12. Dividing 264 by 12 gives us 22, but 22 is beyond the scope of our 1–12 range of notes, so we again divide 22 by 12 to get 1 with a remainder of 10. This means that we have drawn the notes C (from the quotient 1), and A (from the remainder 10).

After performing these numerical conversions and assigning numbers to the notes, I used my knowledge of music theory to arrange the notes into chords (for example, after getting C, A, and B as the output, I added the note E to make an "a minor" chord). This was done for all rows of output **(Figure 1)**. To improve the flow of the piece, I selected chords that had interval relationships of perfect fifths or perfect fourths between them, meaning there were respectively five and seven

Figure 2. Number assignment to distinct keys to form the basis of chord structures and melodies for composition.

Figure 3. The primary musical theme of each movement.

half steps between the starting note and the ending note. From a physics standpoint, a perfect 5th is an interval in which the higher and lower pitches have a frequency ratio of 3:2, and a perfect fourth is one in which the higher and lower pitches have a frequency ratio of 4:3.[5] These ratios mean that the human ear perceives the two pitches to be consonant, or having a pleasant sound due to a lack of destructive interference in their soundwaves. Utilizing these interval relationships during chord transitions and between movements causes the human ear to naturally anticipate the next note, in turn making the piece sound smoother. While

mathematics allowed me to obtain the general structure of the piece pitch-wise, I personally decided upon the articulation (how notes were played), rhythm, dynamics, and all other components of musical development. I composed a theme (a melodic idea) for each section of the piece **(Figure 3)** based on the notes in the chords of that section – the first violin played these themes most frequently because of its tonal prominence, but these themes were passed from instrument to instrument. The piece begins and ends in the same manner, with just the piano playing a light melody over the chords of movements one and three, to give the piece aural symmetry.

WHILE MATHEMATICS ALLOWED ME TO OBTAIN THE GENERAL STRUCTURE OF THE PIECE PITCH-WISE, I PERSONALLY DECIDED UPON THE ARTICULATION

Performances and Future Projects

The piece was originally performed following a brief presentation that detailed the composition process, given during the grand finale of Texas A&M Engineering-Week, a celebration of engineering careers with activities designed to increase understanding of and interest in Science, Technology, Engineering and Math (STEM) fields. The ensemble performed again as the finale of the Engineering Project Showcase on April 26th, 2019. Their project was featured in the "On-Campus Aggies" section of the Fall 2019 edition of Texas A&M Foundation Spirit magazine. A full recording of the piece is accessible on YouTube **(Figure 4)**.

Binomial Rhapsody is an ongoing program sponsored by the Texas A&M College of Engineering through the ENGR[X] program. It is in its inaugural year and is open to any engineering major with musical or technical skills and a passion for innovation as it pertains to music.

Impact

This project adds to a growing collection of musical pieces composed through mathematical means. Although much of music theory is underlined by mathematical relationships and patterns, it did not develop solely as a function of mathematical principles. Rather, music theory developed as a set of rules by which composers could create consistently beautiful pieces of music. Wherever there is a pattern, there is usually math, but not all patterns have been fully explored mathematically. By composing pieces grounded in mathematics, which are then arranged to sound more harmonic, we can reverse the process by which music is usually created, and thereby attain a deeper understanding of the compositional process. Additionally, by synthesizing components of math-based music (our output from the equations) with components of traditional composition (composing a sing-able melody, which the first violin plays), we practice a positive form of human-algorithmic interaction; our creative minds interact with a set formula. Today, the word "algorithm" has a negative connotation when spoken of in association to platforms and applications such as Facebook, YouTube, and Twitter, because there exists an assumption that a computer-run formula dehumanizes our interactions with both creative content

Figure 4. A scannable QR code which links to a video of the piece on YouTube.

and other human beings. However, by utilizing a formula and setting up an algorithmic process for only the base of a musical composition, we enable creativity and set a model for a brighter, more original future in which automating a process does not necessarily mean dehumanizing it.

While the atonality in music was explored in depth by composers such as Arnold Schoenberg in the 1900's, it was done mainly through randomization and not set formulae. While the rules of twelve-tone composition ensured that there was no true "pitch-center" and allowed for a complete break from the previous norms of Western classical music, the technique based in rolling a twelve-sided die could be difficult to work with as the randomization did not lead to aurally appealing compositions. Merging the technicalities of serialism in music and the freedom of "organic" music composition allows for a different, diverse soundscape.

The very existence of a project such as Binomial Rhapsody is indicative of the changing needs of the world at large: there is need for artistic creativity in the world of STEM. By strengthening the link between music and mathematics, we encourage future generations to invest in the arts despite declining funding and focus. While the fine arts do receive significant support in some areas of the United States, few students enjoy such privilege, causing "students who are economically disadvantaged to not get the enrichment experiences of affluent students."[6] Neglecting the arts portends a failure to develop the part of society that most visibly represents humanity and its creativity. Binomial Rhapsody enables those in STEM fields to develop their passion for music. By developing the creative skill set of a musician and the analytical skill set of an engineer, future engineers may be more likely to progress their efforts beyond the boundaries of what physically exists in our world today – it is only by dreaming that we make something possible.

This is the main reason why Binomial Rhapsody is so important: by practicing our ability to physically conceptualize the abstract, whether it be in music or in mathematics, we practice the very creativity that fueled the world's best innovators, tested the bounds of the conventional, and challenged accepted ways of thinking. It is this creativity with which we continue to catapult ourselves into a modernity where we connect with thousands at the touch of a button and literally defy

gravity. By making an effort to adopt a more abstract way of thinking, technological and scientific innovators develop creative solutions that can engender change and benefit the world at large.

Acknowledgments

References

1. Robert Kelley, "Introduction to Post-Tonal Music Analysis," *Resources for Practicing Musicians*, (2002), www.robertkelleyphd.com/home/teaching/music-theory/intro-to-post-tonal-music-analysis/.

2. Mary Simoni and Roger B. Dannenberg, "The History and Philosophy of Algorithmic Composition," in *Algorithmic Composition: A Guide to Composing Music with Nyquist*, (Ann Arbor: University of Michigan Press, 2013): 6-15. http://www.jstor.org/stable/10.3998/mpub.3702280.6.

3. John Renze and Eric W. Weisstein, "Discrete Mathematics," *MathWorld--A Wolfram Web Resource*, (2019), mathworld.wolfram.com/DiscreteMathematics.html.

4. A chromatic scale is a scale where white and black keys adjacent to each other, or notes that are a semitone apart, are played or sung in succession until all twelve notes have been performed

5. Glenn Elert, "Music & Noise – The Physics Hypertextbook," *The Physics Hypertextbook*, (2019), physics.info/music/.

6. Cameron Brenchley, "ED Releases New Report on Arts Education in U.S. Public Schools," *U.S. Department of Education*, (April 3, 2012), blog.ed.gov/2012/04/ed-releases-new-report-on-arts-education-in-u-s-public-schools/.

Ritika Bhattacharjee '22

Ritika Bhattacharjee '22 is a chemical engineering major with a minor in performance studies, specializing in music, from Katy, Texas. She is involved in numerous interdisciplinary projects and programs including the ENGR[X] program, Maroon and White Leadership Fellows, a biomedical engineering research lab (BioInSyst), and she is the student conductor of Ingeniare, the engineering chorus on campus. She hopes to continue work that merges opposing disciplines in order to inspire a more interconnected approach to conventional ideas.

Charlotte's Web: Words, Weaving, and Womanhood

By Rebecca Baumgarten

Introduction

E.B. White ends his classic *Charlotte's Web* with the statement, "It is not often that someone comes along who is a true friend and a good writer. Charlotte was both."[1] Nor is it often that a literary spider comes along who is a sympathetic character. The typical reader, who likely experiences some discomfort with spiders, wonders at White's choice of heroine and the means by which she saves Wilbur. Her femaleness is customary for a literary spider, but whereas in many non-Western cultures spiders are childhood pets and symbols of good fortune or wisdom,[2] most Western literary spiders are depicted as deceitful vampires. Charlotte, a heroine, is thus an anomaly for western readers, but she is in fact the culmination of a long tradition of arachnoid imagery that links language and weaving with feminine power.

This paper will explore the various ways artists and writers anthropomorphize spiders, and then use White's novel and the film adaptations from 1973 (animated) and 2006 (live-action) to analyze the story's linkage of words, weaving, and womanhood to compare Charlotte to some of her fictional counterparts.

Background

Spiders are wonderfully and widely suggestive. Like many bugs, they are associated with death and decay, and the presence of their webs in abandoned places like haunted houses give them a place of honor at Halloween. Webs also symbolize schemes, traps, and manipulation, often for selfish purposes; but more neutrally, networking, hence the Worldwide Web. A spider's ability to spin without instruction symbolizes instinct, and the painstaking labor associated therewith, patience.

Authors often use bugs, especially spiders, to symbolize negative aspects of femininity. For example, the spider is usually cast as feminine because it is a weaver.[i] Weaving has traditionally been seen as woman's work, so firmly so that the word distaff, a spinning tool, is synonymous with womanhood. The Germanic word spider comes from the same root as spinster (an old maid who spins thread for a living), and arachnid comes from Arachne, the woman transformed into a spider for besting the goddess Athena at a weaving contest. Writers spun this association together with arachnophobia to produce the image of a spider as monster-woman. In *Pygmalion*, Ovid uses the spider as an extended metaphor for temptresses' feminine wiles. Joyce Tally Lionarons says that "Spiders have long been a symbol for the kind of dark, insatiable female sexuality that devours the male."[3] The black widow is the epitome of the female spider as dominatrix or succubus.

> ## AUTHORS OFTEN USE BUGS, ESPECIALLY SPIDERS, TO SYMBOLIZE NEGATIVE ASPECTS OF FEMININITY

Literature Review

Arachnophobia is one of the most common fears in the Western world, yet it is absent from the novel and animated film versions of *Charlotte's Web*. The story persuades the reader that, as Charlotte says, "Almost all spiders are rather nice-looking."[4] In the live-action film, the other animals in the barn think her creepy and Wilbur crazy for saying she is beautiful. The

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[i] Like good spiders, male spiders are largely a recent innovation in the West, and their weaving is usually downplayed. J.K. Rowling emphasizes Aragog's ravenousness over his spinning, and various versions of Spider-man differ as to whether his web shooters are a superpower or a piece of technology.

difference in Charlotte's portrayal is due to the medium. In 1973, the celluloid Charlotte is anthropomorphic and therefore friendly-looking, but in 2006, Charlotte is realistically rendered and therefore more disturbing. Her disconcerting appearance means the community must grow to appreciate her as they do Wilbur. Live-action Charlotte proves her worth; her book and animated counterparts have no need.

Charlotte, of course, is not a monster-woman, although the 2006 movie raises the question when one of the barn animals whispers conspiratorially that spiders "eat their menfolk"[5] (a claim that is never addressed). Her lack of monstrosity is especially obvious when one contrasts her with another famous female spider of the 1950s: Shelob from *The Lord of the Rings*. Superficial differences are obvious. Charlotte is a motherly spider of ordinary size who lives in a barn doorway and whose web becomes the means of Wilbur's salvation. Shelob, on the other hand, is a gargantuan terror who mates with her own offspring and then devours them, spinning nearly impenetrable webs in the tunnels of a mountain-pass to capture hapless travelers. Readers may also find their literary significance to be at odds. In "Of Spiders and Elves," Lionarons reinterprets Brenda Partridge's notorious reading of Sam's fight with Shelob as a violent sexual encounter. Instead, she sees it as a contrast between Shelob and the ethereal Elven Lady Galadriel that depicts a triumph of the procreative and unitive aims of sex over animalistic lust.[6] Sam's is the victory of Galadriel over Shelob, a fight against appetite and objectification that Charlotte likewise wins. The key difference is on which side the spider falls.

Galadriel and Charlotte have parallel roles because they are both depicted in ways suggestive of the Virgin Mary. While Shelob resembles either Lilith[ii] or Sin from *Paradise Lost*, Charlotte is portrayed as a maternal virgin. She occupies a place of high spiritual status. Physically situated above the other animals in the barn, she is contemplative and philosophical, with composure in the face of death. In the trinity that resides in Wilbur's stall, Charlotte is the spirit while anxious Wilbur is the mind and gluttonous Templeton, the body. However, she is not a literal mother until the main thrust of the story is complete, and we never hear of the Mr. Charlotte who must have fertilized those five hundred fourteen eggs, so Charlotte seemingly reproduces by parthenogenesis (virgin birth). In addition to the wisdom of sparing child readers the grittiness of

spider-procreation, it would have been cumbersome for White to introduce another character when the focus is Wilbur's story. Therefore, in keeping Charlotte's love life offstage, White also emphasizes Charlotte's selflessness and makes her appear virginal. Meanwhile, her daughters make her death less bleak by giving her a kind of immortality. Her death signifies Wilbur's passage to adulthood. When Wilbur tells Templeton, "She is going to become a mother,"[7] he fails to realize that she has been his mother all along.

Marian symbolism ends there, as Charlotte takes on Christological overtones. Charlotte is probably the first Christological spider, although spiders' vampiric diet makes them Eucharistic in the wrong direction, but feminine Christological characters are nothing new. For example, nineteenth-century fantasy writer George MacDonald filled his stories with them, inspired in part by the medieval mystic Julian of Norwich, who described Jesus as having maternal qualities. As a wisdom figure strongly connected with language, Charlotte is reminiscent of Logos, the Greek concept of divine wisdom and a title for Christ. Logos became Latin Verbum in the Vulgate and thence came into English as Word. Did White descend on this line of thought down to his depiction of Charlotte as a writer? Probably not, but the idea of word as metonym for wisdom is prevalent in Western imagination. Wilbur's salvation by means of words written in a spiderweb parallels the salvation of humanity by means of the Incarnate Word hanging on a cross. Sacrificial love transforms these instruments of death into instruments of life. A commentative song in the 1973 film unites these symbols of cross and web through lyrics that reference a perpendicular intersection, characterizing it as a sign of the power of disinterested love. The song concludes with the lines, "Sometimes when somebody loves you, / miracles somehow appear, / and there in the warp and the woof is the proof of it."[8] Whereas the cross is a product of the masculine craft of carpentry, the web is of the feminine craft of weaving.

Like Christus Victor and Artemis virgin goddess of the hunt, Charlotte is both trickster and defender of the weak. Rowe argues that female tricksters fight for a cause, usually the protection of the weak;[9] and Tatar calls female tricksters double agents, working to change an unjust system from within.[10] While her predatory nature is important to her character, Charlotte is driven not by her own hunger as classic tricksters usually are,[11]

[ii]Lilith is the archetypal monster-woman. In Hebrew folklore, she is Adam's first wife, who through disobedience to God and Adam became a horrific demoness who seduces sleeping men and drinks the blood of sleeping children.

but by the goal of saving Wilbur from human hunger. Charlotte says, "The way to save Wilbur's life is to play a trick on Zuckerman."[12] Tricksters win by their wits—as Charlotte tells Wilbur she does[13]—rather than by any physical prowess. In addition to inventing traps such as nets and hooks, tricksters use verbal trickery, such as riddles, doubletalk, and reverse psychology. The web makes the spider particularly apt to characterization as a trickster. Unlike most tricksters, which Hyde says often fall into their own traps,[14] spiders cannot get stuck in their own webs because they know which threads are safe to step on and their oily bodies resist sticking. Such imperviousness to their own traps ought to win the spider a literary portrayal as a kind of super-trickster, but this is rarely the case; Anansi the Spider of African folklore, for example, falls prey to many of his own tricks. But female tricksters go beyond imperviousness. Because their trickery is more geared toward societal reform than is traditional trickery, which usually revolves around stealing or avoiding capture, it does not produce the kinds of traps to which their own makers will fall prey. The female trickster's goal is to convince others—to trap them in a position she already occupies. The words in Charlotte's web convince others of Wilbur's attributes because Charlotte already believes in them.

Bound up in the characterization of female tricksters is the idea of the voice as vehicle for feminine power. In other famous literary works, Scheherazade and Philomela rescue themselves from victimhood through storytelling. Charlotte's web, like Philomela's tapestry, demonstrates that weaving is a woman's recourse when she is unable to use her primary vehicle of power: her voice. The aforementioned song[15] draws numerous parallels between the web, human spinning, and words: "her tracings" are "lyrical" and a "silent song." White is careful to show that Wilbur cannot spin a web, lacking spinnerets and know-how.[16] As the only writer, Charlotte is the lone animal in the barn cellar able to communicate with the humans, who Dr. Dorian says have forgotten how to listen. She uses human gullibility—"People believe almost anything they see in print"[17]—to reshape the community's conception of Wilbur.

The story contains one last bitter truth: motherhood can be a thankless task. Charlotte is the heroine—it is her name in the title, after all—yet she receives very little credit. Mrs. Zuckerman, herself a woman, is the only one to speculate that "we have no ordinary spider,"[18] only to be dismissed by her husband: the web clearly says the pig is the unusual one. For the rest of the book, everyone attributes the extraordinariness to Wilbur, because "spiders cannot write."[19] Live-action Charlotte even hides herself so there appears to be no spider at all. Even Charlotte says, "Your success in the ring this morning was, to a small degree, my success,"[20] failing to recognize that it was almost entirely her success, even if no one recognizes it. The task is not wholly thankless, though, because her surrogate child understands what she did for him. In the book as well as both movies, Wilbur gives a speech to Charlotte's daughters that ensures a terrific, radiant, and humble legacy. Motherhood may go unsung by society, but not by the children, who grow up to honor the woman who gave them life.

It is tempting to take such commentary too far and conclude that Charlotte's partial discontentment for her spiderhood as analogous to internalized misogyny. When she first meets Wilbur, she tells him:

I am not entirely happy about my diet of flies and bugs, but it's the way I'm made. … Way back for thousands and thousands of years we spiders have been laying [traps] for flies and bugs.

…it is [a miserable inheritance]…But I can't help it. I don't know how the first spider in the early days of the world happened to think up this fancy idea of spinning a web, but she did, and it was clever of her, too. And since then, all of us spiders have had to work the same trick. It's not a bad pitch, on the whole.[21]

Charlotte does not hate being a spider; she simply recognizes that the spider condition could use improvement. The fact that every spider mentioned in the novel is female underscores spiders' femininity in this tale, but if Charlotte's reflections on spiderhood are a comment on womanhood, they are applicable to humanity in general. This is clear near the end of the book, when she tells Wilbur:

A spider's life can't help being something of a mess, with all this trapping and eating flies. By helping you, perhaps I was trying to lift up my life a trifle. Heaven knows anyone's life can stand a little of that.[22]

Everyone's life could do with lifting up, including

8. Charles A. Nichols and Iwao Takamoto, *Charlotte's Web* (1973; New York: Hanna-Barbera Productions and Sagittarius Productions, 1973), film, 40:13.
9. Karin E. Rowe, "From To Spin a Yarn: The Female Voice in Folklore and Fairy Tale," in *The Classic Fairy Tales, Second Edition*, ed. Maria Tatar (New York: W.W. Norton, 1999), 365.
10. Maria Tatar, "From Female Tricksters as Double Agents," *The Classic Fairy Tales, Second Edition*, ed. Maria Tatar (New York: W.W. Norton, 1999), 461.
11. Lewis Hyde, "The Bait Thief," *The Classic Fairy Tales, Second Edition*, ed. Maria Tatar (New York: W.W. Norton, 1999), 456.
12. White, *Charlotte's Web*, 66.
13. White, *Charlotte's Web*, 40.
14. Hyde, "The Bait Thief," 458.
15. Nichols, *Charlotte's Web*, 37:42.
16. White, *Charlotte's Web*, 59.
17. White, *Charlotte's Web*, 90.
18. White, *Charlotte's Web*, 81.
19. White, *Charlotte's Web*, 158.
20. White, *Charlotte's Web*, 163
21. White, *Charlotte's Web*, 39–40.
22. White, *Charlotte's Web*, 164.

> **FOR SIXTY YEARS, CHARLOTTE HAS REMINDED US THAT NATURE ENDOWS THE FEMALE WITH UNIQUE POWER THAT SHE USES TO RESHAPE HER COMMUNITY**

Wilbur's. Spiders' lives could do with improvement, but no more so than the lives of other animals. Women's lives could do with improvement, but not any more so than men's lives. Charlotte understands that life is wretched, but ultimately good.

Conclusion

Other positive Western portrayals of spiders exist (Mrs. Spider, Rosie of Disney-Pixar's "A Bug's Life," etc.), but they all seem to have come about in the last sixty years, suggesting that Charlotte was the first, and that her successors owe much to her. Charlotte's femaleness is inseparable from her role as weaver, writer, and mother. For sixty years, Charlotte has reminded us that nature endows the female with unique power that she uses to reshape her community, build bridges, and protect those she loves.

References

1. E.B. White, *Charlotte's Web* (New York: Harper Collins, 1952), 184.
2. Graham C.L. Davey, "The 'Disgusting Spider': The Role of Disease and Illness in the Perpetuation of Fear of Spiders," *Society and Animals* 2, No. 1 (1994): 7, https://doi.org/10.1163/156853094X00045.
3. Joyce Tally Lionarons, "Of Spiders and Elves," Mythlore: A Journal of J.R.R. Tolkien, C.S. Lewis, Charles Williams, and Mythopoeic Literature 31, no. 3 (2013): 8, https://dc.swosu.edu/mythlore/vol31/iss3/2.
4. White, *Charlotte's Web*, 37.
5. Gary Winick, *Charlotte's Web* (2006; New York: the K Entertainment Company, Walden Media, and Nickelodeon Movies, 2006), film, 20:39.
6. Lionarons, "Of Spiders and Elves," 9.
7. White, *Charlotte's Web*, 149.

Rebecca Baumgarten '20

Rebecca Baumgarten '20 is a first-year graduate student from Schertz, Texas, working toward an MA in English. She has a BA in English and a minor in history. The summer of 2019, she interned as a proofreader at Aggie Press, and now she is a graduate assistant in the Texas A&M Department of English.

Mixed Reality: The VR Experience Visualized for Screens

By John Donaldson

Introduction

Virtual reality (VR) has been technologically possible for decades, but it has not seen wide scale commercial viability until recently. Currently, the modern tech industry is in a period of rapid innovation and growth regarding VR technology and application. Because of its hands on and easily understood design, VR has made its way into video games, classrooms, and the workplace.[1] VR uses the brain's natural perception of depth to transport you to another world. You use the same motions and visuals that you have had since birth to look and interact with virtual environments. People who are unfamiliar with this technology can intuitively interact in virtual environments with ease.

Despite VR being relatively easy to operate, there is a great disconnect between our physical reality and a simulated environment experienced through VR. When a user puts on a VR headset, the display envelopes their vision. This is a singular experience, because only one person can have the headset on at a time. However, when developers want to improve accessibility and convey the experience of VR to an audience, they must use a screen. Everyone has access to a screen, but in its current stage, VR is still in an early adopter phase. This presents a problem because VR content does not naturally fit a flat plane.[2] If VR is to enter and improve diverse entertainments such as educational and professional industries, producers of VR programs need to showcase their content in the most visually appealing, easily accessible, and understandable way. Ideally, this is the method which most closely replicates the unique and immersive experience of a VR headset onto a 2D screen. Our research team at Soft Interaction, under the Department of Visualization at Texas A&M University, is exploring the best methods to display VR to a larger

> **THERE IS A GREAT DISCONNECT BETWEEN OUR PHYSICAL REALITY AND A SIMULATED ENVIRONMENT EXPERIENCED THROUGH VR**

audience. Our goal is to make VR content accessible to multiple people in a live environment while not compromising the experience of entering a virtual world. This way, people can have the experience of VR without needing the hardware. Through mixed reality, we can achieve all of this and more.

Methods

Our research team has set out to address the problem of inaccessibility in VR applications by adapting their content for screens. The challenge was to display how a person acts and interacts in the virtual world in a naturalistic, aesthetic, and practical way. To adapt the content, we built a "mixed reality" system, which composites a live actor into a virtual environment. This creates a final image which is similar to a live action camera shot of an actor, yet the environment is completely virtual **(Figure 1)**.

Our team filmed a live actor in front of a green screen. Then, we attached a positional tracker to the real camera, and created a virtual camera to mirror the position, rotation, and field of view. The actor is then composited into the shot in the position they would be occupying. Because the virtual camera tracks in the same way as the real camera, the virtual scene acts similarly to a real environment. This yields a final shot which seamlessly places the actor in the virtual world.

Results

We defined three guiding criteria for the success of our research:

1. Naturalistic display of the original content onto a screen.
2. Visually aesthetic presentation of VR content.
3. Interactive, multi-person, usability and demonstration.

To make the experience seem naturalistic, objects would have to interact with the actor as they would in the real world. Therefore, we would have to include variable opacity in our composition. If an object appears between the camera and the actor, it must block the subject from view in the same way it would naturally. If the object has translucency, then it should only partially cover the subject. We achieved this through the four panel compositing method, developed by Kert Gartner and the Owlchemy Lab team for the production of VR game trailers.[3]

In order to differentiate the background from the foreground, we implemented LIV compositing software[4] to split the virtual camera into 4 distinct outputs **(Figure 2)**. Each output was layered together with the green screen footage of the actor to create the final composite.

The background layer was programmed to display exactly what that the virtual camera saw, capturing all objects behind the actor. Then, we separated the actor from the green screen so that only his/her body is visible. Next, we used an alpha matte (a black and white template) to extract only the objects between the camera and the subject. In places where the alpha matte is white, something is obstructing the camera's view. In that position on screen, we rendered the image in front of the actor with the foreground layer. Any places where the alpha matte is a gradient between white and black, are either translucent objects or objective markers for navigation and direction in the program. All of this combines to give a final image which places a person seamlessly into a digital space **(Figure 3)**.

Once we placed the actor in the scene, we had to consider the aesthetics of the shot to ensure the greatest production value and transmission of information. By the nature of mixed reality, much of the cinematography was similar to live action production. In the production of our video on Texas A&M University's "Cyber Security VR" application, developed by Dr. Hwaryoung Seo's research team,[5] we approached filming as if we were on location.

We can detail the process of mixed reality

Figure 1. Example of a final composite using the "Mixed Reality" method.

Figure 2. Four output displays captured at once. From top left to bottom right: Foreground, Foreground Alpha Matte, Background, reference POV angle.

video production through our experience of filming a demonstration for "Cyber Security VR." Though this program is used as technical training for server farm technicians, the method of filming any VR program in mixed reality is similar. In "Cyber Security VR," the user, who is training to be a technician, tours a high security server farm. This is a facility which houses computers or servers that process incoming and outgoing data online. The user is instructed on how to perform maintenance on a faulty server rack. It is important that this training can be done in VR, because actual server farms are highly secure and losses can be

Composition Layer Order

Final Shot

Foreground

Alpha Matte

Green Screen

Background Layer

Figure 3. Composition Layering Chart

costly. In a similar fashion to live filmmaking, we filmed the scenes from multiple angles. This is called coverage. With a wide amount of coverage, we could ensure the best camera angles for any given action. However, we experienced a few challenges. In many instances, our virtual camera would start behind a wall or prop, and the action would be blocked. In the preproduction of our next demonstration for "Muscle Action VR,"[6] an educational software that simulates how your muscles move in real time, we decided to attach the physical camera to a steady cam and film the demonstration at any angle that the camera operator moves. This would add dynamic movement to the shot, while also allowing us to adjust angles to obtain more presentable footage.

Lastly, it was important that our footage be practical and applicable. A large portion of VR demonstration occurs at live events, so we wanted the ability to display actors in virtual environments in real time. This would allow our VR demo to become more communal, allowing passersby to immediately understand the application before trying it themselves. In order to do this, we used LIV VR compositing software[7] to composite each video layer in real time and output to a display. While this has proven to work in the lab, we will showcase both the live broadcast method and the final version of Muscle Action VR at VIZA GOGO student showcase in May of 2020.

> **IN EDUCATION WE CAN STEP INTO VIRTUALLY ANY ENVIRONMENT, AND EXPERIENCE LEARNING TOPICS FIRSTHAND**

Conclusion

It is not likely that society will completely forgo two-dimensional displays as our main form of information transfer any time soon. For VR to thrive, it must be available to audiences whose primary interface is through screens. By developing methods which can artistically and practically capture VR on a screen, we can make it more accessible to the general public. In entertainment, we can advertise products and games by showing real people using the software, and having fun. In education we can step into virtually any environment, and experience

IN STANDARD VR, THESE WOULD ALL BE SINGULAR EXPERIENCES, BUT WITH MIXED REALITY, ENTIRE GROUPS CAN INTERFACE WITH THE PROGRAMS

learning topics firsthand. School children could explore life science in a unique way by visiting jungles, oceans, and highlands while staying in the safety of their classrooms. Furthermore, doctors and nurses in training could experience surgery without the threat of human mortality. In standard VR, these would all be singular experiences, but with Mixed Reality, entire groups can interface with the programs. This is just the beginning of how VR can expand into more practical roles. With the advent of Mixed Reality, we can view VR content in a more human way.

Acknowledgments

REFERENCES

1. Nick Babich, "How Virtual Reality Will Change How We Learn and How We Teach," *Adobe Blog*, (January 5, 2018), theblog.adobe.com/virtual-reality-will-change-learn-teach/.

2. Kert Gartner, "Making High Quality Mixed Reality VR Trailers and Videos," KERT GARTNER, Owlchemy Games, (April 5, 2017), www.kertgartner.com/making-mixed-reality-vr-trailers-and-videos/.

3. Gartner, "Mixed Reality," www.kertgartner.com/making-mixed-reality-vr-trailers-and-videos/.

4. LIV, "Main Page," LIV Wiki, Techstars Company, (January 24, 2019), wiki.liv.tv/index.php/Main_Page.

5. Jinsil Hwaryoung Seo, "Soft Interaction Lab," Soft Interaction Lab, Texas A&M University, softinteraction.com/.

6. Seo, "Soft Interaction Lab," softinteraction.com/.

7. LIV, "Main Page," wiki.liv.tv/index.php/Main_Page.

John Donaldson '22

John Donaldson '22 is a Visualization major from Rowlett, Texas. John works with Soft Interaction Labs, Research Team to further VR educational content. Currently, he is the student class representative for his year, as the Media Chair for TAMU Chillennium Game Jam, and a student employee for the Department of Visualization. John plans to continue research and class related activities until he graduates.

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COVER ARTWORK BY

Ashley Hayden '19

An original painting inspired by "InNervate VR: Can Virtual Reality Teach Anatomy?" on page 8.

Ashley Hayden '19

Ashley Hayden is a former student who studied Biology and minored in Bioinformatics and Psychology. Ashley's cover art is inspired by the advancements in VR technology shown throughout Volume 11, particularly the article "InNervate VR: Can Virtual Reality Teach Anatomy?".Ashley especially wanted to convey how remarkable and breathtaking science can be. Now at Baylor College of Medicine, Ashley is currently pursuing a Ph.D. in Neuroscience.

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