Volume 2 • Issue 1 • Fall 2025

SPARC

Interdisciplinary Journal for Undergraduate Research

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Printed in the United States of America.

Student Papers in Academic Research Collaborative

From the Editors-in-Chief

To the readers of SPARC,

It is unremarkable to have remarkable ideas.

Student Papers in Academic Research Collaborative is now in its second year of publication. But what if this *idea* for a journal that celebrates undergraduate research had been brushed away and left to sit on a shelf of transient memory alongside other afterthoughts? *Untapped potential.* Behind SPARC, there were many faces that wanted to realize a vision that two people had. It was an idea that consumed; an idea that turned into an incessant, collective yearning before it was manifested in the blue and white pages of the first volume.

The original work by Michigan State University's undergraduates featured in this journal, although constrained to its finite pages, has consequences that echo far beyond our campus from either sides of the Red Cedar River.

The current issue turns its attention to the *human potential*. There is a world around us and a world within, and the separating boundary is far more permeable than we might think. How learning a language extends the phase space of the mind, changing our very perception of the world; how ecosystems can be reshaped and how belief can reimagine the biological self; how the body tells its own story in female athletes; how hospitals might reduce their footprint through smarter sterilization; how a child's voice can be understood differently when we listen without assuming.

There exists a dynamic equilibrium between these worlds; a steady flow of human potential waiting to be tapped into. Each paper in this issue stands as evidence of that exchange, showing how ideas evolve when curiosity meets intention.

In this careful curation of papers, we have also tried to capture the ethos of undergraduate research at MSU: ask without hesitation, investigate without assumptions, and let the answers sharpen who you become. An idea carries potential but these gossamer-like thoughts mean little if they aren't pulled into meaning – into the world that we live in.

The world is your choice of shellfish.

Sincerely,
Jaini Gandhi and Nityaansh Parekh

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Menstrual Disorders in Female Athletes: A Literature Review

Gwendolyn Urbain[1]

1 College of Natural Science, Michigan State University, East Lansing, Michigan, United States

*urbaingw@msu.edu

Abstract

Menstrual Cycle (MC) disorders among female athletes are highly prevalent. Athletes tend to have heavier bleeding and longer duration between menses (Czajkowska, 2020). Studies examining different sports have defined a few menstrual disorders as the following: Pre Menstrual Syndrome (PMS), Pre Menstrual Dysphoric Disorder (PMDD), Primary amenorrhea (inability to reach menarche), secondary amenorrhea (3+ months without period), and oligomenorrhea (irregular period with increased blood flow). Research on the MC during exercise has identified proposed mechanisms that alter athletic performance and may be implicated in menstrual disorders. This review delves into four proposed mechanisms (body composition, stress, muscle activation, and thermoregulation) and their ability to affect menstrual disorder likelihood or female athletes with existing menstrual disorders. It was found that body composition and physiological stress were most likely to predict menstrual disorder frequency. However, there is a need for further research on the molecular mechanisms governing these conditions to define a relationship between how aberrant cellular conditions cause a menstrual disorder.

Introduction

The female brain exists in a constantly fluctuating neurochemical state due to the menstrual cycle. During exercise this is heightened due to the physical demands and different chemicals released that imbalance the Hypothalamic-Pituitary-Ovarian (HPO) Axis (Stafford, 2005). The HPO axis controls female reproduction, and during exercise, the hormones involved in female reproduction - including estrogen and progesterone - are impacted, causing amenorrhea or oligomenorrhea (Stafford, 2005). Studying how MC phases are altered due to physiological stress caused by exercise may inform athletes on how to train, recover, and perform best based on their menstrual cycle.

Menstrual Cycle Physiology

The female menstrual cycle is variable but normally ranges between 21 and 35 days. This is known as an eumenorrheic cycle and can be separated into the follicular and luteal phases (Carmichael et al., 2021). The eumenorrheic cycle can be broken down further into early follicular, late follicular, ovulatory, early luteal, middle luteal, and late luteal phases (Carmichael et al., 2021). During the early follicular phase, menstruation occurs and a thickened endometrium is shed (Farage et al., 2009). Due to a surge in Luteinizing Hormone, the egg begins to form during the remainder of the follicular phase. (Farage et al., 2009). The luteal phase is characterized by the corpus luteum degenerating, an increase in progesterone levels, and a decrease in estrogen levels (Farage et al., 2009).

Menstrual Cycle Disorders

Menstrual cycle disorders are defined as disrupting the normal reproductive axis. Primary amenorrhea is the inability to reach first menarche (Gasner and Rehman, 2023). Secondary amenorrhea is the absence of a period in over 3 months for normally cycling females, and over 6 months for irregularly cycling females (Rebar, 2000). Oligomenorrhea is both irregular cycling (35+ days) and prolonged bleeding (He et al., 2020).

Exercise and Menstrual Cycle Disorders in Athletes

Endurance athletes are most likely to have oligomenorrhea, while primary amenorrhea is predominantly seen in aerobic sports (Redman and Loucks, 2005). Both secondary amenorrhea and oligomenorrhea are highly prevalent in all sports disciplines (Redman and Loucks, 2005). The mechanism causing menstrual disorder to be more prevalent in athletes, however, remains undefined. Athletes' bodies are subjected to rigorous training during the MC. Studies have been done to understand how objective physiology and subjective feelings of athletes are altered across the MC. Most studies focus on body composition, stress, muscle activation, and thermoregulation (Carmichael et al., 2021; Meignié et al., 2021; Hansen and Kjaer, 2014; Giersch et al., 2020). As such, this review aims to understand the impact that menstrual disorders in female athletes have on these mechanisms.

Methodology

This review was conducted through the PubMED database with access to Journals provided by Michigan State University. The eligibility criteria for journal inclusion in our analysis consisted of: (1) female athletes, (2) a description of menstrual cycle disorders, (3) variation in MC due to exercise. The following Boolean operators were used to refine the search: “menstrual cycle disorder” OR “menstrual cycle irregularity” OR “menstrual cycle abnormality”, AND “athlete” OR “athletic performance” OR “exercise”. Articles published from 1998 to 2025 were included in this study. Excluded material consisted of magazine articles, non-English language articles, and articles with no full text available.

How Body Composition impacts Female Athletic Performance

Athletes commonly experience low energy availability (LEA) as defined by a lack of sufficient ingested energy to support the body during exercise. LEA is known to have an association with body composition by lowering fat mass and muscle protein synthesis (Oxfeldt et al., 2023). Insufficient micro- and macro-nutrients negatively impact physiology (Logue et al., 2018). Additionally, during LEA, female athletes face a decrease in LH pulsatility and bone turnover, which can lead to impaired reproductive function and bone metabolism (Logue et al., 2018). Further, one study found that varying energy levels can predict the frequency of menstrual disturbances (Williams et al., 2015). This concluded that a decrease in energy disrupts reproductive function and increases the risk of developing a menstrual disorder.

Body composition and LEA are also increasingly magnified through the idea of thinness as the determination of fitness. A study on Olympic athletes reported that sports where leanness is painted as optimal for performance tend to have higher rates of athletes with eating disorders (Hagmar et al., 2008). Limiting food intake to reach a satisfactory weight creates a lack of energy. Without adequate food intake, athletes fall victim to LEA. Female athletes face the issue of thinness in competition at a higher rate than males due to societal pressures (Byrne and McLean, 2002). Due to this, a screening tool for female athletes to determine the risk for physiological symptoms from LEA (LEAF-Q Test) was created and validated in 2014 (Melin et al., 2014). This tool determined that ‘at risk’ female athletes exhibit metabolic deficiencies due to a lack of energy. Decreased carbohydrate levels and endocrine changes suppress progesterone and estrogen, resulting in reduced performance (Vanheest et al., 2014). In addition to decreased performance, suppressed ovarian hormones cause an increase in menstrual disorder susceptibility; a study on female collegiate runners found that 54.4% scored ‘at risk’ on LEAF-Q, while 56.5% reported some menstrual disorder (Dambacher et al., 2025). These findings indicate that LEA and menstrual disorder are associated.

Physiological Stress due to Exercise alters Hormones

Cortisol, the body’s stress hormone, is released during exercise as the body is placed under physiological stress. Studies have shown that cortisol reduces Gonadotropin Releasing Hormone’s (GnRH) pulsatile frequency causing lesser production of LH and Follicle Stimulating Hormone (FSH), impacting estrogen and progesterone levels (McCosh et al., 2023; Ralph et al., 2016; Wagenmaker et al., 2009). Higher levels of cortisol are seen in female athletes with menstrual disorders than eumenorrheic athletes (Melin et al., 2015). Amenorrheic athletes with higher cortisol levels were identified to have lower catecholamine concentration and lower blood lactate levels (Schaal et al., 2011). This lessened adrenergic response causes a higher level of exertion for amenorrheic athletes as catecholamines are necessary for sympathetic regulation of cardiovascular and metabolic systems. These results indicate that a reduction in performance due to increased cortisol level in female athletes with MD could be present.

Additionally, cortisol's impact on estrogen extends to serotonin, which has been found to be implicated in Pre Menstrual Syndrome (PMS) and Pre-Menstrual Dysphoric Disorder (PMDD). Specifically, estrogen has been found to increase serotonin levels by increasing transcription of the rate-limiting enzyme in serotonin synthesis: tryptophan hydroxylase 2 (TPH2) (Hiroi and Handa, 2013). As cortisol suppresses estrogen levels, less transcription occurs, leading to lower serotonin levels. Decreased serotonin levels cause PMS symptoms such as fatigue, insomnia and depression (Gudipally and Sharma, 2023).

Muscle Activation is altered through the MC

Estrogen and progesterone are thought to relate to muscle strength and mass (Chidi-Ogbolu and Baar, 2019). Studies contradict one another on the specifics of whether the fluctuating concentrations of ovarian hormones changes muscle activation over the cycle (Oxfeldt et al., 2023; Ikeda et al., 2019 Hansen and Kjaer, 2014). This is largely due to there being unclear rules on how to measure estrogen/progesterone levels accurately and consistently in muscle tissue. Estrogen is known to be involved in signaling skeletal muscles to control muscle activation. Estrogen and progesterone have opposing effects on protein catabolism, as estrogen inhibits protein catabolism while progesterone promotes it (Kissow et al., 2022). By suppressing protein catabolism, estrogen preserves muscle mass and strength. Additionally, the ability to regenerate and recover muscle fibers is highest when estrogen reaches its peak during the late follicular phase (Hansen and Kjaer, 2014). This research indicates that when estrogen is suppressed, as which occurs during menstrual disorders, a decrease in muscle strength and mass may occur.

Thermoregulation upset during MC

Thermoregulation during the MC, specifically the rise in basal body temperature during the luteal phase, is thought to decrease exercise performance (Giersch et al., 2020). Previous studies have demonstrated conflicting results, with many finding no impact of MC on strength and aerobic sports during any phase (Janse de Jong, 2003; Kissow et al., 2022; Giersch et al., 2020). However, one study found endurance exercise was reported to be impacted by an increase in temperature due to increased cardiovascular strain (Janse de Jonge, 2003). A study by A.M. Garcia, using female athletes subjected to 60 minutes of cycling during each MC phase, demonstrated that although those in the luteal phase had an increase in basal temperature, they also experienced an increase in sweat volume during exercise to compensate for the temperature increase (Garcia et al., 2006). This increase in sweat due to increased temperature shows the body's regulatory effect across an hour of exercise but does not delve into cardiovascular impacts of the menstrual cycle.

Furthermore, women experiencing menstrual disorders are at a higher risk for experiencing. symptoms of heat sensitivity and hot flashes due to MC thermoregulation (Hahn et al.,1998). Identifying how women with menstrual disorders are affected by thermoregulation in an exercise context is necessary to understand heat exhaustion and heat illness susceptibility.

Limitations and Future Research

Studies within this field of research are limited in number and lack cohesive experimental measurements and methods. Many experiments are based on subjective questionnaires or consist of a variety of methods for measuring progesterone and estrogen levels. Thus, a significant gap in knowledge is present especially when it comes to the prevalence of menstrual disorders in female athletes.

Future research should focus on creating a validated model to measure estrogen and progesterone levels across the menstrual cycle, as well as a common exercise test for athletic performance. Additionally, a standardized method of training responses, or of measuring physiological response to exercise during the phases, is needed.

Additionally, identifying the relationship between nutrition and menstrual disorders, as well as its implications on muscle mass and strength, is necessary to prevent severe injury in athletes and possible severe imparity of reproductive function. Many studies research the menstrual cycle in eumenorrheic females. However, the implications of exercise on women who already have menstrual disorders is under-studied.

Conclusion

This literature review was conducted to better understand how exercise and menstrual cycle disorders are related. Multiple studies delved into proposed physiological mechanisms altered due to the menstrual cycle with implications for exercise, but studies commonly contradicted one another. The differing methods of measuring progesterone and estrogen, and different exercises used to model acute, mild, and endurance sports varies across sports, leading to conflicting results about the relationship between the two.

Most conclusively, body composition – specifically altered due to LEA – was the most likely cause of menstrual cycle disorder due to exercise. Limiting food intake due to the perception of thinness leading to optimal fitness causes a decrease in performance and impaired reproductive function. The physical stress placed on the body during exercise is also seen to impact menstrual cycle disorders and potentially cause disorders in of themselves. Increased cortisol levels lead to a suppression of estrogen and progesterone occurs, which is known to have negative implications for performance and reproductive function.

Muscle activation and thermoregulation, while commonly investigated as proposed mechanisms by which the menstrual cycle impacts exercise, remain undetermined in their role in menstrual cycle disorders. Muscle activation is thought to be unchanged across the menstrual cycle. Thermoregulation is found to have no impact on performance apart from potentially causing increased cardiovascular strain during endurance sports. Both muscle activation and thermoregulation are thought to be impacted by menstrual disorders; however, future research should focus on how the menstrual cycle is impacted by exercise in non-eumenorrheic athletes.

In summary, the relation between exercise and menstrual disorders is widely unknown and studies researching the menstrual cycle need more standardized methods of measurement and experimentation. A better understanding of how exercise potentially causes menstrual cycle disorders and the implications of exercise for women with menstrual disorders is necessary for both athlete performance and reproductive health.

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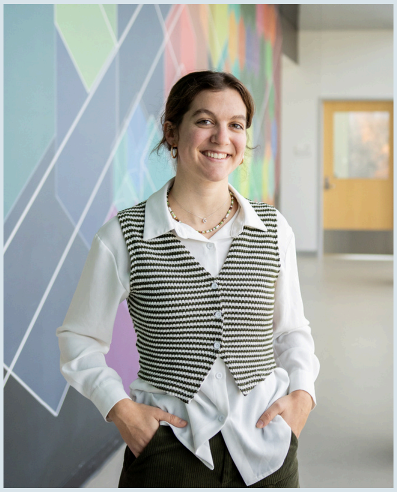

About the Author

Gwen Urbain graduated with a Bachelor of Science in Neuroscience this past August and is now working as a Lab Technician in the Laumet Lab. Her interest lies in investigating reproductive physiology within stress and pain contexts during graduate school. Her work as an undergraduate inspired this article as she performed an independent research project on how stress alters the mouse estrous cycle-this literature review helped her better understand her own research and identify future research areas in the field. Gwen hopes that readers leave with an understanding of the importance of studying female reproductive systems in physiologically stressful conditions.

How Learning a New Language Expands Scientific Imagination

Fatima AlSheikh[1,2]

1 College of Natural Science, Michigan State University, East Lansing, Michigan, United States
2 College of Arts and Letters, Michigan State University, East Lansing, Michigan, United States

*alshei13@msu.edu

Abstract

In this paper, I will look into the connection between language learning and scientific reasoning. I will be focusing on how bilingualism, specifically the study of Japanese and English, would enhance creativity, flexibility, and conceptual understanding in STEM fields, especially Physics. Looking into evidence from cognitive science, neuroscience, and educational research, the paper will argue that bilingualism and literature help stimulate the neural structures in one's brain that are responsible for abstract reasoning and executive control – both of which are crucial in physics and STEM, especially in problem solving. This analysis shows that studying two fields which are seemingly unrelated actually provides deeper connections across disciplines while still encouraging analogical thinking. It also broadens one's intellectual horizons. I will be using my personal experiences as a Physics and Japanese double major to illustrate how language learning can sharpen logical and creative faculties that are directly transferable to scientific inquiry.

Introduction

For the majority of people, language learning and physics are often viewed as incompatible fields, often referred to as "disconnected." Language is grounded in expression and culture, while physics is focused on numbers and universal laws. Yet they are both systems of representation that rely on structure, logic, and creativity. As a student of both physics and Japanese, I have found that language study does not compete with scientific reasoning, it actually enhances it. When switching between linguistic frameworks, the brain trains to have a flexible thinking mechanism and can interpret multiple layers of meaning. These skills directly mirror the mental operations needed in theoretical and experimental physics.

Bilingualism and language learning play a huge role in stimulating cognitive processes which catalyse scientific creativity. Language learning also enhances neural flexibility and pattern recognition which are essential in STEM fields. Both language and physics combine logical precision with imaginative interpretation, and by learning a new language, one can deepen their interest in science by transforming how they perceive patterns, systems, and relationships in the physical world.

Cognitive Stimulation in a Bilingual Brain

Language and Science Processing

Recently, cognitive neuroscience research has demonstrated that bilingualism enhances activity in the prefrontal cortex and anterior cingulate cortex, which are regions that are responsible for executive control, task switching, and problem solving (Bialystok, 2011; Costa and Sebastián-Gallés, 2014). These regions are also heavily involved in complex reasoning and abstraction in physics and mathematics. Managing two linguistic systems by deciding which lexicon to access, inhibiting interference from a different language, and interpreting context is what creates a continuous mental workout that aids in strengthening the neural pathways used for symbolic reasoning.

Bilingual individuals are more likely to exhibit enhanced working memory and superior ability to manipulate mental representations (Marian and Shook, 2012). These are essential skills in visualizing problems in physics. There is an overlapping activation in parietal regions when subjects perform mathematical and linguistic syntactic operations in parietal regions when subjects perform mathematical and linguistic syntactic operations together (Dehaene et al., 2004). This suggests that grammar processing and equation solving share neural resources for structure building and brain development.

Language Learning is a Cognitive Simulation

While language learning seems far away from science, it is a simulation of scientific modeling. For example, when learning Japanese, it is crucial to constantly conjecture the function of particles (*ni*, *wa*, *ga*) in different contexts, and then test this through conversation, and revise them afterwards. This process mimics the scientific method of hypothesis testing. The feedback loop of prediction, testing, and correction help stimulate the prefrontal basal ganglia circuits in one's brain and therefore enhances its adaptability and tolerance for ambiguity (Abutalebi & Green, 2016). The same processes provide physicists with ways to navigate uncertain systems and revise theories when given new data.

With such examples, bilingualism is shown to strengthen one's linguistic abilities in addition to their cognitive skills that support reasoning under uncertainty – which is crucial in fields that require scientific discovery.

Finding a Connection in Disconnection

Challenging Disciplinary Systems

In many modern universities, disciplines are usually separated into different colleges. For example, physics belongs to the natural sciences whereas Japanese belongs to the humanities. However, this separation is not as intellectual as one might think; it is actually more institutional. This is because both physics and Japanese involve decoding patterns, applying rules, and recognizing the changes that occur when these rules break or misalign.

The way polymaths use skills from a certain field to innovate in another is a form of engaging in two distinct disciplines that encourages cognitive diversification (Root-Bernstein, 2001). For instance, in the Japanese language, pattern recognition involved in learning kanji radicals, which are visual components that form characters when added together, translates into enhanced pattern sensitivity when interpreting mathematical and physical components such as graphs, interference fringes, and quantum waveforms.

How Japanese Complements Physics

Japanese, like other languages, trains the mind to think more relationally instead of linearly. The sentence structure is very specific in Japanese, and quite different from the English language. Usually, context and topic are placed before actions and verbs, which encourages the speaker to listen and perceive the whole before the detailed parts, which in a way, mirrors the holistic modeling in systemic physics. In addition, Japanese has a non-phonetic system for kanji characters that requires visual, spatial, and semantic processing. This is quite similar to the mental operation needed in manipulating several representations in physics, especially moving between diagrams, equations, and other conceptual models.

I studied electromagnetism alongside Japanese for a semester. This led me to a rather strange observation: while reading Japanese texts, I was scanning for contextual cues, inferring missing information, and recognizing underlying structures. These skills were the exact same ones I was utilizing in my electromagnetism class. This metacognitive parallel boosted my confidence in tackling multiple abstract physics problems. I believe this is due to the fact that my brain has already been trained in navigating complex systems with many rules through language study.

Logic and Creativity in Grammar and in Physics

Structural Similarities

In many ways, the Japanese language and physics work through elegant systems of rules and exceptions. The grammar used in language studies gives a framework for constructing meaningful expressions, which in a way mirrors the way information and focus on important principles. This mathematical laws provide frameworks for describing nature. The Japanese language has a unique particle system that always reminded me of the syntax of a physical equation. Particles, such as *wa*, *ga*, *o*, and *ni*, help clear the relational dynamics between elements in Japanese, the same way mathematical operators ($+$, $-$, ∇) give a clear understanding of interactions between physical quantities.

To be more specific, in Japanese, *wa* (は) sets the main topic, while *ga* (が) is important in determining the subject, which are such detailed distinctions that require contextual reasoning even though many language speakers do not realize it. On the other hand, in physics, discerning whether a quantity is scalar or vectorial, dependent or independent, utilizes the same contextual logic in the brain, and in both of these cases, a distinct meaning arises from relational structures and isolated symbols.

Creativity Beyond Given Rules

Despite the logical and rational similarities between physics and Japanese, constrained creativity is the most profound similarity between them. The grammar rules and physical laws are what define boundaries, yet within these boundaries, interpretation and imagination are bound to thrive. For instance, literary translation requires constructing meaning while preserving emotional resonance across given systems. This is remarkably similar to the way physicists build theoretical models which result in empirical observations and mathematical abstraction.

For many physicists, Einstein's claim that "imagination is more important than knowledge," does not make a lot of sense. Yet while digging deeper in physics, one finds that this claim emphasizes that creativity is what drives the formulation of new theories. Similarly, composing haiku, which entails capturing meaning in seventeen syllables, embodies the exact creative compression physicists look for when expressing a complex phenomenon in a certain equation.

Interpretation as an Art in Science

Studying Japanese literature has increased my sensitivity to nuance and ambiguity, especially in reading and writing. Having previously read Kawabata's *Snow Country*, where silence and space carry meaning, I realized that even with the lack of words, absence can still be as informative as presence. Null results or symmetries often guide discovery in physics. In both fields, interpretive imagination grounded in disciplined reasoning is extremely rewarded and encouraged.

Bilingualism and STEM Engagement

Language Learning - Motivation for Scientific Curiosity

Foreign language learning is a great way to broaden one's view of the world as it fosters intellectual curiosity which reflects on other fields. This can renew the motivation of many students for science by helping them connect abstract principles to human experience. Bilingual learners develop heightened metacognitive awareness and a stronger sense of cognitive agency compared to others. These qualities are linked to persistence and engagement in STEM fields (van der Walt and Dornbrack, 2011).

Learning Japanese has helped me rethink the ways in which I approach physics problems by providing cultural metaphors for scientific ideas. I have learned about a concept in Japanese called "Zen" that focuses on emptiness, and that stuck with me because of its great similarity to vacuum energy and quantum uncertainty. In addition, the concept of *wa* (harmony) mirrors equilibrium in thermodynamics. These two analogies have evolved my perception of physics. I formerly envisioned it as a purely mechanical pursuit, but I now see it as an aesthetic and philosophical exploration of balance and relationship .

The Cross Linguistic Transfer of Problem Solving Skills

Bilingual education correlates with improved problem solving skills, divergent thinking, and pattern recognition in an individual, which are important skills to succeed in STEM (Adesope et al., 2010). The constant switch between linguistics and physics is a great enhancement for cognitive control and that by itself enables bilinguals to suppress irrelevant skill is quite crucial in physics to navigate complex and multivariable systems.

Interdisciplinary Education and Future Opportunities

Integrating any language and STEM training gives students the chance to be equipped for scientific collaboration and innovation around the world. Any physicist who has the ability to navigate between both technical and cultural languages becomes a great connection between multiple communities.

A New Education Model

Overcoming Separation of Science and Language

The *Two Cultures* lecture given by C. P. Snow (1959), has countered the growing gap between scientists and humanists. My double major in Physics and Japanese is a constant rebuttal to that division placed by others. When engaging both hemispheres of the brain, the analytical and narrative, logical and empathic, many students are able to gain a more integrated understanding of the world.

Fostering similar integration in students can encourage innovation and conceptual translation between disciplines. If more educational programs started teaching scientific writing alongside linguistics and translation, they could create genuine connections between precision in expression and precision in measurement for many students.

Future Scientist and a Cultural Translator

Given the current state of the world – climate change, quantum technology, and emerging questions in AI ethics – there is a strong need for scientists that can think like linguists and humanists. They are more likely to be aware of context, sensitive to ambiguity, and able to communicate across conceptual frameworks. A bilingual physicist embodies this capacity: translation requires deep empathy for the source and the target languages, just as scientific innovation requires empathy for both theory and the natural world.

Personal Reflection

When I first started learning Japanese, I was unsure of what I wanted to study in college. Over the years I developed a marked interest in physics, especially in mechanics and thermodynamics. While balancing both fields, I did not anticipate that language learning would reshape my scientific reasoning. I began to notice similarities in both areas and it made me more determined to study and connect with them. Creating a complex sentence in Japanese was akin to solving for x in an equation since each particle had a specific role that was not necessarily visible. While reading Japanese literature, I was also encouraged to notice the slight shifts in tone, space, or perspective. The more I practiced this, the more I noticed the ways in which physicists infer hidden variables from experimental data.

Surprisingly, my interest in physics created a better understanding and a deeper appreciation for languages as I started to see their structured and dynamic systems. While studying quantum mechanics, I found that its probabilistic nature was similar to how languages can be interpreted differently according to the context. Both fields remind me of the way many things can have different meanings and not everything has an absolute answer. Interpretation can change a lot and not just measurements.

Through my four years in college, I have become confident that bilingualism, multilingualism in my case, is as much a scientific asset as it is a cultural one. It cultivates patience and abstraction and encourages the courage to be lost in uncertainty – qualities that support scientific discovery.

Conclusion

After considerable research, I can say that bilingualism and scientific reasoning are not as distant as they appear: both reinforce one's ability to engage with complexity. In learning Japanese, I expanded not only my linguistic abilities but also my capacity for abstract reasoning, creative modeling, and global thinking. At the same time, mathematical thinking was activating the same neural systems, offering a form of cognitive cross-training that strengthened my work in physics and STEM.

Furthermore, studying what might seem like two unrelated subjects, physics and Japanese, creates unexpected opportunities for deep structural and philosophical connections. Both fields blend disciplined logic with interpretive imagination. They value simplicity, elegance, and harmony, and they share a commitment to uncovering the hidden patterns that link the visible and invisible worlds.

In a time when specialization can narrow one's perspective, being a bilingual scientist broadens the very meaning of intelligence and dedication. It strengthens the ability to listen for meaning rather than only measure it. Thinking in two languages becomes a way of thinking beyond boundaries, and that is an essential skill for all scientists and humanists.

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About the Author

Fatima AlSheikh is a senior majoring in Physics and Japanese. She is interested in language learning, cultural studies, psychology and behavioral analysis, and condensed matter and quantum physics, thermodynamics, and mechanics. As a first-language Arabic speaker who is learning Japanese and Turkish while studying Physics, she has often heard that languages and STEM have no connection. Through this piece, she wants to show how connected they truly are and how both languages and Physics have made her more aware of the world. She hopes people pursue every subject they're interested in and find connections even between things that seem different.

Understanding the herpetofauna of Michigan State University's Corey Marsh Ecological Research Center for future restoration efforts

A. Proudfoot[1], Alexa Warwick[1]

1 College of Agriculture and Natural Resources, Michigan State University, East Lansing, Michigan, United States

*proudf17@msu.edu

Abstract

Reptiles and amphibians, or herpetofauna, have the highest extinction rates of any vertebrate group. We established a herpetofauna monitoring research project at Michigan State University's Corey Marsh Ecological Research Center (CMERC) to better understand the diversity and abundance of local herpetofauna populations. The two focal survey methods were passive acoustic recording of frogs and capture-mark-recapture of turtles using aquatic traps. Additionally, we implemented salamander false cover surveys in partnership with the Salamander Population Adaptation Research Collaborative Network (SPARCnet). We identified eight species of frogs and three species of turtles in total between 2022 - 2024. Frog species at CMERC included spring peepers (*Pseudacris crucifer*), western chorus frogs (*Pseudacris triseriata*), eastern gray treefrogs (*Hyla versicolor*), green frogs (*Lithobates clamitans*), wood frogs (*Lithobates sylvaticus*), northern leopard frogs (*Lithobates pipiens*), bullfrogs (*Lithobates catesbeianus*), and American toads (*Anaxyrus americanus*). Turtle species at CMERC included painted turtles (*Chrysemys picta*), common snapping turtles (*Chelydra serpentina*), and Blanding's turtles (*Emydoidea blandingii*). Salamander species at CMERC solely included the blue-spotted salamander (*Ambystoma laterale*). We also assessed frog reproductive phenology (timing of calling) for *P. crucifer*, *P. triseriata*, *H. versicolor*, and *L. clamitans*. We found that calling frequency is related to the time of year for all four species, but most strongly with early spring breeders such as *P. crucifer* and *P. triseriata*. Similarly, *P. crucifer* calling frequency has a low negative correlation with temperature, suggesting that *P. crucifer* is especially reliant on low early spring temperatures and may be more sensitive to the effects of climate change. Our results provide important baseline herpetofauna data for CMERC and will help guide future habitat restoration, wildlife conservation, and monitoring efforts on the site. Finally, the project has collectively engaged ~500 students, postdocs, faculty, and community partners, providing both research professional development and networking opportunities.

Introduction

Reptiles and amphibians, or herpetofauna, are vital components of the food webs of both aquatic and terrestrial ecosystems. Because they are both more sensitive to changes in the environment due to their ectothermic nature, their combined study is common. In Michigan, there are 13 species of frogs and toads, 18 species of snakes, 10 species of salamanders, and 10 species of turtles; out of these species, 15 are considered either threatened, endangered, or of special concern (Michigan DNR). The reptiles and amphibians of Michigan exist in many roles similar to those around the world as prey, predators, and indicator species. Amphibians in particular are used as indicators of environmental health as a result of their sensitivity to pollution (Sumanasekara et al., 2015). Amphibians' methods of both drinking and breathing utilize their skin; for this to be possible, their skin needs to be permeable. As a result, any substance their skin comes in contact with is absorbed into their system, which causes their sensitivity to pollution (Fenoglio, 2006). Currently, amphibians are under threat of mass extinction and experience the highest rates of extinction compared to all other vertebrate groups (Collins, 2010). Not only are amphibians sensitive to pollution, but both amphibians and reptiles, due to their ectothermic nature, are especially sensitive to temperature changes (Griffis-Kyle et al., 2018). Herpetofauna thermoregulation and breeding patterns are closely related to their climate, and thus, tracking the changes in distributions of these species is necessary for their conservation.

Fifty percent of wetlands have been lost in the lower 48 states from 1780 to 2019 (Lang et al., 2024). Wetlands are vital ecosystems for the wildlife habitat and ecosystem services they provide (Erwin, 2008). This immense loss of a vital ecosystem, such as wetlands, makes understanding how to restore those ecosystems crucial. Michigan State University's Corey Marsh Ecological Research Center (CMERC) offers a unique wetland site to study changes in herpetofauna populations during habitat restoration efforts and a changing climate. CMERC's purpose has not always been ecological research. Before the research center officially opened in 2018, the center was a muck farm where soil types were tested for agricultural use. The previous muck farm status of CMERC allows for questions to be answered regarding the effects of agriculture on restored land and the organisms that repopulate the area.

This project tested the implementation of multiple herpetological surveying techniques to establish a long-term monitoring project at CMERC. The goal of this project is to establish baseline data and understanding of herpetofauna diversity and abundance at CMERC, along with their interactions with climate and land use, to improve herpetofauna conservation efforts. To accomplish this goal, we established five objectives.

1) Establish herpetofauna monitoring methods that can feasibly be carried out long-term by alternating lead undergraduate research assistants.

2) Measure herpetofauna diversity, abundance, and seasonality at CMERC.

3) Identify conservation needs of herpetofauna at CMERC with a focus on the state species of special concern, Blanding's turtle and federally threatened eastern massasauga rattlesnake.

4) Collaborate with diverse institutions to build capacity for replicated herpetofauna monitoring programs across the United States.

5) Provide education and outreach opportunities for students and the general public.

Surveying Methods

Anuran Passive Acoustic Monitoring

In our pilot year, 2022, we deployed two Wildlife Acoustic SongMeter4 (SM4) passive acoustic monitors at CMERC with standard settings (Wildlife Acoustics, 2024), recording at 5-minute intervals from 1900 to 0700 hours from February to October to detect frog and toad (anuran) calling activity. We used settings supported by the literature for similar studies using SM4 recorders (e.g., Larsen et al., 2021; Tabak et al., 2022). In 2023 and 2024, we decreased the amount of data gathered by shortening the recording interval to 2-minute intervals from 2100 to 0700 based on the most common times anurans were calling.

To calculate common calling times, we added the total amount of calls detected at each hourly interval and saw an average increase in calls detected from 1900 vs. 2100 (~200 calls vs. ~900 calls). The average number of calls throughout the entire time period was 917, and from 2100 to 0700, all of these hours detected at least 800 calls. The 1900 and 2000 time slots found less than 25% of the average call amount. As a result, we removed the 1900 and 2000 time slots. Less data also reduced future data analysis burden to new undergraduate students entering the position (Objective 1).

We used Kaleidoscope analysis software to automate frog call identification for four frog species (*P. crucifer, P. triseriata, H. versicolor, and L. clamitans*). We trained Kaleidoscope software through manual identification of detected frog calls to create a training set. Through this manual identification, we also tested the accuracy of the automated identification based on a parameter within the software called "distance from". This parameter indicated how close the identified audio clip was to the training set. We randomly generated 100 numbers corresponding to identified audio clips by Kaleidoscope within the 0 - 1 distance from value, and a second set associated with a distance from value greater than 1. Overall, the identifications associated with a distance from score less than 1 had an accuracy of 77%, while those with a distance from value greater than 1 had 0% accuracy. This, combined with personal correspondence from collaborators at Laurentian University, led us to exclusively consider identifications associated with a distance from value of 0 - 1.

We collected temperature data from NOAA's Lansing area online climate data tables to test for temperature correlations (US Department of Commerce; NOAA).

Turtle Mark Recapture

From 2022 to 2025, we conducted a 7-12-day sampling session for three seasons: fall, spring, and summer. This method is supported by previous literature and the standard operating procedure used by the Michigan Natural Feature Inventory for turtle sampling (Badra et al., 2020). We deployed two types of aquatic turtle traps - a smaller Promar crayfish trap and a larger hoop net. Between 6 - 13 traps were deployed each session, depending on water levels and volunteer availability. We recorded water and air temperatures to compare captures with environmental characteristics. For each captured turtle, we collected morphological measurements (carapace length and width, plastron length and width, total shell height), sex, and assigned a recapture code (Figs. 1 and 2). We marked turtles using a nail file on scute corresponding to a unique two-letter code.

In 2022, we established two 50-board false cover plots for salamander sampling as described in Grant et al. 2024. We checked these plots periodically alongside other Salamander Population Research Collaborative Network (SPARCnet) sampling efforts and with class field trips.

Analysis Methods

All analyses were performed in R Studio. ANOVAs were run on a subset of data corresponding to four frog species: *P. crucifer*, *P. triseriata*, *H. versicolor*, and *L. clamitans*, to determine whether time of year and

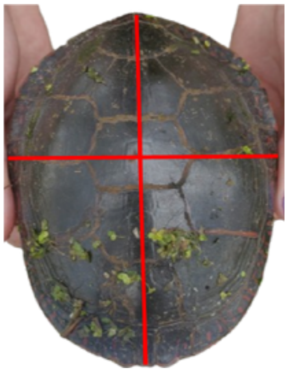

Figure 1. Example of *C. picta* carapace length and width.

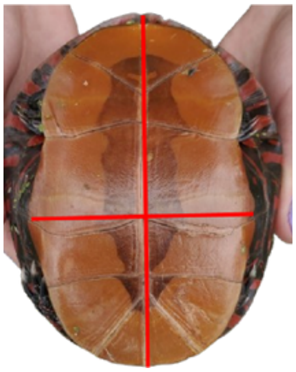

Figure 2. Example of *C. picta* plastron length and width.

amount of detected frog calls were dependent. Pearson correlation tested whether the average daily temperature and detected frog calls were correlated.

Results

Anuran Passive Acoustic Monitoring

Passive acoustic loggers were deployed for 513 days from 2022 - 2024. Eight species were detected, including: spring peepers (*Pseudacris crucifer*), western chorus frogs (*Pseudacris triseriata*), eastern gray treefrogs (*Hyla versicolor*), green frogs (*Lithobates clamitans*), wood frogs (*Lithobates sylvaticus*), northern leopard frogs (*Lithobates pipiens*), bullfrogs (*Lithobates catesbeianus*), and American toads (*Anaxyrus americanus*).

We calculated calling amounts for four species (*P. crucifer, P. triseriata, H. versicolor, and L. clamitans*). *Pseudacris crucifer* and *P. triseriata* calling peaked in April, *H. versicolor* calling peaked in May, and *L. clamitans* calling peaked in September (Fig. 3).

ANOVA tests for independence between the time of year and the calling frequency of individual species showed that *P. crucifer*, *P. triseriata*, *H. versicolor*, and *L. clamitans* calling frequencies are not independent of month (*P. crucifer*, p=2.554e-5; *P. triseriata*, p=0.002178; *H. versicolor*, p=0.03653; and *L. clamitans*, p=0.02698). Pearson correlation tests comparing the average daily temperature to the daily calling frequency of individual species were insignificant for every species except *P. crucifer* (p=1.623e-8; cor=-0.326223).

Turtle Mark Recapture

We conducted eight sampling periods, each with 7-12 days of effort, depending on water levels and volunteer availability. A total of 72 sampling days

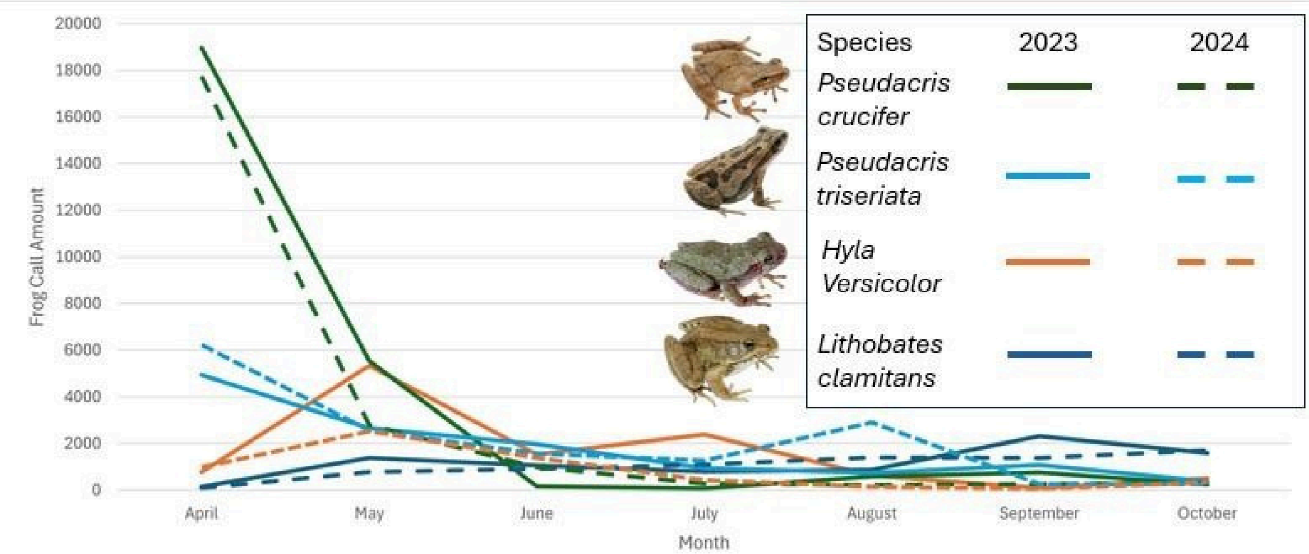

Figure 3: Monthly calling frequency of *P. crucifer*, *P. triseriata*, *H. versicolor*, and *L. clamitans* for 2023 and 2024.

resulted in 123 turtles captured, representing three different species: painted turtle (*Chrysemys picta*), common snapping turtle (*Chelydra serpentina*), and Blanding's turtle (*Emydoidea blandingii*). Across all sampling periods, the most commonly captured species was *C. picta* (Fig. 4). Of the 115 *C. picta* captured, 4 were recaptured, and 75% were males. In total, only five Blanding's were captured in traps, although additional individuals were marked from incidental capture.

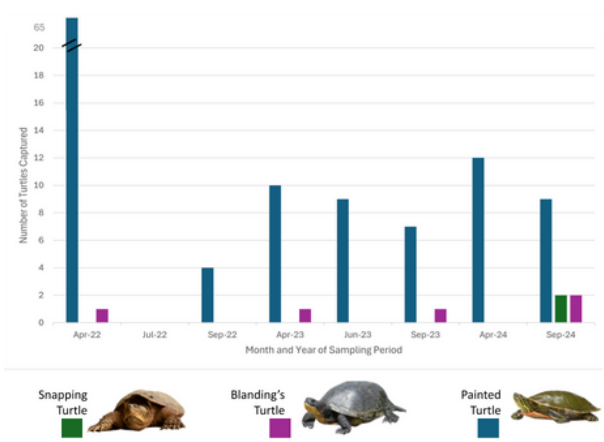

Figure 4: Turtle capture rates for every detected species at CMERC: snapping turtle (*Chelydra serpentina*), Blanding's turtle (*Emydoidea blandingii*), and painted turtle (*Chrysemys picta*) from April 2022 - September 2024.

Salamander False Cover Surveys

From 2022 - 2024, the only salamander species we found was *A. laterale*. As this sampling was in collaboration with SPARCnet, and SPARCnet exclusively collects data on the red backed salamander (*Plethodon cinereus*), we did not record any data regarding *A. laterale*.

Discussion

Our anuran passive acoustic monitoring, turtle trapping efforts, and salamander sampling at CMERC described present herpetofauna species and provided further knowledge on anuran responses to climate variables at CMERC. Anuran breeding periods, when they are most likely to be found calling, are dependent on time of year and climatic variables (Green, 2017; Larsen et al. 2021). At CMERC, we found the same to be true for our four species: *P. crucifer*, *P. triseriata*, *H. versicolor*, and *L. clamitans*; however, this association was stronger for some species (Fig. 3).These species are *P. crucifer* and *P. triseriata*. This association with time of year was weakest for *H. versicolor* (p=0.03653), which may indicate a stronger resilience towards climate change impacts on seasonality (Objs. 2 and 3). Previous literature has documented that early spring breeders, such as *P. crucifer* and *P. triseriata*, are stronger indicators of environmental health due to their reliance on time-sensitive environmental and climatic conditions that are found in early spring (Blaustein, 2002; Green, 2017). *Pseudacris crucifer*, in particular, displays extremely high call rates early in the season, which drop drastically after mid-May (Fig. 3). *Pseudacris crucifer*'s association with these months may partially be related to temperature, as we showed a slight negative correlation with temperature (p=1.623e-8; cor=-0.326223). Other climatic and environmental variables associated with early spring most likely also play a part, as indicated by previous literature (Benard, 2023). Variables that we did not account for include days since the last rainfall and the status of vernal pools. *Pseudacris crucifer* is known to use vernal pools, which are created by spring rains (Korfel et al., 2010). These pools dry later in the season and are most likely connected to the decline in *P. crucifer* call rates. However, temperature cannot be removed from this relationship because high temperatures dry up vernal pools (Keeley and Zedler, 1998). *Pseudacris crucifer*'s reliance on low early spring temperatures suggests that it may be more sensitive to climate change, and thus, it is important to continue monitoring, as its population health may be an early indicator of overall ecosystem health (Objs. 2 and 3).

Across our turtle trapping seasons, we tested aquatic turtle trapping techniques and standardized our trapping protocol for CMERC, which will allow for more efficient and robust future data collection. During this time, we also found turtle species presence, including the state species of special concern, Blanding's turtle. Now that we know this species is at CMERC, future efforts will focus on movement ecology to better inform nesting behavior and increase broader awareness of its population status. Other than the Blanding's turtle, we largely found painted turtles. This is as expected since they are the most commonly found turtle species in Michigan (Objs. 2 and 3). However, it is unclear why we had such a large drop in trapped turtles from the first sampling period in spring 2022 as compared to later sampling periods (Fig. 4). We collaborated with SPARCnet for our salamander sampling efforts, aligning with Objective 4 to collaborate with diverse institutions. However, as SPARCnet solely collects data on *P. cinereus*, and we did not find any *P. cinereus* at CMERC, we did not collect any salamander data other than species presence. The lack of *P. cinereus* at CMERC is a conundrum, as similar sites near CMERC have *P. cinereus*. Further efforts to understand this conundrum are underway.

Along with our herpetofauna monitoring efforts, we supported the education of future wildlife professionals by involving 79 volunteers and 21 MSU lab classes. We also participated in environmental education events open to the general public, such as the ecology extravaganza event held at CMERC. This connects with our objective of outreach and education, and shows the potential of this project to be an educational experience for a large group of undergraduates (Objective 5).

Conclusion

We successfully implemented turtle, frog, and salamander surveys at Corey Marsh Ecological Research Center, carried out by a lead undergraduate organizer and volunteers (Objective 1). This project increased our understanding of the diversity of herpetofauna species at CMERC and the environmental conditions associated with their presence (Objective 2). Early spring breeders such as the spring peeper and western chorus frog are more sensitive to seasonality and have potential to act as environmental health indicators; continued monitoring of these groups is valuable for understanding the health of the entire marsh (Objective 3).

Our establishment of this herpetofauna monitoring project at CMERC provides future research opportunities for undergraduates at MSU (Objective 5). Additionally, this project offers baseline herpetofauna population data to measure the impact of restoration efforts at CMERC on these valuable communities (Objective 3).

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About the Author

Proudfoot is a May 2025 Fisheries and Wildlife BS graduate from Michigan State University with interests in reptile and amphibian conservation. This paper details their undergraduate work creating a reptile and amphibian monitoring project at Michigan State University's Corey Marsh Ecological Research Center. Proudfoot hopes that this paper will provide guidance for future undergraduate researchers interested in wildlife as a whole and inspire others to appreciate reptiles and amphibians.

Rethinking Speech Anxiety: Why Western Diagnostic Models Fail Multilingual Children and How Adaptive AI Could Transform Pediatric Care

Hania Masood[1]

1 Lyman Briggs College, Michigan State University, East Lansing, Michigan, United States.

*masoodha@msu.edu

Speech anxiety tests are used a lot in pediatric settings. Speech anxiety refers to fear, hesitation, or discomfort during verbal communication, and in pediatrics, it is commonly assessed through structured screening tools or instruments such as the Social Phobia and Anxiety Inventory for Children (SPAI-C) (McLeod and Verdon, 2017). These tools help doctors and teachers catch early signs of trouble with communication. But I've noticed a pattern. When these screenings are used with children from immigrant or multilingual families, the results can be misleading. Most of the tools used today were designed for kids who grew up speaking only English, specifically in the United States, in households that follow Western cultural expectations (Bedore and Peña, 2008). If a child doesn't respond the way those tools expect, they can be misunderstood.

This issue isn't about whether the child has anxiety or not. It's about how that anxiety is being defined in the first place. In many evaluations, behaviors such as pausing before speaking, avoiding eye contact, or being quiet are treated as signs. But in a lot of cultures, those same behaviors carry a completely different meaning. For example, in many East Asian cultures, avoiding eye contact is considered respectful, and in Middle Eastern or South Asian households, children often pause before responding out of politeness (Westby and Torres, 2020). A child might pause to think, or because they are translating in their head. They might be quiet because they were taught that's polite. None of that means something is wrong, but the system doesn't take that into consideration.

I began to notice this up close while volunteering in hospitals. At Sparrow Hospital, I worked in the Mother and Baby Unit of the Obstetrics Department, where I helped families from different backgrounds. Some parents were soft-spoken. Some answered slowly or avoided direct eye contact. These weren't signs of discomfort. That's just how they communicated. But sometimes those behaviors raised concern among staff who expected something different. That difference that we have created between expectation and reality is where the problem starts.

I've also seen this in research. At Michigan State University's Speech and Language Development lab, I worked on projects involving child language patterns. I spent a lot of time transcribing how kids responded during speech sessions. It was clear that many kids were being thoughtful, translating, or adjusting their tone depending on who was present and who they were speaking to, but the system didn't see that. It measured how long they took to speak or how quickly they responded. And that's what determined the result. Research supports this. Bilingual children often require additional processing time because they are managing two linguistic systems at once, which naturally increases hesitations and pauses (Paradis, 2010).

What bothered me was how often a pause or hesitation was labeled as anxiety, even when it had nothing to do with fear. Some kids were just trying to figure out the right words in the right language, which requires mental energy and is not something to penalize. But most of the tools being used don't make that distinction. Some efforts have been made to address this issue. A few tools have been translated into other languages Some scoring models have been adjusted slightly. But the core assumptions haven't changed. Most screening tools still expect a certain pace, tone, and style of speaking. If a child's culture encourages something else, they're marked as off-track.

I think artificial intelligence (AI) could help. If trained well, AI could pick up on these differences and adapt its evaluation of each child accordingly. Instead of comparing every child to the same "average," it could learn what's normal in different communities depending on the child's background. A quiet child might be showing respect. A child who pauses could be trying to process the language. If AI could recognize that, it would prevent a lot of unnecessary concern. But this only works if AI systems are trained on diverse linguistic and cultural data; otherwise, they repeat the same biases clinicians already make (Reddy, Allan, and Coghlan, 2020).

Of course, none of this works unless the AI is trained on diverse data. If it only sees one way of communicating, it will just keep repeating the same mistakes. That's why it's important to include individuals from diverse backgrounds in the development of these tools. Parents, researchers, doctors, and students all have contributions to make.

I've also seen how damaging a wrong label can be. At a caregiving job in memory care, I worked with patients who had been defined by their diagnoses. Once a label was in place, it shaped how they were treated and spoken to. Similar thing happens with children. If a child is told they're anxious early on, it changes how teachers see them. It shapes the support they get, or don't get, and it sticks long into their future.

Equity in healthcare isn't just about who gets access. It's also about how we measure things. If the tools we use are built around only one way of seeing the world, then we're setting some children up to fail. We might think we're helping when, in fact, we're actually creating a barrier. The goal should not be to make children adjust to fit our systems; it should be the other way around. Our tools need to grow. They need to reflect the real diversity of the kids they're evaluating. We need to ask better questions. Above all, we need to listen to and understand each child individually.

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About the Author

Hania Masood is a senior studying Human Biology with a minor in Business at Michigan State University. As a first-generation student from an immigrant family, she is especially interested in how culture and language shape the care children receive in clinical settings. Her academic interests include pediatric development, communication differences, and diagnostic equity, and she hopes to become a Child and Adolescent Psychiatrist. This piece grew out of her experiences volunteering in hospitals and working in a speech development lab, where she saw how multilingual children are often misunderstood during screenings.

Sterilization Revolution: Can Autoclaves Reduce Medical Waste in Healthcare?

Rachel Roberts[1], Emma Movahedi[1], Keyan Clapp[2], Allison DeMare[3], Victoria Grieve[2], Kamilia Khatib, Sethmi Madawala[2], Alexia Petoskey[4], Ava Richardson[1], Paige Spitz[2], Selina Tripathy[1], Elizabeth Verhoef[1], Annie Yang[2]

1 Lyman Briggs College, Michigan State University, East Lansing, Michigan, United States
2 College of Natural Science, Michigan State University, East Lansing, Michigan, United States
3 College of Agriculture and Natural Resources, Michigan State University, East Lansing, Michigan, United States
4 College of Social Science, Michigan State University, East Lansing, Michigan, United States

*robe1286@msu.edu, movahed1@msu.edu

Abstract

The expansion of healthcare has led to a sharp increase in medical waste, much of which consists of single-use plastics, disposable equipment, and pharmaceutical byproducts. The reliance on disposable materials, including gloves, syringes, and packaging, poses significant environmental challenges. A large portion of this waste is non-biodegradable, necessitating incineration, which releases harmful chemicals into the environment. Identifying sustainable alternatives to current disposal methods is crucial for reducing the ecological impact of healthcare. This literature review examines the potential role of autoclaves in reducing medical waste and mitigating environmental harm. By systematically analyzing peer-reviewed research from 2010 to 2025, we assess the effectiveness of autoclaving in sterilizing and repurposing medical materials, its feasibility as a large-scale waste management solution, and its environmental impact compared to incineration. Our findings highlight key takeaways regarding the performance of autoclaves, barriers to implementation, and proposed solutions for integrating sustainable waste processing into healthcare systems. Understanding the role of autoclaves in waste reduction can inform policy changes, improve hospital protocols, and support innovations in sustainable medical waste management. This review provides insight into how healthcare institutions can adopt autoclaving as a viable alternative to incineration, ultimately contributing to a more environmentally responsible approach to medical waste disposal.

Literature Review

The demand for personal protective equipment (PPE), including face masks, gloves, gowns, and face shields, surged in response to the COVID-19 pandemic, leading to an unprecedented increase in medical waste. The World Health Organization reported that the accumulation of medical waste during the pandemic increased plastic pollution in the oceans by ten times (Khan et al., 2023). Additionally, hazardous waste generation was estimated at 3.40 kg per infected person per day (Haque et al., 2021), highlighting the immense burden placed on waste management systems. Medical waste includes various disposable tools, such as needles, syringes, and masks, which, while critical in preventing the transmission of infections, contribute significantly to the rising accumulation of waste. This increase has exacerbated an environmental challenge known as PPE pollution, impacting both land and aquatic ecosystems (Haque et al., 2021). Improper disposal of this waste poses significant public health risks, including the spread of infectious or drug-resistant microorganisms, exposure to toxic chemical and pharmaceutical waste, and the release of air pollutants from disposal methods such as incineration (Kheirabadi et al., 2022).

The surge in medical waste has intensified the need for sustainable disposal solutions. One of the most critical yet overlooked aspects of waste management is waste segregation. Studies indicate that the failure to separate biodegradable from non-biodegradable waste properly complicates recycling and treatment efforts, leading to increased disposal costs and longer processing times (Kokkinos et al., 2024). Poor waste management also results in long-term environmental damage, increasing cleanup costs, and the risk of adverse health outcomes in surrounding communities. The financial burden of medical waste management is significant, with costs associated with onsite waste treatment, shipment fees, labor, fuel, utilities, and vehicle maintenance. Additionally, ineffective waste management can further overwhelm healthcare systems, leading to increased hospitalizations, longer treatment durations, and overall higher healthcare costs that impact entire communities (Chartier et al., 2014).

According to the World Health Organization, the waste management hierarchy prioritizes sustainable waste-handling strategies based on environmental impact, public health protection, financial feasibility, and social acceptability. The hierarchy ranks prevention, reduction, reuse, and recycling as the most desirable strategies, followed by recovery, treatment, and finally, disposal as the least preferred option (Chartier et al., 2014). Despite these recommendations, healthcare waste management continues to face persistent challenges. Current disposal methods include thermal, chemical, radiation, biological, and mechanical treatments, with incineration remaining the most widely used approach. While incineration effectively reduces waste volume, it also generates harmful emissions such as dioxins, furans, and heavy metals, which contribute to air pollution (Kheirabadi et al., 2022). Other methods, such as mechanical shredding and chemical treatments, offer waste volume reduction but fail to fully neutralize pathogens.

Autoclaving, a steam sterilization method, presents a more environmentally friendly alternative to incineration and other traditional waste disposal practices. This method uses high-pressure steam to sterilize medical waste, effectively eliminating pathogens without releasing toxic emissions. Research has shown that autoclaving can successfully decontaminate medical waste, including high-risk items such as N95 masks, while maintaining their functional integrity. Autoclaving has also been found effective in neutralizing a range of pathogens, including viruses such as polio, hepatitis B, and MRSA (Chartier et al., 2014).

In research laboratories, autoclaves are routinely used to sterilize and allow the reuse of various instruments and materials. This practice reduces waste generation and promotes cost-effectiveness by allowing items such as glassware, metal tools, and certain plastics to be reprocessed. In contrast, healthcare facilities largely depend on single-use disposable medical devices due to infection control protocols that aim to minimize cross-contamination risks. While this ensures patient safety, it also leads to increased waste production. Many disposable medical tools contain intricate designs that are difficult to sterilize effectively, further reinforcing reliance on single-use devices.

Regulatory frameworks play a crucial role in determining sterilization practices and the reuse of medical devices. In research settings, sterilization guidelines are primarily governed by internal protocols aimed at maintaining experimental integrity and safety. However, healthcare facilities are subject to stricter regulations designed to mitigate the risks associated with reprocessing medical devices. In the European Union, the Medical Device Regulation (MDR) (Regulation (EU) 2017/745) requires reprocessed single-use devices to meet the same standards as original devices (Regulation (EU) 2017/745, 2017). Similarly, the United States Food and Drug Administration (FDA) enforces rigorous standards for reprocessing single-use devices, ensuring that cleaning, sterilization, and functional performance meet safety requirements (FDA, 2006). These strict guidelines prioritize patient safety but also contribute to the growing issue of medical waste accumulation by limiting the ability to reuse sterilized equipment.

As medical waste continues to rise, alternative waste management strategies must be explored to minimize environmental and public health risks. While single-use disposable devices remain a critical component of infection prevention, autoclaving offers a promising solution for reducing the waste volume while maintaining sterility. By shifting reliance away from incineration and exploring sterilization-based reuse methods where feasible, healthcare facilities can move toward more sustainable waste management practices.

Methods

This study utilizes a literature review approach to examining 23 studies to determine the role of autoclaving in medical waste management and its feasibility as a sustainable alternative to single-use disposables. The review synthesizes data from peer-reviewed sources to analyze medical waste production, autoclave efficiency, regulatory barriers, and the cost-effectiveness of these measures. The literature was categorized into key themes, including single-use waste, autoclave effectiveness in hospital and research settings, and environmental impact.

Academic databases were searched for studies related to nonrenewable medical waste and autoclave usage. Sources were selected based on their relevance to healthcare waste management, autoclave sterilization effectiveness, and sustainability in medical settings. Only peer-reviewed articles published after 2010 were included to ensure the data reflect current practices. The review focuses on identifying how medical supplies are discarded, what makes them non-renewable, and how autoclaves can sterilize and repurpose these materials. Studies were categorized into themes of single-use waste, autoclave efficiency in research and hospital environments, and the environmental impact of these applications.

Data on medical waste volume and autoclave efficiency were gathered from existing case studies, government compliance reports, and waste audit sampling studies. Medical waste volume is typically assessed through weight-based measurements, where facilities sort and weigh medical waste before disposal.

Surveys of medical facilities also provide estimates by evaluating the size of disposal containers used and calculating average daily waste per bed. The effectiveness of autoclaving is monitored through mechanical, chemical, and biological indicators. Biological testing often utilizes spores of *Geobacillus stearothermophilus*, a heat-resistant bacterium, to determine sterilization success. If these spores survive an autoclave cycle, it indicates a failure in sterilization. Studies have used various sterilization indicators, including Class-5 chemical indicators and self-contained biological markers, to assess the effectiveness of autoclave cycles. A nationwide cross-sectional study showed that 71% of autoclave cycles failed sterilization tests when measured by traditional methods, though biological indicators rejected these failure results (Panta, 2019). In an Ohio hospital study, MRSA survival rates were significantly reduced by autoclaving, with sterilization decreasing bacterial recovery by a factor of greater than 1:10,000,000 (Donskey, 2014).

To compare medical and research lab practices, the study examined how laboratories safely reuse tools following sterilization and what changes hospitals would need to implement to adopt similar processes. Laboratories rely on sterile packaging procedures, contamination monitoring, and strict regulatory standards to ensure safe reuse of these materials. Tools are stored in sterile cabinets, labeled with expiration dates, and subjected to frequent sterility testing. Research laboratories prioritize reusable glassware and metal tools, whereas hospitals predominantly use disposable medical equipment due to stringent infection control protocols. Regulatory agencies, including the CDC, FDA, WHO, and OSHA, enforce strict sterilization standards in hospitals, which limit the reuse of sterilized tools. By increasing the use of reusable equipment and implementing training programs similar to those used in research settings, hospitals can reduce medical waste while maintaining safety.

Autoclaving was compared to single-use sterile packaging in terms of sterilization effectiveness and feasibility. Autoclaves utilize steam, pressure, temperature, and time to eliminate microorganisms from reusable medical instruments. While effective for materials that can withstand high temperatures, autoclaving is unsuitable for heat-sensitive plastics, which may degrade under high temperatures and pressure. In contrast, single-use plastics ensure immediate sterility but contribute significantly to medical waste due to their non-biodegradable nature. While disposable medical tools, such as syringes, IV bags, and surgical gloves, remain essential for infection control, incorporating sustainable alternatives and expanding autoclave use could help mitigate environmental impact.

A financial analysis was conducted to compare the cost of autoclaving versus single-use disposable medical tools. Autoclave machines require an initial investment ranging from $10,000 to $50,000, depending on size and application. In hospital settings, the cost per autoclave cycle varies based on electricity use, water consumption, and maintenance, with an estimated cycle cost ranging from $2 to $5. The sterilization of a surgical instrument set costs approximately $6.23 per unit, while minor procedure sets cost around $1.35 per unit. In contrast, single-use disposables have lower upfront costs but result in recurring expenses for procurement and disposal. Practice Greenhealth (2010) found that hospitals using single-use disposables spent 30% more on waste management. Additionally, transitioning to reusable systems has been shown to reduce medical waste by up to 50%, as reported by Healthcare Without Harm in 2021. Financial incentives for autoclaves include long-term savings from reduced waste disposal costs and the prevention of supply shortages. However, barriers to implementation include the high initial costs of autoclave systems and the need for ongoing maintenance.

Practice Greenhealth's study also examined ethical and practical considerations regarding the reuse of sterilized medical equipment (2010). Concerns about patient safety, potential contamination risks, and regulatory compliance remain key barriers to wider autoclave implementation. Ethical dilemmas arise in balancing infection control with environmental sustainability, as hospitals prioritize patient safety over waste reduction. Regulations require that reprocessed single-use devices meet the same standards as newly manufactured ones, ensuring they do not compromise patient care. While the adoption of autoclaving could help address medical waste concerns, further research is needed to assess long-term outcomes, financial feasibility, and policy changes required for broader hospital implementation.

Findings and Discussion

The expansion of healthcare has led to a dramatic increase in medical waste, much of which consists of single-use plastics, disposable equipment, and pharmaceutical byproducts. This reliance on disposables such as gloves, syringes, and packaging poses significant environmental challenges, as a large portion of this waste is non-biodegradable and requires incineration, releasing harmful chemicals into the environment. The literature consistently highlights the severe consequences of single-use medical waste, with North and Halden (2013) emphasizing the persistence of plastic waste in ecosystems, its toxic chemical leaching, and the long-term public health risks associated with it. The COVID-19 pandemic exacerbated this issue, with PPE waste increasing ocean plastic pollution tenfold (Khan et al., 2023), while Haque et al. (2021) estimated hazardous waste generation at 3.40 kg per infected person per day, placing immense strain on waste management systems.

Autoclaving presents a promising alternative to incineration and other traditional disposal methods. Studies demonstrate its high efficacy in pathogen elimination, with Donskey (2014) reporting a >99.9999% reduction in MRSA and research confirming successful reprocessing of the N95 mask. However, challenges remain, as Panta's (2019) study found that 71% of autoclave cycles failed sterilization tests when measured by traditional methods, though biological indicators later refuted these results. This discrepancy underscores the need for standardized testing protocols. Additionally, while autoclaving works well for heat-resistant materials like glass and metal, many single-use plastics degrade under high temperatures, limiting their universal applicability.

The financial and operational trade-offs between single-use and reusable systems are significant. Autoclaves require substantial upfront investments ($10,000–$50,000) and ongoing costs ($2–$5 per cycle), yet long-term savings are evident. McGain and Story's (2022) systematic review found that hospitals using reusable devices spent 30% less on waste management than those reliant on disposables. Conversely, single-use systems incur recurring procurement and disposal fees, with supply chain disruptions such as those seen during the pandemic further driving up costs (Innovative Health, 2022). The Johns Hopkins study (2023) reinforced that multi-use systems are economically superior when sterilization protocols are rigorously followed. However, initial resistance from healthcare providers, driven by infection control concerns, remains a barrier.

Regulatory and ethical considerations further complicate the adoption of autoclaving. Strict guidelines, such as the FDA's reprocessing standards and the EU's Medical Device Regulation (MDR), require reprocessed devices to meet the same safety benchmarks as new ones, limiting their reuse (BSI, 2024). Surveys indicate clinician hesitancy due to perceived contamination risks (De Angelis et al., 2022), despite evidence that proper autoclaving effectively mitigates these concerns (Thiel et al., 2015). The HHS has called for policy reforms to incentivize reprocessing, noting its potential to reduce greenhouse gas emissions (Innovative Health, 2022). Meanwhile, the WHO's waste hierarchy prioritizes prevention, reuse, and recycling over disposal (Chartier et al., 2014), yet incineration remains the default in many regions due to convenience and regulatory inertia.

Case studies highlight the potential for integrated solutions. Rizan et al. (2022) found that combining autoclaving with improved waste segregation could reduce healthcare carbon footprints by 30–50%. Similarly, Healthcare Without Harm (2021) reported that transitioning to reusable systems in certain departments cut medical waste volumes by half. However, achieving widespread adoption requires addressing material limitations (e.g., developing heat-stable plastics), standardizing sterilization validation, and providing training on waste segregation and autoclave best practices.

Autoclaving offers a scalable, environmentally friendly alternative to incineration, but its full potential remains untapped due to regulatory, financial, and material barriers. A hybrid approach combining reusable systems for heat-tolerant items with sustainably designed disposables, where necessary, could balance infection control with ecological responsibility. Future research should explore innovations in autoclave-compatible materials, policy incentives for reprocessing, and hospital pilot programs to demonstrate feasibility. By addressing these challenges, healthcare systems can reduce their environmental footprint while maintaining patient safety.

Conclusion

The exponential growth of medical waste, driven by the healthcare sector's reliance on single-use plastics and disposable equipment, has reached a critical juncture demanding sustainable intervention. The findings of this review underscore the urgent need to transition from traditional, high-impact waste disposal methods, such as incineration, toward more sustainable alternatives like autoclaving. While incineration effectively reduces waste volume, its environmental and public health consequences, including the release of toxic emissions like dioxins and heavy metals, make it an unsustainable long-term solution. Autoclaving, by contrast, offers a promising pathway to mitigate these harms by sterilizing medical waste without generating hazardous byproducts, thereby aligning with global efforts to reduce healthcare's carbon footprint.

The environmental benefits of autoclaving are well-documented. Studies confirm its efficacy in neutralizing pathogens, including highly resistant bacteria and viruses, while preserving the structural integrity of reusable medical equipment. However, its implementation is not without challenges. Material limitations, particularly the incompatibility of many single-use plastics with high-temperature sterilization, pose a significant barrier. Additionally, inconsistent sterilization validation methods, as highlighted by Panta (2019), reveal the need for standardized protocols to ensure reliability across healthcare settings. Despite these hurdles, autoclaving has proven successful in research laboratories, where reusable glassware and metal instruments are routinely sterilized, reducing waste generation by up to 50% (Rizan et al., 2022). Scaling this model to hospital settings requires addressing both technical and cultural obstacles, including clinician apprehensions about contamination risks and the stringent regulatory frameworks governing medical device reprocessing.

Financial considerations further complicate the adoption of autoclaving. While the initial investment in autoclave equipment and maintenance is substantial, long-term cost analyses reveal that reusable systems are economically advantageous. Hospitals that have transitioned to reprocessing medical devices report significant savings in waste management expenses, with some studies indicating a 30% reduction in costs compared to single-use systems. Moreover, the hidden expenses of incineration, such as environmental cleanup, public health impacts, and carbon emissions, are rarely accounted for in traditional cost assessments. A full lifecycle analysis, incorporating both economic and ecological factors, would strengthen the case for autoclaving as a cost-effective and sustainable solution.

Regulatory and ethical dilemmas also play a pivotal role in shaping medical waste management practices. Current policies, such as the FDA's stringent reprocessing standards and the EU's Medical Device Regulation, prioritize patient safety but inadvertently perpetuate reliance on single-use plastics. While these regulations are essential for preventing infections, they must evolve to accommodate advancements in sterilization technology and materials science. Ethical tensions between immediate patient safety and long-term environmental responsibility further complicate the decision-making process. However, emerging evidence suggests that these priorities are not mutually exclusive; properly sterilized reusable devices can meet safety standards while drastically reducing waste. Policymakers must therefore explore regulatory reforms that incentivize sustainable practices, such as tax breaks for hospitals that adopt autoclaving or grants for research into heat-resistant medical-grade plastics.

The COVID-19 pandemic served as a stark reminder of the vulnerabilities in global medical supply chains and the environmental toll of disposable PPE. The surge in plastic waste during this crisis underscored the urgent need for resilient, sustainable alternatives. Moving forward, healthcare systems must adopt a circular economy approach, where waste minimization, reuse, and recycling are prioritized over disposal. This shift will require collaboration across multiple stakeholders, including manufacturers, healthcare providers, regulators, and environmental scientists, to redesign medical products for durability, sterilizability, and end-of-life recyclability. Pilot programs in hospitals, particularly in surgical and diagnostic departments where waste generation is highest, could demonstrate the feasibility of large-scale autoclave integration. Education and training will also be critical in driving this transition. Healthcare workers must be equipped with the knowledge to segregate waste effectively, operate autoclaves safely, and advocate for sustainable practices within their institutions. Public awareness campaigns can further amplify the message, encouraging patients and communities to support eco-friendly healthcare policies.

In summary, autoclaving represents a viable and necessary step toward reducing the environmental impact of medical waste. While challenges remain, including material limitations, regulatory barriers, and upfront costs, the potential benefits for both public health and the planet are too significant to ignore. A hybrid model, combining autoclaving for heat-resistant items with innovative biodegradable alternatives for single-use applications, offers a balanced path forward.

By embracing this approach, the healthcare sector can fulfill its dual mandate: safeguarding patient well-being while protecting the environment for future generations. The time for action is now; sustainability must become an integral pillar of modern medical practice. The time for action is now; sustainability must become an integral pillar of modern medical practice.

Final Recommendations

1. Policy Reform: Governments should revise medical device regulations to facilitate safe reprocessing while maintaining high safety standards.
2. Investment in R&D: Funding should be directed toward developing autoclave-compatible materials and improving sterilization validation methods.
3. Hospital Pilot Programs: Large-scale trials of autoclave-based waste systems should be implemented to assess real-world feasibility.
4. Financial Incentives: Tax credits or subsidies could encourage hospitals to transition from single-use to reusable systems.
5. Training Initiatives: Healthcare staff should receive education on waste segregation, autoclave operation, and sustainable practices.
6. Public Awareness: Campaigns should highlight the environmental impact of medical waste and advocate for patient support of green healthcare initiatives.

By addressing these areas, the healthcare industry can lead the way in sustainable waste management, setting a precedent for other sectors to follow. The stakes are high, but the opportunity to create a healthier, more sustainable future is within reach.

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About the Author

Rachel Roberts is a senior at Michigan State University, double-majoring in Biomedical Laboratory Science and Human Biology. She is interested in biomedical, immunology, and clinical research. This project grew from her work as a medical assistant, where she noticed her clinic could reduce costs by autoclaving gauze rather than buying pre-sterilized supplies. With support from her pre-health sorority, she explored whether this practice could be cost-effective and practical. She hopes readers see how evidence-based policy change is essential for making simple, cost-saving solutions more accessible in healthcare.

The Body and the Imago Dei: A Christian Understanding of Human Biology

Benjamin Nketsiah[1,2]

1 College of Natural Science, Michigan State University, East Lansing, Michigan, United States
2 College of Arts and Letters, Michigan State University, East Lansing, Michigan, United States

*nketsiah@msu.edu

Abstract

Throughout Christian history, the doctrine of the *Imago Dei,* the belief that God created humankind bearing the imprints of Himself, has shaped theology, ethics, and our understanding of human dignity. While early interpretations saw the divine image in the spirits, contemporary theology has reclaimed the physical body as central to what it means to be human. This paper explores the intersection of biology and theology, proposing that *Imago Dei* is not an abstract attribute, but a living reality that is mystically embodied in the human form. Drawing from scriptural, theological, and scientific perspectives, it argues that human biology reflects divine creativity, interdependence, and dignity. This embodied vision of *Imago Dei* supports compassionate medicine and a renewed respect for the body's sacred complexity.

Introduction: The Mystery of the Human Body

To be human is to live within a body that both limits and reveals us. This is essentially the idea that every person, by virtue of being human, reflects the image of God (Genesis 1:26). Traditionally, theologians such as Augustine and Aquinas identified this divine likeness with the spirit, the part of humanity capable of reason and communion with God (Augustine, 1991; Aquinas, 1947) . Yet such a view may reduce personhood to an inner abstraction detached from the physical world.

Recent theological developments, particularly in Karl Barth's *Church Dogmatics* (Barth, 1958) and John Paul II's *Theology of the Body* (John Paul II, 2006), challenge this dualism. Both thinkers reinterpret the *Imago Dei* as relational and incarnational. According to them, the divine image is expressed through the unity of body and spirit rather than intellect alone. Similarly, Jürgen Moltmann, in *God in Creation*, argues that the divine image is revealed through embodied participation in God's creative and redemptive life (Moltmann, 1993). In other words, the physical body itself partakes in the *Imago Dei*. Adopting this relational framework has profound implications for biology and medicine.

When we study the molecular intricacies that biochemistry uncovers, from the self organizing systems, cellular cooperation, to the regenerative capacity of living tissue, we see more than just the mechanisms of survival. Such order may be interpreted as an expression of divine intentionality. To study the body, then, is to study a living theology written into the structure of creation.

Theological Foundations of the Imago Dei

Christian tradition has never spoken with one voice about what it means to bear the image of God. Historically, three broad interpretations have emerged:

(a) The Substantive View: Rooted in classical theology, this view holds that humans reflect the image of God through shared intrinsic attributes such as reason, morality, or self-awareness. Augustine viewed the rational soul as the mirror of the divine Trinity, reflecting memory, understanding, and will.

(b) The Relational View: Promoted by theologians like Karl Barth, it locates the image not in individual faculties but within the relationship between God and humanity, and among humans themselves (Barth, 1958). To be in God's image is to exist in love, communion, and responsibility.

(c) The Functional View: Emerging from biblical scholarship, this view understands *Imago Dei* as humanity's vocation to steward and govern creation (Genesis 1:28). Divine likeness is expressed not in inner qualities but in active responsibility within the created order. John H. Walton, in *The Lost World of Genesis One*, interprets the image as a functional role, where humans represent God's authority on earth (Walton, 2009). Likewise, J. Richard Middleton, in *The Liberating Image*, describes the image as a royal-priestly calling to exercise just and creative dominion that mirrors God's character (Middleton, 2005).

Each of these models contributes to a fuller picture: the *Imago Dei* is not limited to intellect, relation, or vocation, but encompasses the entire human being as a living, acting, and feeling body.

The Human Body as Image and Instrument

In Christian theology, *Imago Dei* grounds human dignity not in capacity or achievement but in essence. Humanity reflects the divine reality in its embodied form; the body is not a vessel for the soul but an expression of personhood. As Jean Vanier posits in *Becoming Human*, the body is the means through which the person makes their presence known to the world (Vanier, 1998).

Philosophically, dualistic models inherited from René Descartes, that is, dividing mind from matter, have shaped modern clinical reasoning (Descartes, 1993). Medicine, consequently, has tended to view the body mechanistically, as a system of parts to repair. Yet Christian anthropology resists this reduction. To bear *Imago Dei* is to affirm that every biological process is tied to the moral and spiritual dimensions of human existence.

This understanding reconfigures how we interpret healing and illness. Disease, while affecting cells and tissues, also disrupts the symbolic integrity of the self. Within the *Imago Dei* framework, medicine participates in what Paul Ramsey calls in *The Patient as Person* the "covenantal act of healing", a participation in divine re-creation that restores not only function but meaning (Ramsey, 1970). The clinician's task, then, is to uphold the inherent dignity embedded in each embodied life, even amid decline or death.

Historical Expressions and Secularization of the Imago Dei in Medicine

Across civilizations, the healing arts have long reflected, often implicitly, the conviction that caring for the sick is a sacred vocation. Ancient medical traditions viewed the physician not merely as a technician but as a moral agent participating in a divine order. In ancient Egypt, priest-physicians restored harmony between the sick body and *ma'at*, the divine order of truth and balance. Healing was thus a liturgical act, binding moral, physical, and spiritual worlds. Similarly, Greek medicine under Hippocrates regarded health as alignment with *physis*, the natural order. The physician's task was not to dominate nature but to cooperate with it, embodying a humility that anticipated later theological notions of stewardship rather than sovereignty.

With the rise of Christian monastic hospitals in late antiquity and the medieval period, this moral intuition found its clearest articulation in *Imago Dei*. Every person, regardless of status or ability, was to be cared for as one bearing the image of God. The hospital was not only a place of treatment but a spiritual community of mercy. Acts of nursing and tending wounds were understood as acts of reverence toward God's presence in human frailty. In this sense, early Christian medicine transformed charity into an extension of divine compassion.

By the middle of the 18th century, the Enlightenment brought about a decisive reorientation. As natural philosophy evolved into modern science, medicine began to detach its moral grammar from theological anthropology. The source of human dignity gradually shifted from divine image to rational autonomy, a move most clearly articulated by Immanuel Kant. In Kantian ethics, the person's worth lies in their capacity for reason and moral self-legislation: humanity is an "end in itself." While this secularized *Imago Dei*, it preserved its moral residue: the idea that human beings possess inherent value that forbids their instrumental use (Kant, 1998). Yet, in grounding dignity in rationality rather than sacred origin, the Enlightenment also introduced a subtle hierarchy: those unable to exercise reason: the infants, the cognitively impaired, the dying, could appear less fully dignified.

This philosophical shift paralleled the rise of modern biomedicine, which increasingly defined itself through objectivity and control. The body came to be understood as a mechanistic system, separable from personhood. The physician's role evolved from minister of divine compassion to engineer of physiological systems. Advances in anatomy, microscopy, and later molecular biology yielded immense therapeutic power but at the cost of disenchantment: the patient became an organism to be optimized rather than a person to be cherished. Nevertheless, the older moral memory of *Imago Dei* continued to shape medical ethics, even when unacknowledged. The very language of "human dignity," "patient rights," and "informed consent" carries theological ancestry. When medicine insists that no one should be treated merely as a means, it echoes the sacred intuition that every life bears unquantifiable worth. Thus, even in a secular age, the shadows of *Imago Dei* linger.

The inheritance of this Enlightenment legacy continues to shape the moral imagination of contemporary medicine. As biomedical technologies acquire unprecedented precision and reach, they also amplify the unresolved tension between autonomy and sacredness. The power to edit genes, prolong life, or engineer reproduction situates medicine at the frontier between healing and redesign. In the language of modern bioethics, dignity is often invoked as respect for self-determination; yet the theological roots of dignity remain latent beneath this secular vocabulary. Thus, when debates arise over germline modification, euthanasia, or artificial intelligence in healthcare, they are not merely technical disputes but reenactments of a much older drama: whether medicine's vocation is to serve life as a gift or to govern it as a project. *Imago Dei* invites medicine to remember that mastery, detached from reverence, risks forgetting the very mystery it once sought to heal.

Artificial Intelligence, Machine Learning, and the Imago Dei in U.S. Medicine

Artificial intelligence (AI) has become one of the most transformative forces in modern American medicine. From early rule-based diagnostic systems in the 1970s such as MYCIN, to today's deep-learning models capable of reading medical images with superhuman precision, AI has progressively reshaped clinical reasoning. What once required the intuitive synthesis of a physician's mind can now be assisted or even anticipated by vast computational architectures. In radiology, oncology, and predictive epidemiology, AI systems have already improved early detection and resource allocation, saving lives through speed and pattern recognition that exceed human capacity.

Yet this technological evolution also invites theology to speak anew. The doctrine of the *Imago Dei* grounds an anthropology that sees human intellect and creativity as participations in divine creation, not competitors with it. Within this framework, the rise of AI is not necessarily a threat to human dignity but a testimony to it: the very capacity to design intelligent systems reflects humanity's calling to mirror God's wisdom in cultivating and ordering creation (Genesis 1:28). As theologian Noreen Herzfeld argues, human inventiveness in AI "echoes the creative impulse of the divine, even as it tests our humility" (Herzfeld, 2002).

Still, *Imago Dei* offers a moral compass. It reminds medicine that intelligence, whether human or artificial, must remain ordered toward truth, compassion, and justice. A theology of the image thus reframes the ethical question from "Can machines heal?" to "How can machines serve love?" When AI systems misclassify patients or amplify bias, they obscure rather than honor the image of God within each person. By contrast, when algorithms are designed to promote equitable access, to extend care into underserved communities, and to relieve clinician burden, they participate in the divine work of restoration.

Contemporary scholars such as Ellison Weiner emphasize participatory design as essential to ensuring AI reflects the diversity of the human family (Ellison Weiner et al., 2024). This aligns deeply with an Imago-centered ethic, which insists that every face bears sacred worth. Thus, rather than opposing AI, Christian theology can help orient it toward its proper telos: to serve life as a gift, not a product.

In this light, the history of AI in medicine becomes a story of both human ingenuity and moral maturation. The *Imago Dei* invites practitioners and designers alike to see technology as a vocation of co-creation. When guided by reverence, transparency, and solidarity with the vulnerable, AI can extend, not replace, the healing ministry that first animated the art of medicine.

Conclusion

To view the human body through the lens of the *Imago Dei* is to see biology as theology and flesh as revelation. From the cellular level to the act of compassionate care, life discloses a divine pattern of creativity, interdependence, and redemption. In a culture tempted to fragment body and soul, the embodied image of God reminds us that to touch the human body is to encounter mystery.

If the *Imago Dei* grounds the inherent worth of every human being, then medicine's deepest vocation is not merely to cure, but to restore the meaning of embodiment. Healing, in this view, becomes an act of re-creation and a participation in the divine work that first called humanity good. Within the hospital ward or research lab, this vision reframes both suffering and care: every act of treatment becomes a gesture toward the restoration of a broken image.

Theology thus offers medicine a moral horizon, while medicine offers theology a space for embodiment. The two meet most profoundly at the bedside, where the tension between limitation and hope is felt most acutely. Here, the physician and the patient stand together within the mystery of finitude, confronting not only biological disorder but existential vulnerability. Healing in this context transcends physical repair; it gestures toward reconciliation of the person with their own body, with others, and with the grounding of human worth itself.

A theology of healing, therefore, is not an abstract doctrine but a lived philosophy of care. It affirms that the human body, though fragile and mortal, remains a site of divine encounter. It insists that compassion and clinical precision are not opposites but expressions of a unified truth: that every human life, however diminished or diseased, bears the radiance of divine likeness.

When medicine reclaims this theological depth, it finds again its moral center, a vision of care shaped not only by knowledge, but by reverence. The *Imago Dei* thus reminds the modern physician, researcher, and educator that science is most human when it serves the mystery from which all life arises.

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About the Author

Benjamin Nketsiah is an undergraduate studying Biochemistry and Molecular Biology at Michigan State University. His work sits at the intersection of philosophy, theology, and science, where he loves to synthesize ideas and reflect on the intellectual traditions that have shaped civilization, both consciously and unconsciously. He wrote this piece to explore how these disciplines illuminate one another in an age of rapid technological change. Aspiring to become a physician, he believes a humanities-informed lens deepens cultural sensitivity and empathy, enriches moral imagination, and ultimately helps him care for patients more fully.





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JC VP: westra15@msu.edu



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THROUGH THE LENS: A PHOTOGRAPHER'S PERSPECTIVE

The cover image for SPARC's Fall 2025 issue captures a feeling I return to often: the sense of standing at the edge of something great – caught between reflection and possibility. The warm light, the open landscape, and the quiet silhouette all echo the moments when I pause to reconnect myself with the world around me.

For me, human potential lives in the in-betweens, where the inner and outer worlds start to collide. This photo reflects that gentle meeting point. It's a reminder that the potential to imagine, to grow, and to reshape our surroundings begins with noticing these small, ordinary moments of clarity.

In photographing this piece, I wanted to offer a scene that feels grounding yet hopeful for all of Michigan State University's undergraduate researchers as they step out of the shadows and into the light; something that acknowledges where we are, while still looking toward what could be.

Sincerely,
Farra Lie

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ACKNOWLEDGEMENTS

Student Papers in Academic Research Collaborative would not be possible without the people who entered, supported, and believed in this project at every stage. This journal is the result of shared work and shared conviction: an ongoing reminder that undergraduate scholarship thrives when a community invests in it.

We are honored to feature the work of student researchers whose curiosity, creativity, and academic rigor reflect the spirit of discovery. We thank faculty mentors, professors, and instructors across the university who continue to advocate for undergraduate research and education and whose philosophy towards mentorship in the arts and sciences remains unperturbed.

We are especially thankful to our Board of Advisors for their thoughtful guidance, steady encouragement, and readiness to assist us whenever needed. We thank the student editors and designers whose collaboration, care, and commitment to excellence brought this issue to life. We would like to thank MSU Libraries' Publishing Services, the Honors College, and the Undergraduate Research and Creative Activity (URCA) office for their encouragement and belief in the value of student-led efforts.

We are grateful for all the opportunities that MSU continues to create for undergraduate researchers. The blue of SPARC is deeply rooted in the green of Michigan State.

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