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THE UNDERGRADUATE RESEARCH JOURNAL OF THE UNIVERSITY OF MEMPHIS

# QuaesitUM

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*QuaesitUM* is an annual publication that provides an academic forum where University of Memphis undergraduate students can showcase research from all disciplines.



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# Editorial Board

*Like ripples on a pond our actions spread out and affect others because everything is interconnected.*

*–The 14th Dalai Lama*

# To Our Readers

Since the COVID-19 pandemic began, we have been in 'fight-or-flight' mode. This has eroded our ability to think before we act, and we are prone to reacting emotionally in the moment instead of considering the potential consequences our choices may bring.

In interpersonal interaction, failing to consider consequences can result in impairing good relationships. We risk damaging ourselves and others.

In research we must also pay close attention to choices and consequences. Good research is not haphazard or capricious; it requires careful choices about what data to use and how to collect and analyze it. Being mindful of our choices and their consequences allows us to learn and adjust as our knowledge and understanding increase. Not being mindful of choices and their consequences, on the other hand, risks undermining the future possibilities that our research creates.

The authors whose works appear here have conducted outstanding research. They have taken a disciplined and mindful approach to their studies and seen the possibilities of inquiry in their fields. They have chosen mentors and colleagues to form relationships that foster collaboration and learning. Ultimately, their choices will influence the path that research takes in the future.

Volume 11 of *QuaesitUM* reflects the interdisciplinarity and diversity of research that their choices have brought, with articles from the fields of Music, Biomedical Engineering, Mathematics, Chemistry, English, Physics, and History. It is worth remembering that, although these fields seem separate, they are actually pieces of a larger whole. As a composite they represent the combined quality of research at the U of M. More importantly, they are also 'ripples in a pond' which, when combined, encapsulate our interconnected knowledge of the world we inhabit.

Producing a journal is a complex and time-consuming process and would not be possible without the dedication of many people. My co-editor and the Director of the Helen Hardin Honors College, Dr. Melinda Jones, has continued to lend her expertise and effort to showcase our students' work. Our technical editor, Mr. Heri Yusup has also been a critical component of this endeavor, giving freely of his time and experience to ensure a quality publication. Ms. Sydney Jackson has also been an incredibly valuable addition to our team, offering a new perspective at every stage of the production process. The reviews are yet another vital component of producing a journal of this caliber, and we are grateful for their hard work and insights.

For the 11th year, Mr. Gary Golightly, Professor of Graphic Design, has created a cover that captures the essence of our students' research and the spirit of the journal, which was founded on the principle of interdisciplinarity. Many thanks are also due to those in the Administration who have supported us: Dr. Jasbir Dhaliwal, Dr. Thomas Nenon, Dr. Karen Weddle-West, and Dr. Abby Parrill-Baker.

Every student publishing their work here must have a faculty sponsor, and it is with them that the journey from student to published author begins. Dr. Christine Eisel, Dr. Donal Harris, Zack Corpus, Dr. Xiaohua Huang, Dr. Firouzeh Sabri, Dr. Ben Keller, Dr. Amy L. de Jongh Curry, and Dr. Thomas Hagen have guided their students through their research projects and mentored them as they have progressed along this path. The hard work of the reviewers cannot be understated as well, since they ensure the academic rigor of the work published here.

It is the students themselves, however, who deserve the highest praise. They have designed projects that have yielded a greater understanding of work in their fields and can count themselves as contributors to greater knowledge and understanding of the world around us. The "ripples in a pond" they have created will spread out and affect all of our interconnected knowledge, and their work will contribute to areas of exploration into the future.

With gratitude to all,

Dr. Sage L. Graham
*Quaesitum* Editor-in-Chief

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## Publication and Review Process

Abby Griffith is an English major with a concentration in Creative Writing and is in her junior year. Abby discovered a love of history and essays in high school through an outstanding literature teacher, and a passion for horror media soon after via *Coraline* (2009), which invariably led to the conception of "The Horrors of Motherhood" in sophomore year. It has since received the Major L. Wilson Undergraduate Paper Award from the Department of History. Abby enjoys analyzing both history and modern society through the lens of pop culture and hopes to share insights about our society in anything she writes. After graduation, she hopes to become a librarian and never stop sharing her passion for stories with the world.

**Abby Griffith**

The Horrors of Motherhood:
An Examination of Mothers in the Modern Horror Film

**Faculty Sponsor**
Dr. Christine Eisel

## Abstract

Film has long played a part in portraying the mindsets and values of the time and culture in which it is made. Horror films especially, with a history of employing female characters—often mothers—and exploring traditionally taboo topics, provide a powerful opportunity to analyze the American consciousness on the matter of motherhood over time. From *Rosemary's Baby* portraying America's era of medical motherhood to *Coraline* and the working mother and on into modern day and *The Haunting of Hill House*, American horror media have acted as both representations of cultural motherhood and conversations of the same, simultaneously depicting and influencing perceptions of mothers and motherhood. Both genre and society's perception of motherhood have shifted from punishing women for their perceived shortcomings towards richer depictions of mothers and motherhood. Motherhood is not always something to be feared, and over eighty years of film, American culture has begun to recognize that.

## Introduction

In 1960, Alfred Hitchcock's now-iconic film *Psycho* hit theatres, forever changing the landscape of the American horror genre. *Psycho* introduced America to the wicked mother figure of Norma Bates, shifting the direction of the genre away from monsters and towards the family-centric horror, which notably features mothers and mother figures.[1] American horror films since have often relied on the mother, motherhood, or both as sources of horror and conflict within their narratives. Much like Norma Bates' mark on her murderous son, *Psycho*'s influence continues today in horror as one of the first and arguably the most famous depictions of a bad or wicked mother in horror, thus opening the way for motherhood to become a much-debated topic in horror films, as it has been in American society since the revolutionary era.[2] Film has long played its part in portraying the values of the times and cultures in which it is made. Horror films, overall defined as films where unnatural, violent, and frightening things occur, have a history of employing female characters—often mothers—and exploring traditionally taboo topics.[3] They provide a particularly powerful opportunity to explore the American consciousness on the matter of motherhood throughout its history. This paper examines the presentation of mothers and motherhood in five selections of American horror cinema from the latter half of the 20th century to present day: *Rosemary's Baby* (1968), *Carrie* (1976), *Beloved* (1998), *Coraline* (2009) and *The Haunting of Hill House* (2018). It argues that the chosen data are representative of the time periods in which they were made and provide useful insight into then-current American cultural views on and fears about motherhood.

## Literature Review

Historically, ideals of motherhood in America differ from those in other countries. Prior to the American Revolution, the common view of motherhood in America reflected Puritan ideals; mothers were no more influential on their children than anyone else. In fact, fathers were regarded as moral-

[1] Carol J. Clover, *Men, Women, and Chainsaws: Gender in the Modern Horror Film* (New Jersey: Princeton University Press, 1992), 24–5.

[2] Erin Harrington, *Women, Monstrosity and Horror Film: Gynaehorror* (New York: Routledge, 2018), 188.

[3] Cambridge Dictionary. 2022. "Horror Film." @CambridgeWords. May 25, 2022. https://Dictionary.cambridge.org/dictionary/english/horror-film.

ly stronger than mothers.[4] In the late 18th and early 19th centuries, however, in the aftermath of the Revolution, a new approach to motherhood began to develop in the infant nation. The concept of republican motherhood, that mothers had a uniquely powerful moral influence on their children and a duty to raise them properly above all else, grew to become part and parcel of American society.[5] In the early 19th century, this combined with burgeoning ideals of "true womanhood"—that men and women were complete opposites, with man as sexual and woman as maternal, consigned to the public and private spheres of society respectively—to shape the American consciousness on the role of mothers.[6] Later, at the turn of the century, moral motherhood combined with growing medical knowledge to create scientific motherhood and later psychological motherhood, shifting the power of knowledge (about parenting, pregnancy, and prenatal care, among other things) away from women and into the hands of men as medicine emerged as a profession.[7] Despite the growth of what is regarded today as "modern" motherhood, new scientific and psychological ideals of motherhood did little to alter America's unique views of motherhood as an institution. "Modern mothers," writes Jodi Vandenberg-Daves in the introduction to her book *Modern Motherhood: An American History,* "would be self-consciously gifted with—and burdened by—the idea that they had a unique influence on their children. At least initially, their influence was thought to depend upon their virtue, their watchfulness, their confinement to the home, and their constant availability." American society's ideals of motherhood, historically and even now, place pressure on its women and have held them to impossibly high standards throughout the last few centuries. In many ways, these ideals are responsible for placing the blame for "defective" or troubled children on the mother.[8] Even a casual observer of American horror films can see this blame bleed through into the horror genre over the latter half of the 20th century.

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4 Jodi Vandenberg-Daves, *Modern Motherhood: An American History* (New Jersey: Rutgers University Press, 2014), 11.

5 Ibid, 11.

6 Ibid, 64.

7 Ibid, 4.

8 Ibid, 192.

## Discussion

### *Rosemary's Baby*: Hysterical Mothers and the Horrors of Pregnancy

In 1968, Roman Polaski's occult horror film *Rosemary's Baby* hit theaters amid the height of suburban idealism and burgeoning Second Wave feminism. Though the decade saw the release of other iconic horror films such as Hitchcock's *Psycho* (1960), *Rosemary's Baby* offers an ideal microcosm of the nation's views of motherhood, pregnancy, and women's rights in its themes of female hysteria and natural motherhood. Until 1967, depictions of pregnancy and birth in American films were heavily regulated by the Motion Picture Production Code and were indeed almost non-existent until the latter half of the 20th century due to the Code regarding them as morally unacceptable as late as 1956. The Code was eventually replaced by the Motion Picture Association of America in 1968, the same year *Rosemary's Baby* was released, therefore loosening the restrictions on portrayals of topics such as pregnancy and birth.[9]

Perhaps the most definitive example of pregnancy in horror, *Rosemary's Baby* follows the young couple Rosemary and Guy Woodhouse as they move into a new apartment in a house with a strange history.[10] Rosemary wants a baby, something her odd neighbors seem deeply interested in, and so the couple decides to try to have one. Once pregnant, however, Rosemary begins to feel sick and worry that something is wrong with her or the baby, despite her husband's, neighbors', and physician's constant dismissals. Ultimately, she gives birth to her child and learns that his father is Satan and that she carried the Antichrist as part of her husband's deal with the devil in exchange for success in his acting career. The film ends as Rosemary stands gazing down at the inhuman child she has been forced to bear and faces the question: *Aren't you his mother?*

The question invokes the idea of 'essential' motherhood, which Erin Harrington describes as "the notion that motherhood is a biological and emotional necessity that sits at the heart of the female experience."[11] This construct of maternity as something innately biological stands alongside but not quite opposed to 'ideal' motherhood, or the belief that motherhood is something that must be learned. Beginning in the first half of the 20th

[9] Harrington, *Gynaehorror*, 7.

[10] Ibid, 15.

[11] Ibid, 17.

century and growing more commonplace throughout the decades, increasingly scientific views of motherhood led to decreased emphasis on women's knowledge of pregnancy and their own wellbeing. Doctors, most often male, were regarded as the ultimate authority, regularly admonishing women for talking with friends or reading books on pregnancy they did not specifically recommend. Women no longer knew best about the functions of their own bodies.[12] This historical struggle between women and the people telling them that they know better manifests in Rosemary's conflict of her own body and feelings versus the constant dismissals and degradations of those around her.

While in *Rosemary's Baby* the mother's feelings are ignored because those causing her suffering wish to suppress her and know her claims of something amiss to be true, the events echo a wider trend in history—people's tendency to dismiss the "hysterical" woman, the overly-emotional mother, because of her womb, her menstruation or sexuality, or her "inferiority" to or separation from men. Though the film is supposed fear and fantasy, Rosemary's experiences mirror other depictions of oft-hysterical pregnancy in more ordinary media, whether fictional or scientific.[13] Furthermore, with the onset of the fight for abortion rights and contraception raging throughout the nation in the late '60s and early '70s, as well as the rise of Second Wave feminism calling for Americans to reconsider the roles of women as strictly wives and mothers, not to mention the cultural fear of "over mothering" or "refrigerator mothers" placing even more blame for children who did not meet societal standards upon mothers, Rosemary becomes an even bigger signifier of the women of her time.[14] In the same fashion, it is Rosemary herself who is ultimately blamed for her horror in the film's narrative structure; after all, *she* is the one who wanted a child. Without her insistence, the film seems to be saying, none of this would have happened at all.

It is worth mentioning that the debate over abortion rights, reaching new heights at the time of the movie's release, had become a fight for the rights of the mother versus the rights of the unborn fetus, and at the time, the rights of the fetus were overshadowing the rights of the moth-

[12] Vandenberg-Daves, *Modern Motherhood*, 85–6.

[13] Lucy Fischer, "Birth Traumas: Parturition and Horror in *Rosemary's Baby*," *Cinema Journal*, 31, no. 3 (1992):8.

[14] Vandenberg-Daves, *Modern Motherhood*, 224; Ibid, 180–1.

er, rendering her and her life irrelevant in the face of the child's own.[15] This dismissal of women is mirrored in *Rosemary's Baby* in the way that the film, while featuring Rosemary as the protagonist, ultimately focuses more on the men of the film—her husband's goals, her doctors' dismissals, her baby; even the devil himself. Occult films, a subgenre of horror that, according to Film Studies specialist Carol J. Clover, of which *Rosemary's Baby* is one, tend to feature a woman on the surface while the concerns and the plot ultimately focus on a man instead.[16] In a similar way, women's rights in the 1960s were superseded—and still are—by those of their children. "After all," writes Harrington, "[the] film is titled *Rosemary's Baby,* even though Rosemary herself is the protagonist."[17]

### *Carrie*: Mothers, Daughters, and Absent Fathers

America in the 1970s saw the rise of divorce rates and single-parent homes, as well as the continuation of Second Wave feminism, which continued to challenge women's traditional roles in society and to discuss more openly the rising cultural ambivalence towards motherhood that is commonplace to American culture today.[18] Released in 1976, Brian De Palma's *Carrie,* based off Stephen King's novel of the same title, explores all of these subjects and the resulting cultural fears surrounding them. Other films in the seventies saw similar plotlines involving single mothers and supernatural powers—consider Friedkin's *The Exorcist* (1973)—however; *Carrie* heavily emphasizes (and villainizes) the role of the mother in Mrs. White and revolves around multiple cultural dialogs of its time.

*Carrie* follows a repressed high school girl discovering her telekinetic powers with the onset of her first period. Bullied by her peers and smothered by her mother, Carrie White attends her senior prom and ultimately wreaks havoc on her classmates and teachers with her newfound powers when she becomes the victim of a nasty prank. At the end of the film, Carrie's religious mother, believing Carrie's very conception to be a result of sin and Carrie to be under Satan's influence, attempts to kill her daughter. Carrie kills her mother in self-defense and her powers bring the house down around them, ultimately killing Carrie and sealing her fate as a monster. Perhaps the most pointed shot in the film depicts Mrs. White,

[15] Vandenberg-Daves, *Modern Motherhood*, 54.

[16] Clover, *Men, Women, and Chainsaws,* 66.

[17] Harrington, *Gynaehorror*, 88.

[18] Vandenberg-Daves, *Modern Motherhood*, 248; Ibid, 228.

crucified by her own daughter and yet still unable to redeem either of them from the "sin" of womanhood.[19]

In the face of rising divorce rates between the sixties and the eighties, influenced in part by feminism's own developments, American society began to shift its view of motherhood once again.[20] As the idea of modern motherhood developed, it grew enmeshed with the concept of the private nuclear family, which became heavily emphasized in American culture following the Great Depression and World War II due to its contributions to the revival of the American economy and rising consumer culture.[21] Divorce and single-parent homes, already long stigmatized, threatened this way of society. As a result, single mothers came to be feared and perceived as a source of danger, a view which is incredibly evident in De Palma's depiction of Mrs. White and her ambivalence—or even outright hostility—toward her daughter. [22]

Mrs. White operates as both a vehicle to express societal fears on motherhood and changing cultural values, and a look into the male perception of feminism and issues of women's liberation. In the seventies, Second Wave feminism brought to the table the idea that women's power could be found in their biology.[23] Alternatively, *Carrie*—written by men, directed by a man, produced by a man—implies that both female sexuality and female biology are monstrous and destructive by linking menstruation and female bodies directly to horror and Carrie's ruinous powers.[24] At the time of release, many critics considered *Carrie* to be a critique of American ideals and a tale of female sexual liberation; however, Shelley Stamp Lindsey, writing a critical examination of *Carrie* later in 1991, argues for *Carrie* as a reinforcement of the American patriarchal society, the supposed destructive nature of female sexuality when unregulated by

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[19] Shelley Stamp Lindsey, "Horror, Femininity, and Carry's Monstrous Puberty." *Journal of Film and Video* 43, no. 4 (1991): 40.

[20] Vanderberg-Daves, *Modern Motherhood*, 248.

[21] Ibid, 3; Michael D. Gillespie, "The Family as an Economic Institutio: Historical Contingencies and the Great Recession." *International Journal of Sociology of the Family* 40, no. 1 (2014): 1.

[22] Harrington, *Gynaehorror*, 203.

[23] Vandenberg-Daves, *Modern Motherhood*, 230.

[24] Lindsey, "Carry's Monstrous Puberty," 34, 36.

men, and the "curse" of femininity.[25] Lindsey's article has the benefit of hindsight and the ability to place *Carrie* in its historical context—namely the upstart caused by women's liberation movements calling for a new "just" society as opposed to more nebulous equal rights—while examining its content.[26]

*Carrie,* with its telekinesis and emphasis on the struggle between spiritual and secular, is yet another example of the occult horror film, featuring Carrie as its supernaturally powerful monster.[27] But every Frankenstein's monster must have its Frankenstein. As with the wider trend in American culture during the 20th century, the blame for Carrie's transgressions falls on Mrs. White's shoulders. She is the classic monstrous mother, overbearing and smothering, the reason Carrie is shy and awkward and ultimately bullied by her peers—and thus, the reason Carrie becomes a monster herself. Both the narrative and the characters within it blame Mrs. White for not educating Carrie, for not wanting Carrie, for not killing Carrie, for not loving Carrie. Everything a mother can do wrong, Mrs. White does; she cannot even kill the horror that her daughter has become. She embodies 1970s America's belief that fatherless houses lead to horrors.[28]

### ***Beloved*: Black Motherhood**

But where is Black motherhood in all these years? Despite America's foundation upon African American labor and its large population of Black citizens, Western media—especially American media—often lacks non-white representation.[29] Though representation has improved in recent years, horror movies also follow this trend. Despite this lack of diversity in mainstream media, Black culture and media has long shown an interest in horror and haunting.[30] *Beloved,* released in 1998 and based on the ac-

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[25] Ibid, 33-4.

[26] Jo Freeman, "What in the Hell is Woman's Liberation Anyway?" in *Through Women's Eyes: An American History with Documents*, Fifth Edition, Ellen Carol Dubois, Lynn Dumenil (Massachusetts: Bedford/St. Martin's, 2018), chap 11, Kindle.

[27] Clover, *Men, Women, and Chainsaws,* 71.

[28] Clover, *Men, Women, and Chainsaws*, 34.

[29] Tanya Maria Golash-Boza, *Race and Racisms: A Critical Approach*, Brief Second Edition (New York: Oxford University Press, 2019), chap 4, Kindle.

[30] Kinitra D. Brooks, Alexis McGee, and Stephanie Schoelman. "Speculative Sankofaration: Haunting Black Women in Contemporary Horror Fiction." *Obsidian* 42, no. 1/2 (2016): 237.

claimed novel by Toni Morrison, is a film which not only afforded Black women a place in more mainstream horror, but also provided a unique glimpse into historical Black motherhood. *Beloved* is not the most well-known horror film to emerge from a decade full of movies about cannibals, Freddy Krueger, and horror movies themselves, nor is it what most people would consider a horror movie—it presents as more of a historical drama with psychological horror elements than stereotypical horror film. And yet, *Beloved* remains a horror story at heart, full of ghosts, gore, and the true horror: history.

Set in post-Civil War America, *Beloved* follows former slave Sethe and her daughter, Denver, as Sethe is haunted by both her past and a poltergeist who drives away her sons. A mysterious girl appears in Sethe's life, slowly sapping her attention, money, and eventually, her life. She is later revealed as Sethe's reincarnated daughter, Beloved, whom Sethe killed as an infant to prevent her from being taken back into slavery when Sethe's master came looking for his runaway slave. After an exorcism, Beloved vanishes, leaving Sethe bedridden and mourning the second loss of her daughter. At the end of the film, Paul D., Sethe's lover, comes to her bedside and reassures Sethe that he and Denver will take care of her, and that she is her own best thing, not Beloved.

Representations of Black motherhood have been present and indeed debated in American society dating back to the period of slavery.[31] Harmful racial stereotypes such as the Bad Black Mother still contribute to mischaracterization of Black mothers today.[32] America has spent centuries weaponizing Black motherhood—using it to paint Black mothers as sexually and socially deviant, cementing slavery as a condition passed down through the mother, and racializing infanticide, to name just a few.[33] *Beloved,* however, as a story written about a Black woman by a Black woman, and adapted for the screen by Black women, offers a departure from the historical norm and gives them a chance to be heard fairly. The narrative treats Sethe sympathetically and recognizes the cultural differences between Black and white motherhood and how they affect both the narrative and the reality of Black women's lives and social perceptions.

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[31] Christopher J.P. Sewell, "Mammies and Matriachs: Tracing Images of the Black Female in Popular Culture, 1950s to Present." *Journal of African American Studies* 17, no. 3 (2013): 309.

[32] Golash-Boza, *Race and Racisms*, chap 4.

[33] Vandenberg-Daves, *Modern Motherhood*, 57; Ibid, 16; Felicity Turner, "Rights and Ambiguities of Laws: Infanticide in the Nineteenth-Century U.S. South." *Journal of the Civil War Era* 4, no. 3 (2014): 350–1.

In the latter half of the 20th century, America began to see cultural changes that some saw as the decline of the white suburban nuclear family that had long been the American societal ideal. During this time, cultural fears focused on "bad" mothers, among other things, whom society saw as threats to the American family and their traditional way of life. Unsurprisingly, these so-called bad mothers whom society feared were largely unmarried non-white women.[34] During Reagan's presidency in the 1980s and later in 1996, America underwent massive restructuring of welfare policies which reduced public aid drastically. These reforms, though not mentioning race specifically, were targeted at reforming the (racist) stereotype of Black women as "welfare queens."[35] *Beloved*, released amid these targeted reforms, both embodies and responds to these fears, showing the very mother society was afraid of—deviant, Black, husbandless, unable to keep her family together, unable to protect her children, standing with her dead and bloodied child in her defiant grasp—and then showing her humanity, her pain, and her love, even if that love is "too thick," as Paul D. says.

Because Black mothers' historical lived experiences differ so starkly from those of white mothers, it is unfair and ahistorical to examine and depict Black motherhood as if it is the same as white motherhood. The horror in *Beloved* shifts from the traditional narrative of the mother as the cause of the horror to motherhood itself, paralleling white feminism's views of motherhood as something that confined and impaired women, but diverging in the way it considers the systems of slavery and white-dominated society as equal or even greater causes of the horror.[36] This echoes the differences in Black feminism as opposed to mainstream white feminism, acknowledging the full picture of women of all colors rather than only white women. Sethe's motherhood, had it been untainted and unthreatened by white power, would not have led to the horror that it did in the events of *Beloved.* Within the historical context of Black women in horror, hauntings—and, it seems, motherhood and mothers both—are not inherently negative.[37]

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[34] Vandenberg-Daves, *Modern Motherhood*, 253–4.

[35] *Golash-Boza, Race and Racisms*, chap 2.

[36] Jodi Vandenberg-Daves, "Teaching Motherhood in History." *Women's Studies Quaterly* 30, no. 3/4 (2002): 236-7.

[37] Brooks, McGee and Schoellman. "Speculative Sankofarration," 239.

### *Coraline*: The Working Mother

The concept of the working mother is not a new one. Mothers have been a part of the American workforce for decades, from poorer women working outside the home to provide for their families to women joining the workforce during and in the aftermath of World War II.[38] From the 1950s onwards, middle-aged women, most of them mothers, were encouraged to join (or rejoin) the workforce, and that number only increased over time.[39] Much of American society feared the entrance of mothers into the workplace, and though those fears ultimately peaked in the 1980s, they still endured as a longstanding cultural anxiety revolving around the inadequacy of women to fulfill roles as both mother and career woman, despite late-20th century feminism's insistence that women could and should handle both.[40] *Coraline* (2009) explores the intersection of inadequate mothering and the working mother as a product of these fears. *Coraline,* being an animated children's film based on a children's novella, may seem a surprising choice for this data set. However, it is indeed classified as horror (typically dark fantasy horror) and satisfies typical horror definitions—unnatural and terrifying things happen. There are monsters and body horror and ghosts, and most importantly, the trope of the monstrous mother. With the ever-increasing trend of PG-13 horror films in recent years, it feels remiss to ignore the realm of children's horror in American cinema, especially considering *Coraline*'s relevance. For many people, myself included, *Coraline* was our first introduction to the horror genre.

Based on Neil Gaiman's novel, *Coraline* follows the young protagonist Coraline Jones as she attempts to adjust to her new life after moving across the country. Bored and emotionally neglected by her parents, shown as constantly in conflict with her mother, Coraline is intrigued when she notices a little door in her living room. Going through the door in what she thinks to be a dream, Coraline finds herself in what she learns is the "other world" in which awaits her Other Mother, who claims to love Coraline more than her real mother. Coraline soon discovers the Other world is nothing but an elaborate trap, and the Other Mother wants to feed on Coraline to survive. Though the film ends on a hopeful note with the Other Mother defeated and Coraline's parents restored, it still presents a striking depiction of both the absent and the monstrous mother as well

[38] Vandenberg-Daves, *Modern Motherhood*, 249.

[39] Rebecca Jo Plant, *Mom: The Transformation of Motherhood in Modern America* (Illinois: University of Chicago Press, 2010), 39.

[40] Vandenberg-Daves, *Modern Motherhood*, 247; Harrington, *Gynaehorror*, 202.

as a contrast between the working and domestic spheres of motherhood. Throughout the film, Coraline and her mother are constantly at odds, highlighting the implied impossibility of a balance between mother and child.[41] The story does not shy away from showing Coraline's unhappiness and her arguments with her mother, who seems generally inconvenienced by Coraline's existence. Coraline's mother embodies the cinematic trend in the late 1990s and 2000s of portraying mothers in horror less as the horrors themselves and more as "inefficient gatekeepers" unable to prevent terrible things from happening to their children.[42] The film contrasts the brusque modernity of Mrs. Jones, who does not cook, dismisses Coraline in favor of her work, and is overall emotionally unavailable, with the more old-fashioned domesticity of the Other Mother, who cooks, sews, and seemingly shows interest in Coraline's activities and wellbeing at every turn. The Other Mother even appears more traditionally feminine, wearing fashionable clothes, makeup, and nail polish in contrast to the frumpy, tired appearance of Mrs. Jones. The conflict between the Other Mother and Mrs. Jones parallels the historical "mommy wars"—disputes between stay-at-home moms and working mothers from the 1990s onward.[43]

Though the Other Mother is ultimately revealed to be a monster, the narrative alleviates Mrs. Jones of very little blame, as the danger could never have reached Coraline without her mother's help—it was, after all, Mrs. Jones herself who physically unlocked the door to allow the horrors in, and her emotional unavailability that pushed Coraline to venture into the Other world in the first place. In the end, she seems to regret her absorption in her work, following the American cultural norm of commonplace guilt among working mothers. "If these women did not feel guilty on their own," writes Vandenberg-Daves, "the mass media was there to help them along."[44] In her failure to protect Coraline from the dangers lurking within her own home, Mrs. Jones embodies the next evolution of American fears surrounding inefficient mothers; she, like all mothers as compared to society's impossible and ever-shifting standards, is doomed to fail.[45]

[41] Harrington, *Gynaehorror*, 184.

[42] Ibid, 202.

[43] Vandenberg-Daves, *Modern Motherhood*, 263.

[44] Ibid, 257.

[45] Harrington, *Gynaehorror*, 201.

### *The Haunting of Hill House*: Motherhood as Horror

Over the years, America's perception of mothers and motherhood has often been characterized as one thing or another, in stark and polarizing terms, rather than considering it in a more nuanced light. Motherhood is a complex existence often characterized by individual experiences and cannot fit neatly into every stereotype the media of any given era has chosen to focus on. From Aster's *Hereditary* and Krasinski's *A Quiet Place* to the television series *Bates Motel,* American horror cinema in the 2010s has featured mothers and motherhood often, but perhaps none so poignantly as Mike Flanagan's supernatural horror drama *The Haunting of Hill House.* The series considers these nuances and issues in its rich and messy portrayal of motherhood, motherly love, and the dual nature of both.

Released on Netflix in 2018, *The Haunting of Hill House* is a ten-episode TV mini-series following the Crain family—father, mother, three sisters, two brothers—through two major timelines; one of their summers spent in the titular Hill House in 1992, and one following their youngest sister's suicide and its aftermath in 2018. Though based on the Shirley Jackson novel of the same title, *Hill House'*s plot diverges onto a path all its own as it reveals the tragedy of their mother's suicide in 1992 and the ghosts of Hill House, both of which continue to affect the children as adults, and depicts a family grappling with grief, addiction, and mental illness as they try to understand what happened that fateful night in Hill House. The show presents multiple mothers of different generations and tropes, but at its heart is Olivia Crain and the lasting effect her tragic death leaves on her children. In *Hill House'*s most striking moment, it reveals Nell's suicide was not a suicide at all but was caused by Olivia's ghost to "protect" her children from the world. Flanagan depicts the dual nature of Olivia's motherhood with this scene—the powerful love with which Olivia kisses her daughter's forehead, and the equally powerful suffering she causes by pushing Nell to her death.

Though it is possible to argue *Hill House* as a continuation of the typical trend of depicting children "ruined" by poor mothering and the previously mentioned historical practice of blaming mothers for mental illness or developmental disorders in children, ultimately that position must contend with the fact that despite Olivia causing her share of death and suffering, the narrative still portrays her as a victim herself, with the house utilizing her motherhood and her fears of harm coming to her children as a weapon against her.[46] *Hill House* takes American culture's longstanding

[46] Ibid, 197.

belief in moral motherhood—that a mother should be unambivalent and self-sacrificing, willing to do anything for her children—and turns it on its head, exploring the idea that a mother's love can go too far.[47]

This depiction contrasts the historical criticisms of late 20th century feminism against motherhood, that it was a tool of women's oppression and hindered women as an instrument of a patriarchal society.[48] Olivia's motherhood is something she chose, loved, and would not want to undo; and yet it still causes her suffering. In alignment with the contemporary American mother's ambivalence toward motherhood, *Hill House* chooses to portray Olivia's motherhood as neither good nor evil, harmful nor helpful, but rather capable of being an instrument for both.[49] Due to the narrative's sympathetic light, Olivia presents a depiction of motherhood that is more personal and complex than her typically cut and dry predecessors, representing the progression of modern society where more and more women have begun to consider and discuss the struggles and merits of motherhood.

## Conclusion: Looking Back, Looking Forward

Ultimately, motherhood possesses a long and storied history in both American history and horror cinema. Over time, the genre has seen something of a shift from the likes of Hitchcock and De Palma, punishing women for their perceived shortcomings, towards richer depictions of mothers and motherhood as American society itself evolves.[50] From *Rosemary's Baby* and the rise of medical motherhood to *Coraline* and the working mother, and still more, American horror films have often acted as both representations of cultural motherhood and conversations of the same, depicting and influencing perceptions of mothers and motherhood at once.[51] Examining the course of the genre's depiction of mothers over the last eighty years, it seems an accurate assessment that whenever American motherhood is headed next, horror will follow. Perhaps the best assessment can be found

[47] Vandenberg-Daves, *Modern Motherhood*, 72.

[48] Ibid, 223.

[49] Ibid, 3.

[50] Clover, *Men, Women, and Chainsaws*, 61.

[51] Harrington, *Gynaehorror*, 181.

in an exchange from the final episode of Flanagan's *Hill House.* When Olivia's ghost sees what has become of her children, she pleads with her husband, saying, "It's a horror!". Hugh responds, hopefully, "It doesn't have to be." In the end, motherhood is not always something to be feared, and American culture has begun to recognize that over time.

## Works Cited


Brooks, Kinitra D., Alexis McGee, and Stephanie Schoellman. "Speculative Sankofarration: Haunting Black Women in Contemporary Horror Fiction." *Obsidian* 42, no. 1/2 (2016): 237–48. http://www.jstor.org/stable/44489515.

Cambridge Dictionary. "Horror Film." @CambridgeWords. May 25, 2022. https://dictionary.cambridge.org/dictionary/english/horror-film.

Clover, Carol J. *Men, Women, and Chainsaws: Gender in the Modern Horror Film.* Princeton, NJ: Princeton University Press, 1992.

De Palma, Brian, director. *Carrie*. Beverly Hills, CA: United Artists, 1976. *Max* video. https://play.max.com/movie/6d50b04d-bb21-4bdc-8a21-3e93d2f50c25.

Demme, Jonathan, director. *Beloved*. Burbank, CA: Buena Vista Pictures, 1998. *Prime* video. https://www.amazon.com/Beloved-Oprah-Winfrey/dp/B007TOLD6A.

Fischer, Lucy. "Birth Traumas: Parturition and Horror in 'Rosemary's Baby.'" *Cinema Journal* 31, no. 3 (1992): 3–18. https://doi.org/10.2307/1225505.

Flanagan, Mike, director. *The Haunting of Hill House.* "The Bent-Neck Lady." *Netflix* video. 01:09:42, October 12, 2018. https://www.netflix.com/watch/80189226?trackId=200257859.

Freeman, Jo. "What in the Hell is Women's Liberation Anyway?" In *Through Women's Eyes: An American History with Documents*. Fifth Edition. Ellen Carol DuBois, Lynn Dumenil. Boston, MA: Bedford/St. Martin's, 2018. Kindle.

Gillespie, Michael D. "The Family as an Economic Institution: Historical Contingencies and the Great Recession." *International Journal of Sociology of the Family* 40, no. 1 (2014): 1–26. http://www.jstor.org/stable/43488413.

Golash-Boza, Tanya Maria. *Race and Racisms: A Critical Approach*. Brief Second Edition. New York, NY: Oxford University Press, 2019. Kindle.

Harrington, Erin. *Women, Monstrosity and Horror Film: Gynaehorror.* New York, NY: Routledge, 2018.

Lindsey, Shelley Stamp. "Horror, Femininity, and Carrie's Monstrous Puberty." *Journal of Film and Video* 43, no. 4 (1991): 33–44. http://www.jstor.org/stable/20687952.

Plant, Rebecca Jo. *Mom: The Transformation of Motherhood in Modern America.* Chicago, IL: University of Chicago Press, 2010.

Polaski, Roman, director. *Rosemary's Baby*. Hollywood, CA: Paramount Pictures, 1968. *Prime* video. https://www.amazon.com/Rose-marys-Baby-Mia-Farrow/dp/B000I9W272.

Selick, Henry, director. *Coraline*. Universal City, CA: Focus Features, 2009. DVD.

Sewell, Christopher J. P. "Mammies and Matriarchs: Tracing Images of the Black Female in Popular Culture 1950s to Present." *Journal of African American Studies* 17, no. 3 (2013): 308–26. http://www.jstor.org/stable/43526418.

Turner, Felicity. "Rights and the Ambiguities of Law: Infanticide in the Nineteenth-Century U.S. South." *Journal of the Civil War Era* 4, no. 3 (2014): 350–72. http://www.jstor.org/stable/26062175.

Vandenberg-Daves, Jodi. *Modern Motherhood: An American History.* New Brunswick, NJ: Rutgers University Press, 2014.

Vandenberg-Daves, Jodi. "Teaching Motherhood in History." *Women's Studies Quarterly* 30, no. 3/4 (2002): 234–55. http://www.jstor.org/stable/40003260.

Leah Flettrich graduated summa cum laude from the University of Memphis in May 2023 with a bachelor's degree in English and a minor in Pre-Health Professions. She also earned Honors in English and University Honors with Thesis designations. As an avid Taylor Swift fan, Leah desired to research Swift's work, believing that it was worthy of the further interpretation that her previous works lacked. With the help of Dr. Donal Harris and Dr. Emily Skaja, Leah conducted research on Swift's album, *folklore*, for her Honors English Thesis. This thesis was awarded the "Best Thesis" award during her time at the University of Memphis, ultimately pushing Leah to submit her work to *QuaesitUM*. Although she has enjoyed her journey with English at the University of Memphis and is grateful for the opportunities she has been given, Leah plans to attend medical school in the future and enter the healthcare workforce.

Leah's paper received a *QuaesitUM* outstanding paper award.

**Leah Flettrich**

Taylor Swift, Pop Music, and the Creation of Modern Folklore

**Faculty Sponsor**
Dr. Donal Harris

## Abstract

This article explores how Taylor Swift's album, *folklore*, engages with the history of folk traditions. Throughout *folklore*, which was released a few months into the COVID-19 lockdown, Swift embraces and alters elements of traditional folklore in order to present pop music as a modern kind of folk. In times of cultural transformation, like that of the COVID-19 pandemic, pop songs as folk offered Swift a means of managing the distress that came with lockdown, while also providing a way to connect with others experiencing similar feelings. In highlighting certain clusters of songs from the album, these familiar yet reinvented elements of folklore are brought to light, culminating in the argument that Swift's songwriting in *folklore* creates a contemporary version of traditional folklore, ultimately serving to create unity in isolation.

## Introduction

In July of 2020, only four months into the national COVID-19 lockdown, Taylor Swift surprise-released *folklore*, a seventeen-track album written and recorded in the depths of isolation. In this collection of songs, Swift explores numerous storylines—some that are personal to herself, and others that are completely unrelated. In an Instagram post introducing the album, Swift says that "I found myself not only writing my own stories, but also writing about or from the perspective of people I've never met, people I've known, or those I wish I hadn't" (@taylorswift, 2020). Whereas Swift has previously been known to write about her personal life, *folklore* exhibits the star's sophisticated songwriting ability, as she elegantly recounts the individual stories of her cast of characters. While Swift's reputation as a writer hinges on the autobiographical content of her songs, the isolation of lockdown counterintuitively found her looking outward. At the very moment when she was mostly alone, her songs became populated with other people's stories, both real and imagined.

This Grammy-winning record is Swift's eighth studio album, as well as a major shift from her previous work. Prior to *folklore*, Swift had released four albums in the country genre, and then three more after making the complete transition into pop music. What critics praise on *folklore* is Swift's immensely matured songwriting—something that had been largely ignored in the past. While Rob Sheffield of *Rolling Stone* calls *folklore* Swift's "most audacious move, full of story-telling depth she's never come close to before," Jill Mapes of *Pitchfork* recognizes that Swift's "biggest strength is her storytelling, her well-honed songwriting craft meeting the vivid whimsy of her imagination." Before *folklore*, Swift's songwriting skill was generally overlooked, with more focus being put on her personal life, namely her romantic relationships, rather than her artistry. The musicologist Nate Sloan attributes this public obsession with Swift's personal life, rather than her artistry, to gender bias. In his article, "Taylor Swift and the Work of Songwriting," he writes, "gender and genre bias have clouded perception of Swift's particular skills and techniques . . . Swift has been continually undercut by critics who devalue her technique as either hyper-calculating or unconscious." So, when critics like Sheffield and Mapes recognize *folklore* as the epitome of her songwriting ability, it begs the question, "What is Swift really trying to do on *folklore*?"

This article argues that Swift borrows and modifies elements of traditional folklore, both its formal features and its status as a vessel of cultural knowledge, to present contemporary pop music as a new kind of folk.

Especially in times of cultural transition, such as the early days of the COVID-19 pandemic, pop songs as folk for Swift offered a way to give structure to inexpressible trauma, and therefore to connect with others who also felt isolated, scared, and rudderless. In the song "seven," where she writes, "and just like a folk song / our love will be passed on," Swift makes it clear that this album thinks through how folk connects a community especially in a time of isolation (Swift, "seven"). After conducting my studies on the intricacies of folklore, and performing an in-depth content analysis of Swift's lyrics on the album, it became evident that while Swift does employ some of the features attributed to the folk tradition, she also twists these qualities to create something rather different, or modernized. Therefore, this article examines the way that Swift uses lyrics to explore and redefine the folk tradition. In order to bring these reimagined elements to light, this article is divided into three sections, with each one highlighting a certain cluster of songs that present a reinvented feature of traditional folklore to the attention of Swift's listeners. The first section discusses Swift's use of folk elements to telescope time, serving to connect people and time periods to each other. The second section revises the traditional folktale, highlighting Swift's modification of certain folk archetypes. Finally, the third section delves into a "folkloric way of processing," discussing the use of folklore to process certain situations or events. Ultimately, this analysis culminates in the argument that through her songwriting, Swift masterfully creates a modernized take on the traditional folklore that has been passed down for generations. By leaning on and reimagining certain elements of folklore, Swift presents pop music as a modern folk tradition, aiming to create unity in a time of complete isolation.

## *Folklore* and the History of Folklore

Swift's turn to folklore as a means of articulating the anxieties surrounding the COVID-19 pandemic, and subsequent lockdown, becomes even richer when we consider scholarly accounts of the development of European folk traditions. During the 1800s, industrialization caused drastic changes to virtually every aspect of society, leading to individual and group struggles for those attempting to adapt. With science and technology rapidly advancing, new class structures beginning to emerge, and the development of nation-states creating new forms of political identity, complete social transformation became the new reality, and the want for grounding in shared culture became a more desperate need (Slobin 56). Particularly in Germany, which had been continuously fragmented into several states, this desire for unity became more apparent, leading to the term "volk"—a

word that translates to the people of a nation—becoming the basis for an understanding of German nationalism (Slobin 56). As the effects of industrialization began to manifest in America, a similar desire for shared community and a common purpose began to surface. As a result, William Thoms suggested the term "folk" as the English counterpart to the German "volk" in 1846. By proposing this new idea, Thoms also coined the term "folklore" as a way to describe the specific elements of a particular culture, whether it be customs, beliefs, stories, or anything in between (Slobin 57).

At the time of its coinage, the term "folklore" signaled the presence of an underlying conflict between the felt unity of pre-industrial social formations and the fragmentation that industrialization caused, and the term was used as a solution to solve the problem. In this particular case, folklore served as the mechanism for dealing with an identity crisis on the national level, and as an approach to managing the personal and group struggles of a society in turmoil (Slobin 56–7). In a sense, folklore represented a kind of nostalgia for a time before the extreme changes that industrialization introduced. In this way, Slobin sees folklore as a way to "get through individual and collective experiences," meaning that folklore acts as a strategy for coping with a certain situation, feeling, or encounter in a moment of crisis or uncertainty (19). More generally, folklore grows out of a cultural transformation, as it "signals, or emanates from, social experience" (Bronner 52). This becomes apparent in *folklore*, as we see Swift responding to the cultural and social transformations that the pandemic induced throughout her album.

While folklore's origins are in the nineteenth century, it is not only a historical genre. Often, folklore is considered to be bound to memories and histories of past communities; however, organizations such as the American Folklore Society see folklore as a living art form that preserves the culture or community of which it speaks, arguing that the crux of folklore lies in its ability to capture the identity of a culture or make sense of a certain time in the world (*What Is Folklore?*). In this way, folklore may be tied to the past, but it is also tethered to the present in the new traditions being established today (*What Is Folklore?*). Thus, folklore is a more elastic concept, as it can apply to any cultural form that serves to sustain the traditions, beliefs, or customs of a particular group of people. Similarly, Bronner describes how folklore manifests in today's technological world, saying that "people incorporate the symbolic and projective functions that folklore distinctively provides" by using the Internet to communicate with one another (22). This idea of folklore as a living genre—one that has a history but also continuously adapts to new cultural circumstances—be-

comes a critical lens in the analysis of Swift's *folklore*, as it permits the discussion of pop music as a kind of contemporary folk. As we will see in the later examination of the album, Swift leans on this element of folklore to process the drastic changes that the pandemic imposed and preserve the experiences and emotions of a society in isolation.

Folklore, then, can refer to both historical and modern artworks that attempt to represent a community's reaction to a felt crisis. However, it is also worth considering how folklore tends to follow particular plot structures, employ specific character types, and contain repeated formal elements, as Swift's album also draws on these features. A trademark of folklore is that it is dependent upon the transmission from person to person, ultimately allowing it to be preserved through time. Because of its reliance on oral tradition, however, folklore can be variable; because it inevitably changes over time, it is impossible to know the exact origin or true form of a single piece of folklore ("Literary Terms").

In terms of its structure, folklore has no set composition because it is dependent on the culture in which it was produced; in fact, it can take many forms, such as a folktale, a folk song, a dance, a belief, or even an oral expression ("Literary Terms"). For the sake of relevance to my discussion of Swift's album, I call greater attention to the conventions of folktales, and more specifically, fairytales. Folktales are fictional stories, and this genre encompasses a number of subcategories, such as the fairytale, the religious tale, and the humorous tale (Hansen). Folktales tend to follow simple plot lines, and fairytales are no exception. In fact, Marina Warner calls them "one-dimensional" with a "characteristic matter-of-fact manner" (25).

These stories characteristically begin with "once upon a time" and end in "happily ever after." Think of "Cinderella" or "Jack and the Beanstalk" and we see the familiar storyline appear; we are introduced to a protagonist who has to face some kind of obstacle, and after the protagonist overcomes the setback, he or she lives happily ever after (Hansen). These stories employ specific character types, like the hero or heroine and the villain, as well as other supporting character groups, such as adversaries and companions. Again, similar to how Warner describes the traditional fairytale, these characters are rather flat or uncomplicated; the hero or heroine is filled with good, virtuous qualities, while the villain seems to have solely undesirable traits ("Research and Course Guides: Fairy Tales"). As the story progresses and these characters interact with one another, folktales and fairytales alike often weave morals, lessons, or values throughout

the plot. By the end of the tale, the audience has gained an understanding of a greater issue that has been communicated to them through the storytelling (Warner 25). In *folklore*, Swift pulls from these typical elements of traditional folktales, not only implementing them into her lyrics, but also complicating certain features to create a more intricate story.

A final component to this discussion that is worth considering is the economic relationships behind folklore and Swift's *folklore*. Folklore is generally seen as a variable expression rooted in tradition, while popular culture and production is commercialized and more relevant to modern times (Bronner 36). In other words, traditional folklore and popular culture seem to be at odds with one another, rather than on a similar level for comparison. With that in mind, it seems that Swift's *folklore* completely goes against the ideals associated with traditional folklore. Swift's status as a major presence in the music industry undoubtedly raises some red flags when we try to see her album as contemporary folklore. More specifically, Swift's place in the pop music industry, where pop music is underwritten by and circulated through commercial music labels, seems to displace this traditional and organic community that surrounds folklore. In this way, the version of folklore that Swift creates throughout the album appears to be less an attempt at creating a meaningful folk tradition, and more a means to greater financial success.

An adjacent critical debate in cultural studies about the artistic viability of pop music can help us make greater sense of this aspect of Swift's *folklore*. In particular, I refer to the works of Adam Bradley and Michael Robbins, who each position pop music and poetry as related to one another, rather than as completely separate entities. Bradley focuses on the continuity across lyric creation through music and poetics, highlighting the artistic sophistication that comes with the formation of pop music. He also hones in on the idea that pop music is a kind of poetry that must be heard, rather than read, to obtain the full effects of its excellence. Robbins emphasizes the shared community that pop music and poetry both create, arguing that the two modes of expression are essential tools for understanding and appreciating life. We can see how this relates to our discussion of folklore. It was pointed out earlier that folklore has been centered around a want for shared community, which directly associates it with Robbins' standpoint on pop music and poetry. The contours of this debate, then, can help us see Swift's *folklore* as an album worthy of literary interpretation, as well as an album allowed to be compared to folklore.

It is also worth noting that the economics behind *folklore* are starkly different from any of Swift's previous albums. Swift's preceding albums were triumphs in the industry, but they were also major musical productions in terms of marketing tactics and the possibility of future tours; however, the COVID-19 pandemic completely upended these classic routines, causing *folklore* to be an entirely different album than any of Swift's previous ones, both stylistically and in the realm of production. Swift's *folklore* was a "surprise release," meaning that there was no public marketing or singles released before the album's arrival. In addition, the musical composition of *folklore* is wholly different than any of her previous albums. By applying the viewpoints of Bradley and Robbins, which focus on music and the community it creates, we are better equipped to see the ways that pop music can serve a similar role as folklore. Because both pop music and folklore can offer a shared set of stories for a given culture, it becomes more feasible to compare the qualities of Swift's *folklore* to those of traditional folklore on an equal level.

## Folkloric Connections Through Time

In creating a contemporary folk tradition, Swift borrows and modifies elements of folklore to fashion a modernized take on the genre. As we have seen, folklore serves to unite and create community, and is developed in response to a felt crisis. Because of its place as an acknowledgement of social or cultural transformation, folklore is specific to a certain time or place. In this section, however, I discuss three songs that use these folk structures to layer the past onto the present and telescope time, creating an intergenerational continuity throughout each track.

In the case of "epiphany," Swift creates a link between two stories from completely different time periods, each of which deal with separate crises. Throughout the song, Swift discusses the impact of traumatic events—the kind of events that you can only bear witness to, but can never find the strength to speak about. Swift reveals that the inspiration for this song arose from researching her grandfather, a soldier who fought in the Battle of Guadalcanal in the 1940s (*folklore: The Long Pond Studio Sessions* 1:11:19–1:14:41). After uncovering the horrors that her grandfather likely witnessed during World War II, she connected these traumatic experiences to those of the medical professionals working through the COVID-19 pandemic. Swift illustrates this relationship in the parallel verse structure of "epiphany," as she compares the harrowing sight of a

soldier bleeding out to a woman suddenly declining in health while quarantined in a hospital: "crawling up the beaches now / 'sir, I think he's bleeding out' / and some things you just can't speak about / . . . / holds your hand through plastic now / 'doc, I think she's crashing out' / and some things you just can't speak about" (Swift, "epiphany"). At the end of each verse, when Swift deems these events as "things you just can't speak about," she highlights the anguish that comes with simply observing these instances take place. When we think about the historical context of these verses, we see Swift employing an intergenerational continuity throughout the song. While traditional folklore focuses on preserving a specific time, place, or event, the songwriting of "epiphany" spans decades, connecting entirely different instances that happened eighty years apart. In this way, Swift participates in the folkloric tradition of passing down stories to later generations, as she uses the repetition of the verses' final lines to create emotional links between the past and the present. Swift makes these connections to highlight the fact that trauma has a lasting effect on the individual experiencing it; in other words, trauma itself spans generations, just as the verses of the song do.

In the bridge of the song, Swift declares an epiphany as the only way of understanding and escaping these harsh realities: "only twenty minutes to sleep / but you dream of some epiphany / just one single glimpse of relief / to make some sense of what you've seen" (Swift, "epiphany"). Due to the repetition of the chorus after each respective verse, we can look at these lyrics in the sense that each character Swift imagines has a similar epiphany even though each person is experiencing an entirely different type of trauma; however, we have to wonder, what does this epiphany look like, and how does it bring comfort to each individual? I speculate that Swift draws on the aspect of folklore that represents a nostalgia for simpler times. In the context of the song, the epiphany is a twenty-minute dream that reminisces on a time before war, or a time before the pandemic, bringing the hope of a return to these times for each person. With these ideas in mind, we can see how the epiphany that each respective character has acts as a type of folklore in and of itself; although each individual endures a unique traumatic experience, the epiphany brings a similar kind of solace to each person even though the two characters are unrelated. In this way, the folklore in "epiphany" is not a concrete writing or expression that each generation can replicate; rather, it is a unifying experience that serves to connect the past to the present. In a context outside of this track, however, the epiphany is "epiphany" itself. In each experience that Swift relates, the lingering effect is that it isolates the person and renders them speechless, unable to talk about the trauma they have witnessed. "epipha-

ny," then, becomes an outlet of expression for this particular community, as the epiphany is the recognition of shared experience that comes with narrating these events, and this song gives a voice to these individuals that remain unable to articulate their trauma.

Whereas the verses of "epiphany" directly compare two separate historical moments, Swift narrates the life of a singular person throughout the entirety of "the last great american dynasty." In this track, Swift recounts the story of Rebekah Harkness, a recent divorcée that marries William "Bill" Harkness, the heir to the Standard Oil fortune (*folklore: The Long Pond Studio Sessions* 14:15–15:27). Swift incorporates a more narrative-like device in this song, as she chronicles the story of how Rebekah, and the outrageous parties she threw in her and Bill's Rhode Island mansion, called "Holiday House," did not quite fit in with society. In the chorus, Swift uses third-party gossip to narrate how high society viewed Rebekah's scandalous exploits: "and they said / 'there goes the last great American dynasty' / 'who knows if she never showed up what could've been' / 'there goes the maddest woman this town has ever seen' / 'she had a marvelous time ruinin' everything'" (Swift, "the last great american dynasty"). It is worth noting that by using gossip as the dialogue for this song, Swift points out how folklore can be corrupted; in this instance, oral tradition is transformed into gossip. At the conclusion of the song, Swift employs a plot twist to reveal that she bought the infamous "Holiday House" just fifty years after Rebekah gave it up, and this shift is supported in the final chorus of the song, as Swift alters the lyrics to place herself in the same situation as Rebekah: "and then it was bought by me / who knows if I never showed up what could've been / there goes the loudest woman this town has ever seen / I had a marvelous time ruinin' everything" (Swift, "the last great american dynasty").

In viewing these connections between Rebekah Harkness and Swift herself, we can see how "the last great american dynasty" is another example of how Swift's *folklore* spans decades, linking Rebekah, who was primarily active in the 1950s, to Swift in the twenty-first century. We can also see how Swift participates in the long-established folkloric tradition of passing down tales to the next generation. In a more literal sense, Swift uses this narrative songwriting to give an account of the Rebekah Harkness story, essentially employing the actual mechanism of oral tradition. In a more figurative sense, however, Swift creates an analogy between songs and buildings, both of which have the ability to outlive a singular lifetime. In this way, "Holiday House" itself acts as a symbol for folklore, as it serves to link the distant time periods in which Harkness and Swift

live, as well as their seemingly unconnected human lives. In this particular instance, folklore is a landmark that serves to couple the lives of Harkness and Swift, and on a larger scale, this track again serves to connect the past and the present, just as "epiphany" did.

Rather than connecting time periods or lifetimes, like "epiphany" and "the last great american dynasty" do, "the lakes," a bonus track to the album, links *folklore* to Romantic poetry, explicitly placing the album in a literary tradition. In this track, Swift discusses the historic tradition of poets, amongst other artists, retreating to the Lake District in England. Specifically, Swift alludes to the "Lake Poets," a group of English poets consisting of William Wordsworth, Samuel Taylor Coleridge, and Robert Southey, that fled to the Lake District, and lived there, during the 19th century. In her documentary, Swift reveals that she has had a similar "exit plan" tucked away in her mind since the beginning of her career; just as the "Lake Poets" retreated to the Lake District, Swift also had this idea for escape herself (*folklore: The Long Pond Studio Sessions* 1:38:35–1:41:46). In the verses of the song, Swift discloses the reasons for wanting to escape. The first verse reveals a desire to leave behind the world of modern technology, as well as the pressures that come with it: "I'm not cut out for all these cynical clones / these hunters with cell phones" (Swift, "the lakes"). Similarly, the second verse calls attention to the drama that has probed at Swift's career for years. As Swift communicates her wish to break free from this tension, she also cleverly inserts Wordsworth's name into the lyrics: "I've come too far to watch some namedropping sleaze / tell me what are my words worth" (Swift, "the lakes"). Swift's subtle inclusion of Wordsworth's name not only highlights the poetic history that surrounds the song, but also calls attention to the fact that this desire for escape has occurred before.

This Romantic impulse to escape culminates in the chorus of the song: "take me to the lakes where all the poets went to die / I don't belong, and my beloved neither do you / those Windermere peaks look like a perfect place to cry / I'm setting off, but not without my muse" (Swift, "the lakes"). Here, Swift mimics the themes of Romantic poetry; she wants to escape modern life and the turmoil that it involves. Thus, "the lakes" seems like an anti-folk song, as it centers around a turn away from community and a celebration of the individual. As the concluding track of the entire album, it is odd that Swift would seemingly undo the work of folklore that she has intermingled throughout the record. The last line of "the lakes," however, gives us a different view of this anti-folk attitude. Where-

as the previous choruses have ended in "I'm setting off, but not without my muse," the final chorus ends in "I'm setting off, but not without my muse / no, not without you" (Swift, "the lakes"). The line "not without my muse," that closes the previous choruses, presents Swift's retreat as an escape into art, as the partner she references is present only as personal inspiration. This would be the position of Romanticism, where others are seen as inspiration for one's own creativity. The shift in the final chorus to "no, not without you," however, changes our view of the song as a turn to the Romantic, making it seem like more of an invitation for her listeners to join on this escape. Swift's escape plan, then, includes us, her listeners, making "the lakes" more of a turn to folklore, as it encourages community. This lyrical shift also suggests that folklore is the artistic descendent of Romantic poetry. While Romantic poetry gives a voice to individuals wishing to escape modern life, folklore gives a voice to individuals with shared experiences; in the case of "the lakes," this experience is the common sense of desire to run away. While "the lakes" may seem like the opposite of folklore at first glance, the lyrical shift at the end of the song proves it to be the opposite, rendering it as more of an invitation for community, rather than a turn away into isolation.

## Reinventing the Folktale

When *folklore* was first released, Swift revealed that there would be a collection of three songs that she deemed "The Teenage Love Triangle" trilogy. As fans have since discovered, and Swift herself has disclosed, the three songs that make up this triptych are "cardigan," "august," and "betty." What Swift does in these songs is explore a teenage love triangle from the perspectives of all three characters involved, with each view occurring at a different point in time. When listening through the album, it is not evident that these songs are connected, as Swift employs something of a double fragmentation; the three songs are physically fragmented on the album, as "cardigan," "august," and "betty" are tracks two, eight, and fourteen, respectively, and the love triangle itself is fragmented between three different perspectives. Within these songs, Swift creates a rather archetypal storyline: the boy dates a girl, the boy makes a mistake, then the boy tries to get the girl back. This generic style is similar to what we see in traditional folktales, namely fairytales, which tend to follow relatively straightforward plot lines and end in happily-ever-afters. In more deeply analyzing her trilogy of songs, however, we see Swift complicating the conventions of these traditional fairytales. By spreading the narrative

across three songs, each told from a different character, Swift modifies folk archetypes like "the hero," "the villain," and "the temptress," while also reshaping the structure of a traditional fairytale.

Swift's storyline contains three main characters: James, Betty, and the unnamed "other woman" that narrates "august." The basic plot line is this: James and Betty are in a high-school relationship when James goes away for the summer and cheats on Betty, leading to the demise of their relationship. "betty" is told from James' perspective directly after his summer affair when he returns to school. In "august," listeners receive the perspective of the girl involved in the summer fling, as she looks back on the relationship sometime after it occurred. Finally, "cardigan" is narrated by a much older version of Betty, who is reflecting on her first love and heartbreak—her young relationship with James.

If we consider the folk archetype of the hero vs. the villain, Betty is undoubtedly the hero of Swift's teenage love triangle, as she is the character that is seemingly wronged by the other two; however, Swift complicates this convention in "cardigan" by illustrating an older Betty reminiscing about her lost young love. The fact that Betty is much older than when her relationship with James occurred becomes evident at the beginning of the song, with the repetition of the lyric "when you are young, they assume you know nothing," already appearing twice within the first verse (Swift, "cardigan"). Because of its constant repetition throughout the track, Swift signals the importance of this lyric, highlighting the fact that young love is typically seen as fleeting or insignificant. In the choruses, however, Swift counters this attitude as she continuously inserts the line "I knew you" in her lyrics (Swift, "cardigan"). With the repetition of "I knew you" directly contrasting the recurrence of "when you are young, they assume you know nothing," we can see how Betty clashes with the stereotype that young lovers are naive. In fact, this idea culminates in the final verse of the song: "But I knew you'd linger like a tattoo kiss / I knew you'd haunt all of my what-ifs / the smell of smoke would hang around this long / 'cause I knew everything when I was young" (Swift, "cardigan"). In these lines, it becomes evident that Betty is the exception to this rule; she deeply knows about love and pain, and knows even more how the loss of her young love would affect her in the future. Even as Betty reflects on her past relationship years after its end, it still troubles her in the present. In the refrain of the song, however, Betty notes that the memories of her relationship with James are not all painful ones: "and when I felt like I was an old cardigan / under someone's bed / you put me on and said I was your favorite" (Swift, "cardigan"). Although Betty remains saddened by the end of her young

romance, she also still holds on to the more comforting emotions that came with her and James' relationship. In this way, we can see how Swift complicates the idea of a folk hero in her songwriting as Betty is still deeply broken, which is rather uncharacteristic of a traditional folk hero. After a folktale ends, we rarely hear about the repercussions of the events that they experienced, but in "cardigan," Swift gives us the means to contemplate this idea in Betty's particular situation; specifically, Swift highlights the traumatic effects of betrayal and loss. In this way, Swift provides a more realistic hero—one that may be flawed and haunted by the past, but is also rich in wisdom because of her experiences.

Similarly to "cardigan," the perspective related to us in "august" is narrated by an older version of the girl involved in James' summer affair. Because we know that the summer fling is in fact a cheating scandal, we can see how the folk archetype of "the temptress," or more modernly, "the other woman," comes into play. What Swift makes clear in "august," however, is that this stereotype is unsound for the narrator. This complication becomes most apparent in the bridge of the song, when the narrator reveals that she had true feelings for James: "back when we were still changin' for the better / wanting was enough / for me, it was enough / to live for the hope of it all / cancel plans just in case you'd call / and say, 'meet me behind the mall' / so much for summer love and saying 'us' / 'cause you weren't mine to lose" (Swift, "august"). In addition to having genuine affection for James, these lyrics also highlight the fact that the girl not only has hope that their relationship will continue after summer, but also that she wants it to. With these ideas in mind, we can see how Swift complicates "the temptress" archetype, as she provides a detailed look into the authentic emotions of someone who is actively harming another person; by doing so, she also makes our ideas of good and bad ambivalent. Swift even discusses this is in her documentary: "She seems like a bad girl, but really, she's not a bad girl. She's like, really a sensitive person who really fell for him . . . she thought they had something very real" (*folklore: The Long Pond Studio Sessions* 44:47–46:47). By taking Swift's own judgement into consideration, we can see how she obscures the idea of "the other woman;" although most would immediately regard the girl involved in the summer affair as a "home-wrecker," Swift gives her more credit, as she highlights the presence of her sincere feelings for James, ultimately making the intentions behind the summer fling more complex.

Unlike the other two songs of the trilogy, "betty" takes place within the same time as when the affair occurs—when James returns to school after summer ends. Listeners receive James' account of his summer fling

throughout this song, as well as his attempts to obtain Betty's forgiveness. "betty" takes the form of an apology, and if Swift were to abide by the conventions of a traditional fairytale, we would assume that James wins Betty back and they live happily ever after; however, this traditional happy ending is not what listeners receive in "betty." In the pre-chorus of the song, James immediately reveals his feelings of remorse when he says, "the worst thing that I ever did / was what I did to you" (Swift, "betty"). From the start of the song, we see James' guilt from the affair unfold. James further details this sense of regret in the bridge of the song, while also revealing his ever-present feelings for Betty while the fling was happening: "I was walking home on broken cobblestones / just thinking of you when she pulled up like / a figment of my worst intentions / she said 'James, get in, let's drive' / those days turned into nights / slept next to her, but / I dreamt of you all summer long" (Swift, "betty"). As James divulges the reason that the summer fling started, as well as the persistent feelings that he still had for Betty, we become inclined to think that the story might end happily with James and Betty salvaging their relationship. In the final chorus of the song, however, we see James' attempt to get Betty's forgiveness by showing up at her party and apologizing: "yeah, I showed up at your party / will you have me? / will you love me? / will you kiss me on the porch / in front of all your stupid friends? / if you kiss me, will it be just like I dreamed it? / will it patch your broken wings? / I'm only 17, I don't know anything / but I know I miss you" (Swift, "betty").

It is important to note that this final chorus has a musical key change in comparison to the other choruses, amplifying the emotional tension in the song. With this key change working in tandem with James' grand gesture, we would expect to receive a rather happy ending to the story, but Swift does not give us this resolution. Instead, James reminisces on a time when he and Betty were happy in their relationship in the outro of the song: "standing in your cardigan / kissin' in my car again / stopped at a streetlight / you know I miss you" (Swift, "betty"). These lines could be seen in the sense that Betty and James get back together; however, this does not appear to be the case, as the concluding line of the song is "you know I miss you," suggesting that, in the end, James still longs for his past relationship with Betty. With these ideas in mind, we can see how Swift complicates the structure of a traditional fairytale. While traditional fairytales tend to have a clear, happy ending, Swift concludes her fairytale ambiguously, ultimately revising its structure. In this way, Swift's folktale is more realistic for the actual situation that it details; relationships are more

complex than what contemporary fairytales portray, and unfortunately, more often than not, human stories do not result in a fairytale ending.

## A "Folkloric Way of Processing"

In an interview with *Vulture*, Aaron Dessner, a member of the band The National and one of Swift's cowriters on *folklore*, calls the album a "folkloric way of processing" (Gerber). Because Dessner only provides us with this singular statement, we have to wonder what exactly he means by describing *folklore* in this way. Here, I turn to Helen Morales' book, *Antigone Rising: The Subversive Power of the Ancient Myths*, to help us make sense of Dessner's comment. Particularly, Morales discusses the staging of *Antigone* in Missouri as a response to the death of Michael Brown Jr., who was killed by a police officer in 2014. When wondering why *Antigone* would be used as a means of handling this tragedy, Morales concludes that "myth allows us to explore extreme situations without risking crassness of dramatizing the specific events," meaning that myth provides the distance that is necessary to see a traumatizing event or difficult situation through a wider lens, due to the absence of explicit details (8). Because myth gives us this agency, Morales says, myth in turn becomes "a way of thinking through complicated moral dilemmas;" in other words, Morales argues for a mythical way of processing, and I suggest a similar meaning for Dessner's "folkloric way of processing" (9).

Folklore for Dessner works like myth does for Morales. It abstracts out the specifics of something, ultimately allowing a certain degree of detachment from whatever situation we decide to apply to the folklore. Just as Morales' mythical way of processing permits the contemplation of a problem or difficult situation from a pulled-back perspective, folklore provides us with the same kind of mechanism for thought and reflection. Throughout *folklore*, we see Swift employing this technique, particularly in the songs that are not obviously connected to each other, as we have seen in the previous analyses. In this section, I focus on three songs, each of which discuss entirely different situations, that seem to demonstrate the embodiment of Dessner's "folkloric way of processing" most clearly. In these songs, we see Swift extracting major details from the event she discusses; instead of dwelling in the specifics of a problem, Swift uses poetic devices and narrative styles to provide an overarching look into the various situations she presents.

When discussing "my tears ricochet" with Jack Antonoff, one of Swift's collaborators on *folklore*, Antonoff says that the track has a "bird's

eye view quality . . . It's very pulled back and commenting on the whole experience of it" (*folklore: The Long Pond Studio Sessions* 26:40–28:50). While the rest of the album is keyed into specific details, like the names of the characters and full plot of "The Teenage Love Triangle Trilogy", "my tears ricochet" is extremely general in the sense that it lacks any major details. This difference in diction and specificity seems to be what Antonoff means in his comment, signaling its importance to this section.

In this track, Swift discusses the trauma of betrayal, using the metaphor of a funeral to relate a situation in which a person who deeply knows another becomes the individual who inflicts the most hurt; however, this comparison only becomes evident in the chorus of the song. Before this understanding comes to light, listeners have no indication of what Swift is discussing. Take the opening line of the song, for example: "we gather here" (Swift, "my tears ricochet"). This statement is typically used as an opening to various rituals, such as weddings or funerals, and the fact that she is referring to a funeral only becomes clear in the chorus when she says, "and if I'm dead to you, why are you at the wake?" (Swift, "my tears ricochet"). This ambiguity demonstrates a "folkloric way of processing"; because Swift is leaving out the details of this situation, making the exact event unknown to the listener, she allows an interpretive distance that would not be present if these specifics were included.

What Swift does give her listeners, however, is a mechanism of processing betrayal, ultimately implementing a "folkloric way of processing" throughout the song. This idea is seen in the changes between each chorus. In the first chorus, Swift depicts a hero that serves to maintain his or her own reputation, rather than rescue others: "and you're the hero flying around, saving face" (Swift, "my tears ricochet"). With this line in the first chorus, listeners receive the view of the betrayer as someone who is selfish, only caring about their own public perception. In the second chorus, however, Swift provides a look into the partnership before the betrayal occurred: "cause when I'd fight, you used to tell me I was brave" (Swift, "my tears ricochet"). Here, listeners see that the betrayer was an uplifting person at some point in the partnership. In the final chorus of the song, Swift provides a realization in regard to the situation. In the first line, we see an end to this issue: "I didn't have it in myself to go with grace / and so the battleships will sink beneath the waves" (Swift, "my tears ricochet"). Just as the battleships disappear into the ocean, the problem seemingly fades away. In the lines that follow, however, Swift gives us an interpretation of the betrayer's feelings, appearing to rationalize the act of betrayal and sympathize with the betrayer: "you had to kill me, but it killed you

just the same / cursing my name, wishing I stayed / you turned into your worst fears / and you're tossing out blame, drunk on this pain / crossing out the good years" (Swift, "my tears ricochet"). Specifically when she writes that the betrayer "had" to do whatever the betrayal was, we see how the deception is seemingly justified, along with the further indication that the same kind of suffering was felt by both parties. This idea is reiterated when Swift writes that the betrayer's accusations are vindicated by the all-encompassing agony that he or she felt. By giving her listeners this glimpse into the betrayer's emotions, Swift shows us how this situation is intricate and multifaceted, communicating the familiar message that there are multiple sides to every story.

Because she provides this overarching examination, Swift gives us an agency to processing betrayal. In the choruses, Swift goes from an angered view of the betrayer, to looking back on the positive qualities of someone that was once a companion, then finally accepting the fact that the partnership has ended, while beginning to empathize with the person that caused harm. Again, this takeaway would be impossible without Swift's choice to leave out the specifics of the betrayal she discusses. In providing this distance, Swift allows her listeners to apply the song to any set of circumstances, making it a more universal means of processing.

Similarly to "my tears ricochet," Swift uses a conceit in "mirrorball," as she compares celebrity and flawed individuals to a disco ball. However, rather than leaving out the details of a certain situation, and using a metaphor to relate the instance she discusses, Swift uses the disco ball conceit to view a specific situation in a different way throughout "mirrorball," again allowing an interpretive distance for her listeners. Swift begins the song with describing what a disco ball does; it glamorously shines, but only in the presence of an outside source of light. In the chorus, Swift reveals what happens when there is no longer a light being shone on the disco ball, and no one is entranced by it anymore: "when no one is around my dear / you'll find me on my tallest tiptoes / spinning in my highest heels, love / shining just for you" (Swift, "mirrorball"). Even when the disco ball is in the absence of light and no one is paying any attention to it, the disco ball is still up on a pedestal, performing the same function that it does in the presence of light. In her documentary, Swift explains that she experienced similar feelings during the pandemic; she knew that she could easily take a break from her stardom, but she found herself creating more music, still attempting to keep up her artistry (*folklore: The Long Pond Studio Sessions* 33:34–36:56). She also discusses a second aspect of this conceit, explaining that people tend to change who they are in order

to satisfy the expectations of others; however, just as the disco ball still shines when no one is around, people are still deeply broken when they are completely alone.

Swift addresses both components of her conceit in the bridge of the song: "and they called off the circus / burned the disco down / when they sent home the horses / and the rodeo clowns / I'm still on that tightrope / I'm still trying everything to get you laughing at me" (Swift, "mirrorball"). Here, Swift metaphorically speaks of the COVID-19 lockdown in the beginning of the bridge, describing how she has continued to make music even though she is unsure of her decision to do so. It is worth noting that Swift compares her own artistry to the likes of a circus, something typically seen as silly or trivial, ultimately setting a disconcerting tone in regard to her work. I suggest that this comparison mirrors her own feelings about creating music in isolation; in a time when there is an excuse to step back from your career, it seems frivolous to continue the work when it may amount to nothing. While these lyrics may seem more personal to Swift herself, they can be applied to the experiences of any artist in lockdown. In *folklore: The Long Pond Studio Sessions*, Antonoff comments on the gravity that these lyrics hold in regard to artists handling the isolation of lockdown: "It's not about the pandemic. It's about the experience of what happens to an artist when you're living through a pandemic. You start to dream" (33:34–36.56).

At the conclusion of the bridge, Swift touches on the other aspect of the conceit, highlighting the feeling of always having to try hard to please others, and emphasizing the emotions that come with simply enduring the human experience: "I'm still a believer but I don't know why / I've never been a natural / all I do is try, try, try / I'm still on that trapeze / I'm still trying everything / to keep you looking at me" (Swift, "mirrorball"). Again, these lyrics could relate to a number of individuals, as there are no specific details that point in a singular direction. Thus, the entirety of Swift's conceit in "mirrorball" can appeal to different groups of people; whether it be an artist struggling with the isolation and uncertainty of lockdown, or a person that is constantly battling individual insecurities, all can find solace in the lyrics of "mirrorball." By using this central conceit of the disco ball—a transposable conceit that has the ability to pertain to multiple situations—she allows the interpretive distance that is necessary to be included as a "folkloric way of processing."

While "my tears ricochet" and "mirrorball" employ poetic devices to extract details from particular situations, "seven" uses storytelling as

a way of processing. Throughout this track, we see Swift actually using the "folkloric way of processing" herself, rather than providing the necessary distance for her listeners to apply the lyrics to their own personal circumstances. "seven" acts as something of an ode to childhood, as Swift memorializes her own childhood throughout the song, reminiscing on the feelings of being explorative and innocent and questioning where our childhood tendencies go. However, "seven" also details the way that children process trauma, namely through imagination, and Swift pleads for us to return to this way of thinking. In the first verse of the song, Swift says, "please picture me / in the trees / I hit my peak at seven feet / in the swing / over the creek" (Swift, "seven"). The use of "please" in the opening line of the track suggests that Swift is begging us to see her in this childlike way. The next few lines contain memories of playing and swinging in the woods, but Swift uses a powerful lineation when she says "I hit my peak at seven feet." If we simply read the lyrics, it seems like she is referring to the action of swinging, but when we listen to the actual song, she pauses after the word "seven," indicating that she peaked at the age of seven, rather than at the height of the swing. This halt in the lyrics suggests that Swift sees this magical way of childhood thinking as the best version of herself, further urging her listeners to return to this way of processing.

This kind of thinking is described in the bridge of the song, as Swift discusses the weight of domestic abuse on a friend, and plans an escape so that the friend no longer has to endure this mistreatment: "and I've been meaning to tell you / I think your house is haunted / your dad is always mad and that must be why / and I think you should come live with / me and we can be pirates / then you won't have to cry" (Swift, "seven"). Swift emphasizes the naivety of childhood here, as she details how a child deals with this kind of trauma; the house must be haunted because the dad is mad, and if they leave to be pirates, they will not cry or be afraid. As I said, this childlike way of thinking seems to bring comfort to Swift; as a child, we do not fully understand the gravity of a certain situation, but as we age, these things start to make sense, causing us to feel a sense of guilt for not being equipped to help. So, returning to these events, and remembering them in the way that they happened, allows us to make sense of these instances.

In the chorus of the song, Swift implies that she has lost touch with this friend: "and though I can't recall your face / I still got love for you" (Swift, "seven"). The lines that follow contain one of the most important lyrics of the entire record: "and just like a folk song / our love will be passed on" (Swift, "seven"). Obviously, these lyrics allude to the title of

the album, and the workings of folklore throughout the record; however, we have to consider why Swift would blatantly speak of folklore in this particular song. I suggest that she means to communicate that folklore works within our individual lives. Throughout our lifetime, we tell and retell stories from childhood, or we frequently think about instances from our childhood as we grow up; in this way, we pass down folklore from our own childhood within the span of our lifetime. For Swift, this storytelling does not fix the situation she discusses; she does not prevent the abuse her friend experiences, and she does not maintain this friendship. Rather, the storytelling she employs in this song allows her to process these specific events from her childhood. Telling this story and returning to this way of processing gives her an agency to revitalize this friendship that so clearly meant something to her childhood, and make sense of other things that may have occurred during this time. In giving us this tribute to her own childhood, Swift provides an example of how this "folkloric way of processing" can be implemented into our own lives—through storytelling and returning to a childlike way of thinking.

## Conclusion

This article, I hope, has provided an interesting lens with which we can view Swift's *folklore* as more than just an awarded musical album. In a time of confusion, isolation, and mystification of the modern world, Swift's elegant lyrical composition and powerful storytelling capabilities gave way to a means of comfort for so many. In investigating the nuances of traditional folklore, and thoroughly examining Swift's lyrical content on the album, the ways in which she redefines the folk tradition to present pop music as a contemporary kind of folk become clear, ultimately providing a fruitful approach to the album's analysis. From reinventing formal elements of traditional folklore to embracing features of its position as a cultural phenomenon, Swift effectively creates a modernized take on the folk tradition. Although her songwriting has generally been overlooked in the past, Swift's work on *folklore* has demonstrated how her lyrical content is worthy of further interpretation. What is still to be done, however, is the application of this lens to other frameworks, whether that be music, literature, or other forms of artistic creation. With such masterful creations continuously being made in the modern world, it is important that we continue to investigate them. Works of popular culture can sometimes be written off, but these creations deserve to be appreciated for what they are, as well as what they could be—even if it might not meet the eye at first glance.

## Works Cited


Bradley, Adam. *The Poetry of Pop*. Yale University Press, 2019.

Bronner, Simon J. *Folklore: The Basics*. Routledge, Taylor & Francis-Group, 2017.

*folklore: The Long Pond Studio Sessions*. Directed by Taylor Swift, Taylor Swift Productions, Big Branch Productions, 2020. *Disney+*.

Gerber, Brady. "The Story Behind Every Song on Taylor Swift's Folklore." *Vulture*, 27 July 2020, https://www.vulture.com/2020/07/taylor-swift-folklore-aaron-dessner-breaks-down-every-song.html.

Hansen, William. "folktale." *Oxford Classical Dictionary*. 27. Oxford University Press. Date of access 2 Apr. 2023, https://oxfordre.com/classics/view/10.1093/acrefore9780199381135.001.0001/acre-fore-9780199381135-e-8030.

"Literary Terms." *Encyclopædia Britannica*, Encyclopædia Britannica, Inc., https://www.britannica.com/browse/Literary-Terms.

Mapes, Jill. "Taylor Swift: Folklore." *Pitchfork*, 27 July 2020, https://pitchfork.com/reviews/albums/taylor-swift-folklore/.

Morales, Helen. *Antigone Rising: The Subversive Power of the Ancient Myths*. Bold Type Books, 2020.

"Research and Course Guides: Fairy Tales." *Home - Fairy Tales - Research and Course Guides at Missouri Southern State University*, https://libguides.mssu.edu/c.php?g=185298&p=1223604.

Robbins, Michael. *Equipment for Living: On Poetry and Pop Music*. Simon & Schuster, 2018.

Sheffield, Rob. "Taylor Swift Leaves Her Comfort Zones Behind on the Head-Spinning, Heartbreaking 'Folklore'." *Rolling Stone*, 24 July 2020, https://www.rollingstone.com/music/music-album-reviews/taylor-swift-leaves-her-comfort-zones-behind-on-the-head-spinning-heart-breaking-folklore-1033533/.

Sloan, Nate. "Taylor Swift and the Work of Songwriting." *Contemporary Music Review*, vol. 40, no. 1, 2 Jan. 2021, pp. 11–26, https://doi.org/10.1080/07494467.2021.1945226.

Slobin, Mark. *Folk Music: A Very Short Introduction*. Oxford University Press, 2011.

Swift, Taylor. "august." *folklore*, Republic Records, 2020. *Apple Music*.

- - - . "betty."

- - - . "cardigan."

- - - . "epiphany."

- - - . "mirrorball."

- - - . "my tears ricochet."

- - - . "seven."

- - - . "the lakes (bonus track)."

- - - . "the last great american dynasty."

Swift, Taylor [@taylorswift]. "In isolation my imagination has run wild" *Instagram*, 23 July 2020, https://www.instagram.com/p/CDA-sU8BDzLt/?utm_source=ig_web_copy_link.

Warner, Marina. *Fairy Tale: A Very Short Introduction*. Oxford University Press, 2018.

"What Is Folklore?" *What Is Folklore?*, American Folklore Society, https://whatisfolklore.org.

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**Olivia Remak**

Rebuilding the Pyramid [of Sound]: Shifting Ensemble Pedagogical Approaches

**Faculty Sponsor**
Zack Corpus

## Abstract

Individual achievement is often overlooked by certain pedagogical practices within ensemble settings. Directors' application of methods that do not directly benefit individual performers may result in students who are following performance practices not well suited to their specific instrument. Common band pedagogical practices, including but not limited to approaches to ensemble intonation, balance and blend, and aural examples were analyzed in the context of improving individual achievement within the ensemble. The researcher contacted high school and collegiate band directors regarding their personal pedagogical practices and beliefs within their own program. Director responses, in conjunction with the literature analysis, demonstrate that a mindset shift towards a learner-centered approach to pedagogy is vital in the face of shifting classroom environments and a greater need for individual achievement.

## Introduction

Established band pedagogy, such as the McBeth pyramid of sound or a Bb scale in rounds, often overlooks the varied needs of each instrument family within the ensemble.[1] Factors such as the number of students in a program, uneven instrumentation, geographical location, district and school funding, age of the program, external support, and other external factors mean that there is not one "correct" pedagogical approach to improving any given program. However, there are certain pedagogical practices which may provide greater impact to certain programs compared to others, and would better benefit certain individuals.[2] In this study, the researcher will explore commonly used secondary band pedagogical practices and how this pedagogy might differ in efficacy between instrument families and individual students.

### History

Prior to the introduction of bands in American schools in the 19th century, instrumental music education was practically non-existent outside of the military or private study. Entering into the early 20th century, more and more school bands were founded, and the 1920s in particular began to see an explosion of the number of school programs and new pedagogy being introduced to support these programs. Beginning in 1920, there were 88 school band programs. This number rose to an estimated 15,000 to 25,000 by 1929, with a further increase to over 50,000 band programs by 1941.[3] This exponential increase in school band programs, coupled with a lack of standardized curriculum, meant band programs and the pedagogy applied to them were largely developed by the director of the program, thus creating significant differences in pedagogical approaches.[4]

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[1] Micah Everett, "The Limitations of the 'Pyramid of Sound'." *The Reforming Trombonist*, December 2, 2021. https://thereformingtrombonist.com/2021/12/02/the-limitations-of-the-pyramid-of-sound/.

[2] Scott Rush, *Habits of a Successful Band Director : Pitfalls and Solutions*. (Fort Wayne, IN: Focus of Excellence, 2003).

[3] Clarence Nelson Jr. Fritts, *The Historic Development of the Concept of Comprehensive Musicianship in School Bands*. DMA diss., The Catholic University of America, Washington, D.C., 1991. ProQuest Dissertations & Theses Global.

[4] Theodore F. Normann, *Instrumental Music in the Public Schools* (Bryn Mawr, PA: Oliver Ditson Co., 1939).

The field of music education has continued to expand into the 21st century, with the 2019 Arts Education Status report detailing that 92% of students in schools have access to some form of music education.[5] This expansion elicits a need for an upgraded mindset to better suit the varied performers found in each ensemble. Certain pedagogical ideas remain in regard to approaching how to lead an ensemble, even as pedagogical philosophies began to shift away from the militaristic background of music education. There exists a "teacher-centered" approach to pedagogy that has been present since the foundation of the school band as we know it. In this approach to band directing, the conductor's word is law, with the students simply being tasked with following it in order to achieve the director's ideal band sound.[6]

New philosophies began to emerge as music education transitioned into the 21st century, deviating from a "teacher-centered" approach to pedagogy towards a more "learner-centered" approach to pedagogy. The pedagogical shift from a teacher-centered approach to a learner-centered approach to pedagogy brings several benefits. Band pedagogue David Elliott promoted the development of individual musicians through guided experiential learning as a way to increase overall ensemble achievement through increasing the skills of the individuals within the ensemble.[7] A learner-centered approach encourages students to become more involved in the subject of study, ergo garnering greater educational benefits through an increased willingness to learn and a more welcoming and encouraging educational environment. Additionally, a learner-centered approach allows students to develop critical thinking skills and other necessary skill applications to help them develop into independent learners.[8] With this approach to learning, the director's job shifts from a role of dictating what the students must learn towards a role of guiding young musicians

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[5] National Arts Education. "National Arts Education Status Report." Accessed June 2023/. https://artseddata.org/national_report_2019/.

[6] Jeremy Hepner, "Meeting Literacy Goals with a Learner Centered Band." *Musicien Éducateur au Canada* 51, no. 3 (2010): 39–43.

[7] David J. Elliot, *Music Matters: A New Philosophy of Music Education* (Oxford: Oxford University Press, 1995), 241–295.

[8] Julie K. Brown, "Student-Centered Instruction: Involving Students in their Own Education."*Music Educators Journal* (May 2008): 30-35. https://www.jstor.org/stable/20685476.

through the process of learning and growing with their craft.[9] Individual achievement and support leads to improved achievement in the program as a whole. When ensembles are individually efficient at what they do, their ability to master more advanced musical concepts can have a greater impact on the overall ensemble performance. A common example would be that an increased attention to improving individual players' intonation in the flute section would lead to a more supported flute sound.

As a director, it might be easy to lose sight of the individuals that make up the band when the achievements of the whole ensemble are the end goal: achieving a certain score at a concert festival, performing at the spring concert, ensuring a quality ensemble throughout the semester. In order to provide mentorship, the director of an ensemble must have a detailed and current knowledge of each instrument in their ensemble, in addition to the instrument specific workings and tendencies characteristic of the various instrument families and the individual instruments within those families. The success of an ensemble relies on these details, as well as the knowledge and application of the students on their own instruments, with guidance from the director.[10] It is important for ensemble pedagogy to be impacted and shaped by the needs of the individuals in order for a director to best support them as their skills and the level of the ensemble progresses. A pedagogic shift with an increased focus on individual achievement is likely a more pedagogically sound way of influencing and affecting ensemble sound and skillset, especially for instruments that are not within a director's primary area of knowledge.

## Literature Review

The director is the most important facilitator in this shift from viewing the ensemble as a whole to viewing it as the individuals who make it up. The skill sets and educational needs of the students largely dictate the direction the rehearsal or lesson should go, but the teacher or director is responsible for developing the educational foundation of tone and technique to base

[9] Brown, "Student-Centered Instruction" 33.

[10] Glen Gillis, "The Band Director's Multiple Roles." *Canadian Music Educator* 52, no. 4 (Summer 2011): 35-7, https://www.proquest.com/scholarly-journals/band-directors-multiple-roles/docview/881979663/se-2.

ensemble performance upon.[11] While it is easy to advocate for an individually minded approach to pedagogy, experienced music educators will also know that, in times of pressing upcoming performance engagements, the individual learning experience may be overlooked in favor of ensuring the ensemble is at the desired performance level. It will not always be possible to address every individual in the ensemble at every rehearsal; however, approaching rehearsals from a learner-centered mindset allows musicians within the ensemble to be guided to become independent problem solvers who are aware of how ensemble pedagogy affects them and their instrument. This approach to pedagogy provides learners with ways in which to solve instrument-specific problems that may arise within repertoire or ways in which to identify ensemble-minded teaching strategies that are used within a rehearsal. For a director, focusing on these strategies can encourage independent musicians who, when building their skills from the pedagogy they are exposed to day after day in rehearsals, can further themselves as musicians and performers when that pedagogy supports their specific instrumental and learning needs.[12] A more systematic approach to every-day rehearsal tactics could empower ensemble directors to be more mindful of the individuals within the ensemble and how certain pedagogical practices benefit or detract from individual instrumentalist achievement.

#### Warm-Ups

Warm-up practices are one of the easiest tools to implement in improving individual achievement, but if approached from an ensemble-first mindset while overlooking the individual sections within the band, some warm-up practices may prove more detrimental than intended. For instance, chorales are a major tool and resource for any wind band warm-up. This form of warm-up can be used to address intonation, phrasing, articulation, and musicianship, among other skills. However, chorales can also prove detrimental over time. If the same chorale is used by the director in warm-up every day, it has the potential to become a monotonous chore for director and ensemble alike. Consider the percussion section. Is their part in the chorale challenging enough and/or technically involved, or is it simply

[11] Daniel Shelley Hiestand Jr., "An Evaluation of Recommended Literature for the High School Band." Order No. EP62034, University of Southern California, 1958. In PROQUESTMS ProQuest Dissertations & Theses Global, https://www.proquest.com/dissertations-theses/evaluation-recommended-literature-high-school/docview/1652525239/se-2.

[12] Keith Koster, "Revisiting Teaching Strategies for Woodwinds." *Music Educators Journal* 96, no. 3 (March 2010): 44-52. https://www.jstor.org/stable/20685502.

mallets mirroring the melody? If the chorale is winds only, reflect on the time spent on this chorale. The pedagogical benefits to winds reaped by spending a significant portion on the chorale are overshadowed by the detriment to percussion, especially if the rest of the warm-up has also been centered on the wind players.[13]

Warm-ups are an opportunity to hone individual technique and skill and address gaps in fundamentals that, when corrected and improved upon at the individual level, will have a positive impact on overall ensemble achievement in the context of a piece of repertoire that utilizes the fundamental skills focused on during warm-up. When students have context and understanding for why and what they may perceive as a boring, every-day chore is important to their individual development as musicians, warm-ups may be approached with greater efficacy in the rehearsal space.

#### Intonation

Intonation provides pedagogical considerations that can be applied to different areas of rehearsal in order to better achieve a student-first mindset. For example, tone is a major factor in a musician's intonation, and tone production must be directly addressed before intonation problems can be approached.[14] If a director instructs a clarinet player with poor tone that they are severely out of tune, this directive might go unresolved if the player is unaware of the cause of the intonation problem or how to resolve it. It is important for directors to maintain an awareness of the discrepancies in the musical education backgrounds and privileges of students. The end pedagogic goal can only be achieved by a music educator through guiding students through all the necessary steps, from point A to point Z, until students are able to navigate musical problem-solving on their own. Specific solutions to the underlying problem of poor tone quality are of a greater help to students than general directives.

Other external factors that impact student intonation may include the quality of a student's equipment, temperature within the performance or rehearsal space, range, tone as previously mentioned, or the innate pitch tendencies of a particular instrument. This is not an exhaustive list by far,

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[13] Todd Stalter, "Using Chorales to Teach Intonation, Articulation, and Phrasing." *School Band and Orchestra*, April 2018. https://sbomagazine.com/commentary-using-chorales-to-teach-intonation-articulation-and-phrasing/.

[14] Michael D. Worthy, "Effects of Tone-Quality Conditions on Perception and Performance of Pitch among Selected Wind Instrumentalists." *Journal of Research in Music Education* 48, no. 3 (2000): 222–236. https://doi.org/10.2307/3345395.

and even these broad umbrella terms have smaller branches of factors within them.[15] To achieve an improved ensemble sound and encourage student growth and independent musicianship, it is vital for the director to be aware of the impact of various factors on the performers and to aid in the diagnosing and problem-solving the students must apply to their playing to offset some of these factors. In doing so, the director is guiding and shaping independent musicians, who can then apply the knowledge and problem-solving skills imparted upon them by their director to other aspects of ensemble playing, or in their own private study or individual practice time to become well-rounded and more developed musicians.

Pedagogical tactics such as singing within the rehearsal or addressing an individual's tone production as a means to improve intonation have direct pedagogic benefits to the students. A student who demonstrates lack of understanding or proficiency in certain musical areas, such as an inability to hear when a note marked in the key signature is played with the incorrect accidental or a lack of awareness regarding their individual intonation problems, requires specific input from the director to address and conceptualize these areas of struggle. Through director modeling, student-led guidance, and direction towards individual growth and problem solving, students of all ability-levels will grow to become more self-sufficient musicians.[16]

#### Instrument Specific Pedagogy

Consider the three main band instrument families: brass, woodwinds, and percussion. Aforementioned techniques, such as singing in rehearsal, have direct impact on the instrumentalists contained within these families. For brass players, singing can improve audiation skills, leading to increased accuracy in performance of partials and improved intonation when a student is able to hear that the note within their head does not match what they are performing on their instrument. Improved singing and pitch recognition directly aids student musicians from all instrument families in the

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[15] Brian C. Wuttke, "A model describing the effects of equipment, instruction and director and student attributes on wind-band intonation." Order No. 3456375, University of Miami, 2011. https://www.proquest.com/dissertations-theses/model-describing-effects-equipment-instruction/docview/871631429/se-2. ProQuest Dissertations & Theses Global.

[16] Mitchell Robinson, "To Sing or Not to Sing in Instrumental Class." *Music Educators Journal* 83, no. 1 (1996): 17–47. https://doi.org/10.2307/3398989.

quick and accurate tuning of their instrument.[17]

Brass pedagogy is inherently different from woodwind pedagogy, which is even further removed from percussion pedagogy. Not every rehearsal will address each instrument family evenly, but it is important for directors to maintain awareness of their personal implicit biases. This often manifests in an uneven instruction of one instrument family due to the director's familiarity with one aspect of pedagogy more so than others, such as a trumpet-playing band director focusing almost exclusively on brass pedagogy due to their greatest concentration of instrument-specific knowledge being in that area.

Woodwinds, for example, are known to have complicated intonation tendencies that a director may perceive as hopeless if they do not understand these tendencies or the factors which can impact them. However, a director must ensure that certain details such as embouchure, air support, posture, and correct usage of equipment are in order prior to approaching pedagogy related to woodwind intonation, as improper knowledge of these factors can provide a roadblock to ensuring student success and achieving the desired sound.[18] When woodwind players are taught the intonation tendencies of their specific instrument, students are able to better identify the source of common issues they will face within the ensemble. Through exposure to the specifics of their instrument and guidance from their instructors, students can build this knowledge into their musical skill base and decision making.

There are instrument-specific techniques, warm-ups, and tendencies which can be discussed with the ensemble as a whole can benefit from knowing. Pedagogy of instruments outside the director's primary instrument family is often a deficit in many directors' pedagogical lexicon. Despite this, an active attempt to create intentional ensemble warm-ups which benefit all instrument families and a working knowledge of the impact of different factors on band intonation can positively influence individual achievement. This is not an exhaustive list, and there should be a continued pursuit of expanding knowledge in areas of deficit in any director's given pedagogical knowledge base.

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[17] Chad Criswell, "Brass and Woodwinds: Tuning the Woodwind Section." *Teaching Music* 16, no. 1 (2008): 65.

[18] Chad Criswell, "Brass and Woodwinds: Tuning the Woodwind Section." *Teaching Music* 16, no. 2 (2008): 56–57.

### Aural Examples

As a student's tone development and control improves, so does intonation, thus positively impacting the ensemble as a whole. However, it is up to the director to guide young musicians towards this state of improved tone production. Modeling and auditory examples of tone and musical expectations are prime pedagogical approaches in doing so.

Aural examples are vital for student improvement. The multitude of tasks necessary to play an instrument, such as embouchure and mouth control, finger coordination, and reading of the music, can detract from students' auditory environment when they are asked to actively listen while also engaged in playing. Providing students with aural examples they can be wholly attuned to can better create independent, self-sufficient musicians.[19] By providing reference recordings or recording the rehearsal for students to later listen back to, directors can ensure students develop a greater understanding of the music they are playing. Directors can promote a sustained knowledge of the characteristic sounds of the various instruments through positive auditory examples of more advanced players in each section and videos or audio recordings of professionals on each specific instrument.[20]

It is necessary to promote these positive aural examples for all instruments within the band. All musicians in the ensemble are deserving of a positive auditory example from which to learn from and grow. Aural examples can be implemented in short but consistent exposure, such as playing a recording of a professional at the start of class while students are setting up. The same holds true for the ensemble sound as a whole. Exposure to positive aural examples of professional bands and orchestras can aid in molding students' perceptions of overall ensemble goals and achievement.

### Balance and Blend

One of the most notable pedagogical contributions relating to ensemble balance is the double pyramid balance system developed by W. Francis

[19] Brady Glenn McNeil, "Aural Skills Pedagogy in the Wind Band: A Survey of Secondary and Collegiate Wind Band Conductors' Perceptions and Strategies." Order No. 30272862, Auburn University, 2021. https://www.proquest.com/dissertations-theses/aural-skills-pedagogy-wind-band-survey-secondary/docview/2800162206/se-2. ProQuest Dissertations & Theses Global.

[20] Linda C Thornton, "The Effect of Grade, Experience, and Listening Condition on the Melodic Error Detection of Fifth- and Sixth-Grade Woodwind Students." *Update: Applications of Research in Music Education* 26, no. 2, (2008): 4-10. https://doi.org/10.1177/8755123308317612.

McBeth. This system, more commonly referred to as the pyramid of sound, was intended to correct ensemble intonation, and was derived from McBeth's belief that "Pitch is a direct result of balance."[21] The pyramid is a so-called "double pyramid" because McBeth breaks down the ensembles into two separate pyramids: one for brass and one for woodwinds. These pyramids are structured from top to bottom, with the highest instruments at the top and the lowest at the bottom. A simpler version of the double pyramid is notated as a single pyramid with all the instruments for younger ensembles as seen in **Figure 1** and **Figure 2** below. **Figure 2** is what most people refer to today when referencing the pyramid of sound.[22]

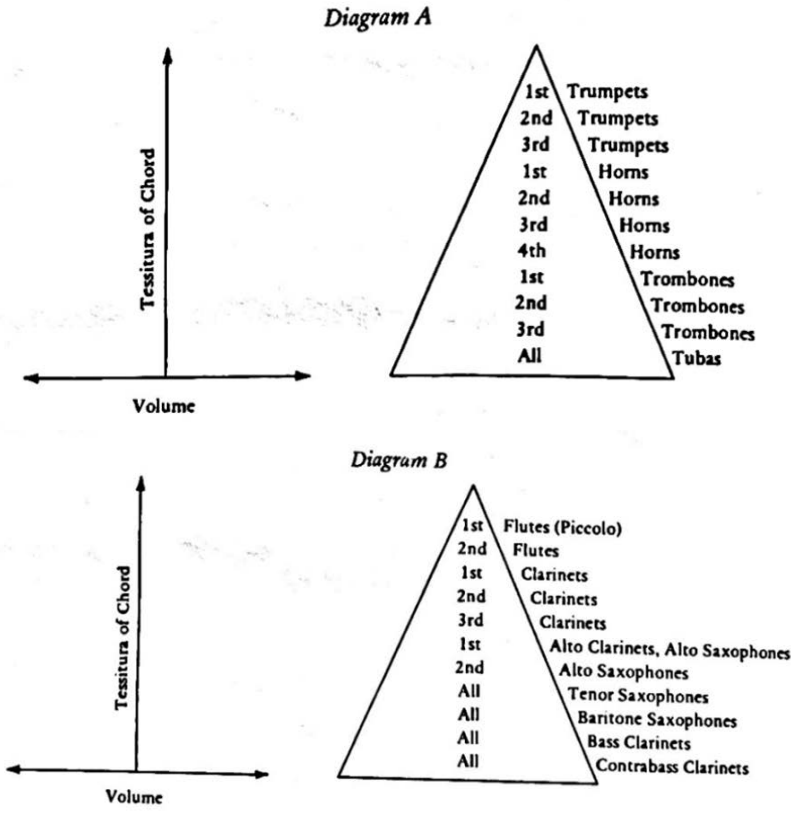


**Figure 1**. McBeth Double Pyramid of Sound (McBeth 2–3)

[21] William Francis McBeth, *Effective Performance of Band Music* (San Antonio: Southern Music Co, 1972).

[22] McBeth, *Effective Performance*, 2–5.

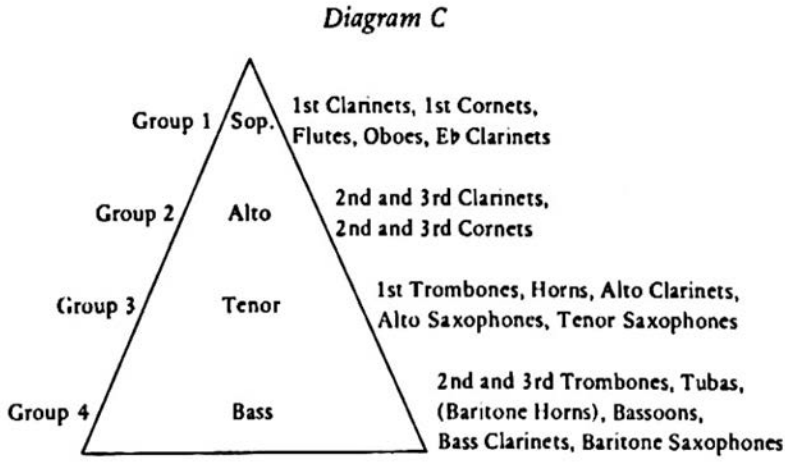


**Figure 2**. Simplified Pyramid of Sound (McBeth 5)

According to McBeth, balance cannot automatically be achieved through blend, good intonation, or tone production, even as students improved in their musical skill. He wrote that it was necessary to adhere to this pyramid system to achieve balance within the ensemble. McBeth's pyramid system is a commonly referenced pedagogy when balancing ensembles, with directors encouraging upper woodwinds to play softer and low brass to play louder to achieve the desired ensemble balance. However, consider the impact of sustained use of the pyramid on the individuals within the ensemble.[23] Prerequisites to achieving improved woodwind intonation include proper air support, amongst other factors. Encouraging upper woodwinds to play softer in order to achieve a balanced sound, thus improving ensemble pitch according to McBeth, can negatively impact less developed players who may not yet have the proper knowledge or systems to achieve a softer tone without sacrificing their air flow. Contrary to what McBeth wrote, a focus on intonation over the supposed balance provided by the pyramid will lead to a more natural development of a balanced sound. A director can achieve this form of balance without having to box

[23] McBeth, *Effective Performance*, 6–8.

instrument families into uncomfortable dynamics or ill-advised methods of sound production that can cause fundamental flaws in performance.[24]

Encouraging individual student performance rather than diminishing individual dynamics for the sake of ensemble blend and balance can be a more effective pedagogical approach for music educators. The latter may encourage poor performance practices and detract from individual growth. Detriments may arise through adhering to the pyramid of sound through practices such as constantly "giving the hand" to upper woodwinds to play softer for the sake of balance. Upper woodwind players may develop an unsupported tone with poor intonation control, while their low brass counterparts who are consistently encouraged to play out, thus utilizing proper breath control and support, may develop a more developmentally characteristic tone on their instruments. It is important for directors to remain cognizant of the pedagogical impacts on certain instrumental groups in order to better aid in the development of more independent musicians.[25]

#### Application to Pedagogically Relevant Repertoire

Pedagogical applications as they apply to ensemble warm-ups are one thing, but the primary focus of most rehearsals center around prepared repertoire. To further the discussion on creating an inclusive and student-centered learning musical environment, it is important to analyze pieces of band repertoire that may be encountered by both directors and students within their time in the band room. The primary goal of band as an educational medium must be the musical development of the students more so than the performances given to the audience. An important facet of band education lies in exposing students to repertoire that they can successfully perform, but also which challenges their musicianship and performance skills. It is to this end that the director is responsible for maintaining and developing a well-balanced band and imparting musical concepts and rehearsal techniques to aid in the creation of this music.[26]

There are certain pieces of repertoire commonly known throughout the band world, and which high school directors and students alike will

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[24] Wuttke, Brian C. 2011. "A model describing the effects of equipment, instruction and director and student attributes on wind-band intonation." Order No. 3456375, University of Miami, https://www.proquest.com/dissertations-theses/model-describing-effects-equipment-instruction/docview/871631429/se-2. ProQuest Dissertations & Theses Global.

[25] Everett, "The Limitations of the Pyramid of Sound."

[26] Hiestand, *An Evaluation of Recommended Literature*, 199–200.

likely encounter during their time in the band classroom. *Into the Clouds!*, a concert band grade 3 piece by Richard Saucedo, is an example of a commonly performed piece of band repertoire that many students will encounter over the course of their time in band. This piece was selected upon review of 9–10 and 11–12 grade West Tennessee School Band and Orchestra Association (WTSBOA) District Honor Band (All-West) programs from 2012 to present in conjunction with Memphis Area Concert Festival programs from the past 2 years. Both the WTSBOA All-West and the Memphis Area Concert Festival are benchmarks of performance quality in West Tennessee. Their educational and musical relevance to all students and educators in the area provide trustworthy and pedagogically relevant programs from which to determine a musical selection.

*Into the Clouds!* was selected based on composer relevance throughout the programs. Richard Saucedo's music was performed a total of 9 times throughout the analyzed programs, with *Into the Clouds!* appearing twice.

As previously mentioned, Saucedo's work is a concert band grade 3. In order to understand the pedagogical and skill-level implications of these numbers, it is important to understand the concert band grading system. Across the United States, there is not a universal system for which to assign skill-level necessities to concert band repertoire. The grading system differs from state to state, as well as between various music publication houses. There are similar systems in place, often with numbers assigning a grade level to a piece based on musical and technical difficulty, with the grade level ranging between 0.5 and 6. Younger instrumental ensembles typically perform music between a grade 0.5 to a grade 2+.[27]

[27] Grace E. Baugher, "Finding the Sun: An exploration of the band grading system through an original work in three levels for concert band." Master's Thesis, University of Tennessee, Knoxville. 2019. https://trace.tennessee.edu/utk_gradthes/6064.

The Manhattan Beach Music Grading System.

| | |
|---|---|
| Grade 1 | All middle schools and first-year bands |
| Grade 2 | All middle schools and small high school bands |
| Grade 3 | Better middle schools, all high schools, all universities |
| Grade 4 | Better high schools, small colleges, all universities |
| Grade 5 | Advanced high schools, better small colleges, all universities |
| Grade 6 | The best high schools, all universities |

The Hal Leonard Grading Scale.

| | |
|---|---|
| 1 | Very Easy – 1 year of playing experience |
| 2 | Easy – 2 years of playing experience |
| 3 | Medium – 3-4 years of playing experience |
| 4 | Medium Advanced |
| 5 | Advanced |
| P | Professional |

**Figure 3**. Numerical Grading System for Band Literature (Baugher 17)

Grade level 3 is a relatively standard level for most high-achieving middle school ensembles or honor bands, and average for most high school ensembles, thus providing a middle ground. As previously mentioned, grading systems of band literature vary widely. For the sake of this analysis and the determination of the grade levels of the selected pieces, I used the Tennessee Band Master's Association (TBA) state music list. This list provides a list of all approved pieces for concert festival performance in addition to their assigned grades.[28]

#### Richard Saucedo: *Into the Clouds!*[29]

Richard Saucedo's *Into the Clouds!* is scored for standard band instrumentation. There are divided parts in Bb clarinet, Eb alto saxophone, Bb

[28] Tennessee Bandmasters Association. "TBA Tennessee State Music List." Accessed August 2, 2023. https://tennesseebandmasters.org/concert-band/.

[29] Saucedo, Richard. *Into the Clouds!* Milwaukee, WI: Hal Leonard Corporation, 2007.

trumpet, and percussion. While these divided parts necessitate harmonic independence within the section, many of these split parts contain unison rhythms, allowing for less experienced players to build independence and confidence even while on a different part than their peers. A primary concern regarding the simplicity of the instrumentation within this piece is the lack of engaging percussion parts. The percussion parts that appear include two mallet percussion parts, as well as two auxiliary percussion parts involving snare and bass drum, triangle, cymbals, and timpani. This is standard percussion instrumentation for most pieces of band repertoire, and, while important, can lead to an under-engaged percussion section, especially if there are greater technical and rhythmic concerns within the winds.

This piece is written with a tempo marking of "Lively!", with quarter note equaling 160 beats per minute (see **Figure 4**). The tempo remains consistent throughout the entirety of the piece. This quick, unchanging tempo may have two-fold benefits. The lack of tempo fluctuations can aid in ease of learning, as less experienced players do not have to worry about the added musical challenge of navigating a tempo change. Additionally, the quick tempo and upbeat melodic lines may prove more engaging to certain students. Repertoire engagement is important for students when rehearsing, as it can lead to increased focus, enjoyment, and drive while developing vital musical and technical skills, leading to greater levels of achievement. This quick tempo may also be challenging to younger players and can allow for students to learn how to approach learning a piece of music that is too fast to sight read at tempo. The students can then apply this musical skill in other areas of their playing or individual practice.

Saucedo's *Into the Clouds!* begins with a syncopated melodic motif in high brass—F horn and trumpet—along with alto saxophones, supported with interjections by low brass and low woodwinds, with upper woodwinds and mallets playing a sixteenth eighth ostinato, or repeated musical fragment (see **Figure 4**).

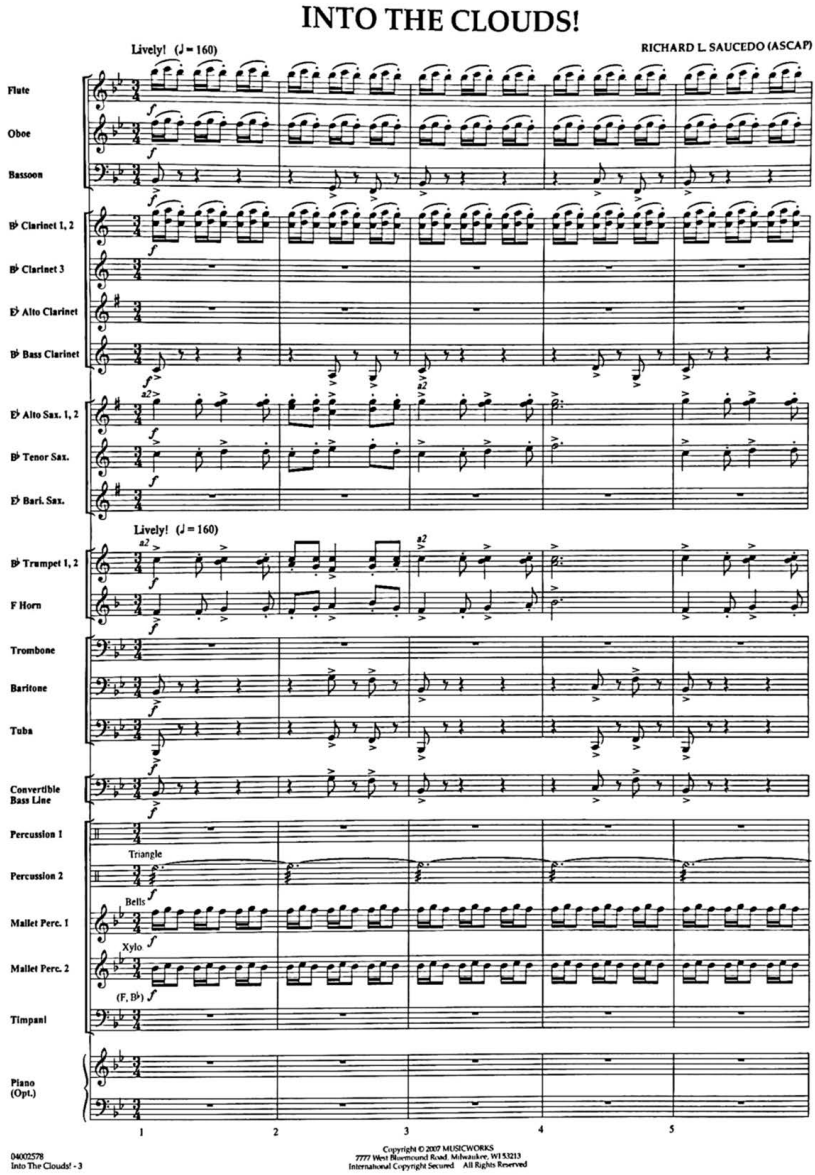



**Figure 4**. *Into the Clouds!* mm. 1–5

These three sections—upper woodwinds, low woodwinds and low brass, and upper brass and saxes—largely remain grouped together throughout the piece. These blocked sections provide greater support and solidarity within the performers, which can increase performer confidence and aid in

engaging rehearsal practices. Despite this, one still needs to consider the varying needs of the instrumentalists within these groups. It is also important to keep percussion in mind, especially if the winds appear to struggle more in learning their parts than the percussionists. It is important to have varying levels of individual achievement to keep students engaged and explore the boundaries of their instruments. This is especially true for more advanced players who do not find ensemble playing challenging.

Measures 17 through 37 provide an exposed percussion part, coupled with a flute solo supported by a clarinet countermelody (see **Figure 5**).

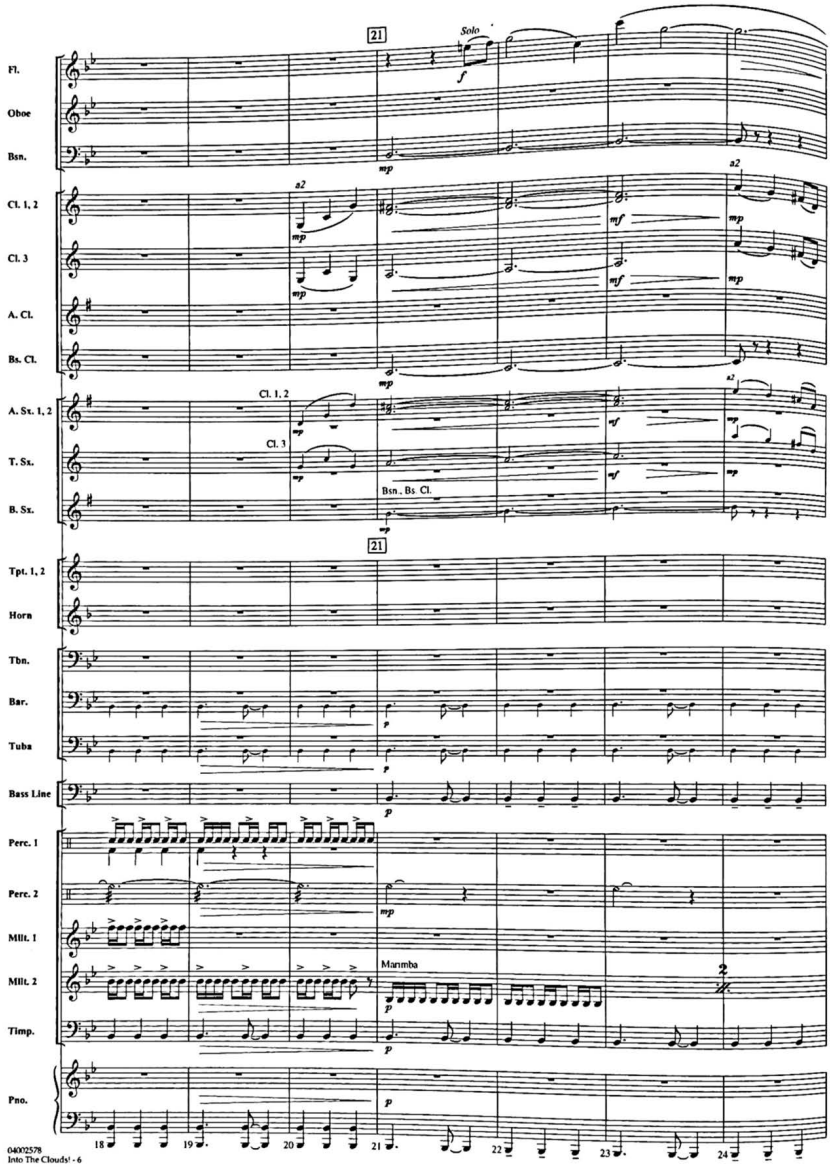



**Figure 5**. *Into the Clouds!* mm. 18–24 and mm. 25–31

The inclusion of these more exposed parts, as opposed to the melodic blocking seen through most of the piece, is beneficial to encouraging individual performance practices. However, it is important to note the instrument-specific nuances and challenges that may arise as a result of this solo. Most notably, the solo flute risks being covered up by the entirety of the

clarinet section with the counter melody. This section is already marked *mezzo piano* for the clarinets and involves important harmonic supporting lines to the solo. Rather than asking clarinets to play quieter at the risk of suffering poor intonation, encourage increased tone production and air support to yield a greater and more resonant flute tone.

While not the primary focus of this phrase, low reeds also play an important part in this upper woodwind feature. The bassoonist and bass clarinet, while having performed in tandem with low brass prior to this section, now sustain a single note for the entirety of the section. While the part may be unengaging and "easy" to these players, it is vital that the director informs them of the harmonic importance of their part. Encouraging low reed players to shape the long note with the melodic phrase can add further musical nuance and interest to this feature. Additionally, the simplicity of their part is important to note. These students cannot solely rely on ensemble repertoire to be challenged. Exclusive performance of ensemble repertoire by students such as low brass and low reeds is a detriment to these players if one is not encouraging soloistic growth along with encouraging more musical performance practices in ensemble playing.

The upper woodwind feature seen in measures 17 through 37 is the only occurrence of a juxtaposition of lyrical woodwind sections between fast paced reiterations of the main theme that occurs in the entire piece. Despite its brevity, this section can provide great pedagogical benefit to the woodwind players. This can occur through discussion of the best way to attain stylistic differences through articulations found in the section such as slurs, tenuto, and the notable lack of accents and staccato compared to the rest of the piece. In addition, focusing on a more woodwind centered ensemble color compared to the bright and brassy color found in the rest of the piece encourages the development of instrument-specific tone.

The remainder of the piece is scored for the full ensemble, with a few phrases of note that feature specific sections. Measures 56 and 57 contain a percussion interlude the winds rest while only the percussion play (see **Figure 6**).

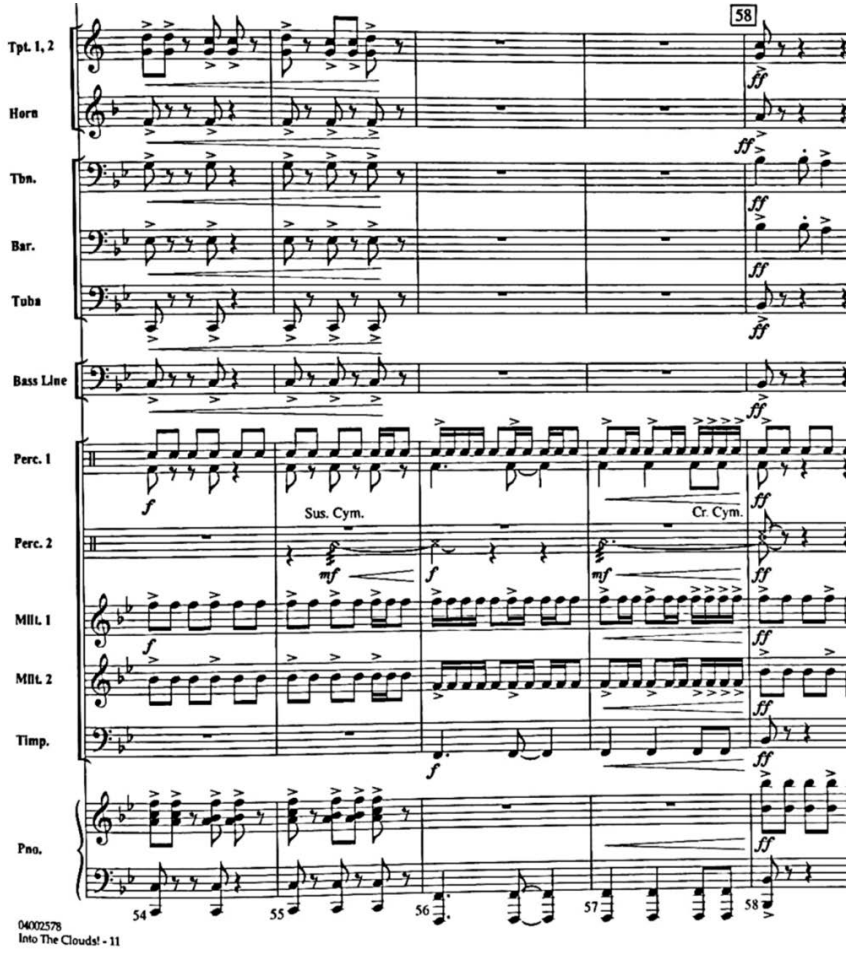



**Figure 6**. *Into the Clouds!* mm. 54–58

It is important for percussionists to be rhythmically accurate during these measures, but these two measures are the most exposed and arguably challenging measures for the percussion section, a fraction of the musical gravitas the piece holds compared to the rest of the ensemble.

The extremely repetitive melodic material that occurs in multiple sections throughout the piece can be a benefit to an ensemble, especially one that is struggling to achieve at a high level with prepared repertoire. The predictable form and repetitive nature of the piece provides recurring melodic and harmonic motifs that can allow a lower-achieving ensemble to reap the benefits of musical achievement without challenges that may prove insurmountable.

Unison rhythms, harmonies, and melodies allow for less "musical" interest from an audience perspective; however, it should be noted that audience entertainment should not be the primary educational focus of an ensemble. These unison musical motifs, while overlooked by many as lack of musical interest or lack of challenge to certain ensembles, can provide ample pedagogical opportunities to lower-achieving bands, while still exposing them to well-established band literature. An example of unison musical motifs occurs in measures 81 to 86 (see **Figure 7**). This span of music demonstrates unison rhythm in upper woodwinds and percussion, along with block melodies and harmonies occurring in brass and alto saxophones.

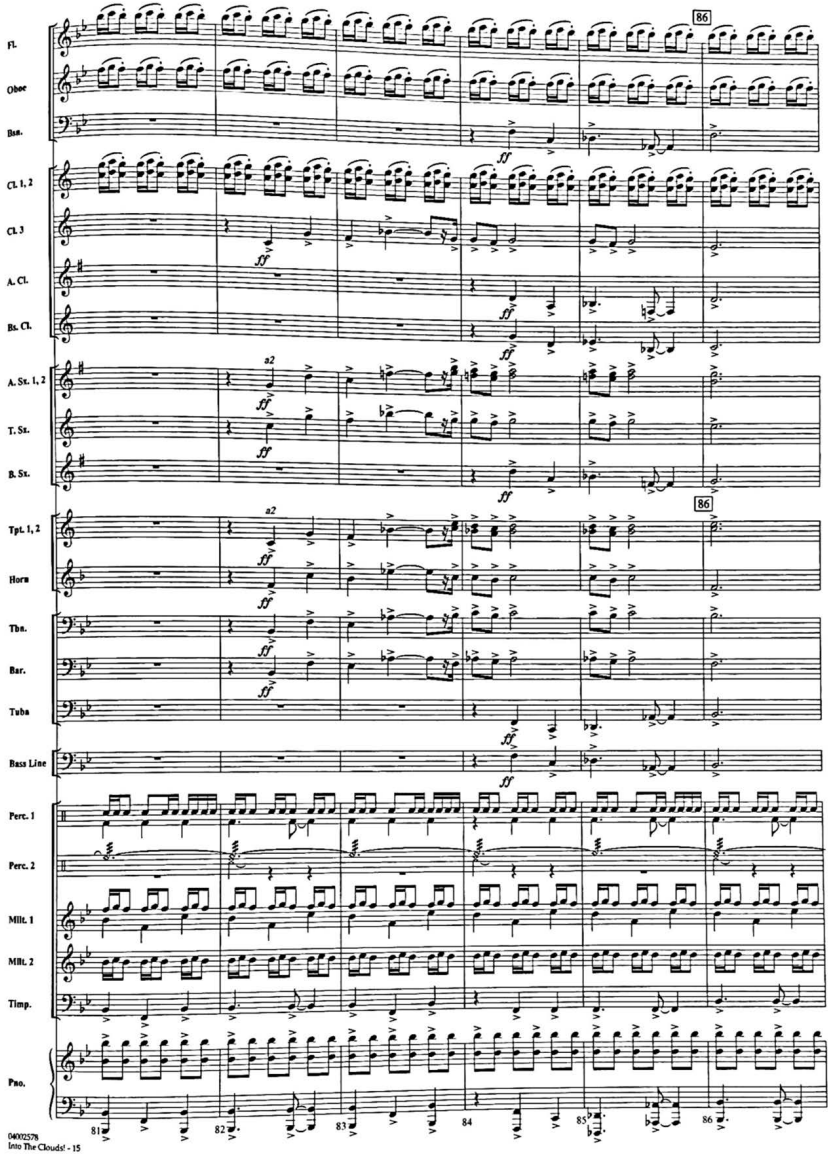



**Figure 7**. *Into the Clouds!* mm. 81–86

When approached with the intention of providing as much benefit to the performers, Saucedo's work allows lower-level bands to feel a sense of accomplishment through inclusion of solos and unison rhythms to allow for further musical growth while also pushing them towards a higher standard of performance.

## Conclusion

Viewing a piece of repertoire based on the potential pedagogic benefit it can offer ensembles of varying levels can help to further aid in the development of directors' growth mindset when it comes to encouraging student development and performance ability through the use of repertoire. Music education, which includes learning and performing repertoire, is to benefit the students. Student exposure to challenging literature, whether it is through aural examples or a low-stakes rehearsal for the sake of demonstrating what it might be like to perform such literature, can be considered a vital part of student music education.

## Research Methodology

Ensemble playing alone does not encourage student performance development. In an effort to further improve and encourage student soloistic growth and to enable current, qualitative and quantitative data, high school directors were contacted regarding their individual pedagogical philosophies. These directors were high school directors who are members of the West Tennessee School Band and Orchestra Association (WTSBOA) in addition to collegiate directors at colleges and universities within Tennessee that offer a Bachelor of Music or higher. This provided a geographic limit for the research participant pool. These music educators were sent a survey inquiring about their personal pedagogical practices and beliefs within their own program. The aim of this vein of research is to investigate if there is any correlation between the specific pedagogical practices of certain directors and the relevance analysis conducted on written sources. The demographics of the two groups of surveyed directors varied widely, as seen below in **Table 1**.

| | WTSBOA | COLLEGIATE |
|---|---|---|
| **Male** | 67% | 100% |
| **Female** | 33% | 0% |
| **African American** | 17% | 0% |
| **White** | 83% | 100% |

**Table 1**. Participant Gender and Race Demographics

It should be noted that there are no female collegiate band directors in the state of Tennessee. Hence, the gender disparity is evident in the demographic results. Additionally, while collegiate directors of all racial and ethnic backgrounds were contacted, the demographics reflect only those who responded to the surveys.

Both groups of participants included directors of all instrumental backgrounds: woodwind, brass, percussion, and even piano, voice, and composition. The distribution can be seen in **Chart 1** below.

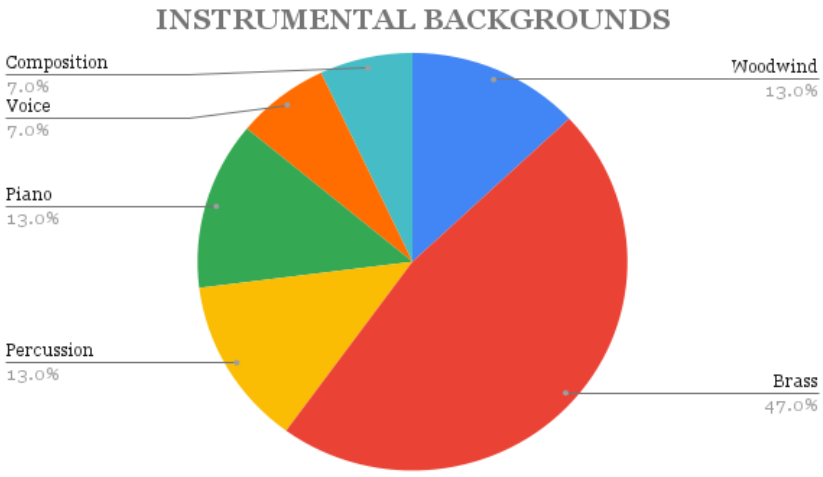



**Chart 1**. Participant Instrument Backgrounds

WTSBOA respondents recorded teaching experiences ranging from 1 to 25 years of classroom experience, with a mean of 9 years. There was a notable increase in years of experience from the collegiate respondents spanning 13 to 41 years of experience and a mean of 23.5 years. The education distribution reflected a similar trend, with collegiate directors recording a higher level of post-graduate education than the WTSBOA participants (see **Table 2**).

| | WTSBOA | COLLEGIATE |
|---|---|---|
| **Bachelors** | 67% | 0% |
| **Masters** | 33% | 14% |
| **Doctorate** | 0% | 86% |

**Table 2**. Participant Education Distribution

The size of the instrumental programs the directors ran ranged from 24 to 180 students in the WTSBOA results, and 15 to 400 students in the collegiate results. Despite the large range in both WTSBOA and collegiate responses, the average size of the high school ensembles was 70 students, while the collegiate ensembles averaged 212 students.

Participants were asked to provide a few sentences regarding the key aspects of their instrumental teaching philosophies. The majority of responses, at both levels, were focused on student achievement before musical performance. The quotes below, one from each participant group, highlight this.

> "My philosophy in teaching music is acknowledging that all students are unique in their own way. Therefore, all students have different learning needs. Everyday I strive to create the best environment for every student to learn in. An environment that breeds positivity, inspiration to learn and grow, as well as hard work." (**WTSBOA**)

> "I teach people first and use music as the vehicle. Teaching musical literacy towards the goal of matriculating independent, life-long learners and critical thinkers is at the core of what I do. The job of a teacher is to help students realize potential they may not know they have and to spark passion and joy for learning and performing." (**Collegiate**)

Directors were also polled in regard to their opinions on certain pedagogical practices and how they line up with their own pedagogy. There were three categories in total: intonation practices, balance and blend, and music literature. These categories were chosen in an effort to align with the primary pedagogical approaches discussed within the analysis of literature, as well as the pedagogical application to musical repertoire. Within these categories, directors were given a total of 7 phrases that reflect various pedagogical approaches relating to the category. Directors were asked to indicate their preference for each approach on a scale of 1 to 10, with 1 being the least important and 10 being the most important. It should be noted that directors were allowed to assign the same value to multiple approaches within the same category, due to the acknowledgement that these approaches were not laid out in such a way that was conducive to a set numerical order. The responses to each of these categories are outlined in the sections below.

Prior to discussing the responses to each category, however, it is pertinent to describe the measurements used to come to the described conclusions. There were two numbers referred to in order to decipher the numerical responses to written questions. First was the mean, which demonstrates the average number assigned to each subcategory. Secondly was the standard deviation, which indicates the spread of the numerical data. The higher the standard deviation, the greater each individual response deviated from the mean, while a lower standard deviation indicated that most of the responses fell within a closer range to the mean. The standard deviation was used to corroborate that the response with the highest average, or mean, aligned with the highest rating from directors. Additionally, a high standard deviation also indicated the most "contested" answer. Namely, the pedagogical approach which most directors assigned widely varying ratings. The variance was also calculated for all responses and will occasionally be referred to in conjunction with the standard deviation.

### Intonation Practice

The table below outlines the subcategories regarding intonation practices, as well as the responses provided for each category from WTSBOA directors.

| # | Field | Minimum | Maximum | Mean | Std Deviation | Variance | Count |
|---|---|---|---|---|---|---|---|
| 1 | Tuning the whole ensemble to a single pitch (ex: Concert F/ Bb) | 4.00 | 10.00 | 6.33 | 1.97 | 3.89 | 6 |
| 2 | Split tuning (ex: Tuning woodwinds and brass separately, either with a single pitch or two different pitches) | 0.00 | 10.00 | 7.50 | 3.45 | 11.92 | 6 |
| 3 | Tuning woodwinds with a separate pitch from brass (ex: Concert A) | 0.00 | 10.00 | 6.83 | 3.67 | 13.47 | 6 |
| 4 | Tuning each individual with a tuner | 6.00 | 10.00 | 7.33 | 1.60 | 2.56 | 6 |
| 5 | Tuning with a drone | 4.00 | 10.00 | 7.60 | 2.94 | 8.64 | 5 |
| 6 | Tuning an ensemble down (to the tuba) | 5.00 | 10.00 | 7.83 | 1.57 | 2.47 | 6 |
| 7 | Tuning an ensemble up (to the oboe) | 1.00 | 9.00 | 4.50 | 3.20 | 10.25 | 4 |

**Table 3**: WTSBOA Intonation Responses

No notable conclusions can be drawn from the results, as all categories received a rating of 10 from at least one respondent and exhibit similar means.

The table below outlines the subcategories regarding intonation practices, as well as the responses provided for each category from collegiate directors.

| # | Field | Minimum | Maximum | Mean | Std Deviation | Variance | Count |
|---|---|---|---|---|---|---|---|
| 1 | Tuning the whole ensemble to a single pitch (ex: Concert F/ Bb) | 0.00 | 9.00 | 4.29 | 2.91 | 8.49 | 7 |
| 2 | Split tuning (ex: Tuning woodwinds and brass separately, either with a single pitch or two different pitches) | 0.00 | 10.00 | 6.83 | 3.53 | 12.47 | 6 |
| 3 | Tuning woodwinds with a separate pitch from brass (ex: Concert A) | 0.00 | 10.00 | 5.00 | 4.16 | 17.33 | 6 |
| 4 | Tuning each individual with a tuner | 0.00 | 8.00 | 2.00 | 2.89 | 8.33 | 6 |
| 5 | Tuning with a drone | 0.00 | 10.00 | 3.83 | 4.41 | 19.47 | 6 |
| 6 | Tuning an ensemble down (to the tuba) | 5.00 | 10.00 | 8.17 | 1.95 | 3.81 | 6 |
| 7 | Tuning an ensemble up (to the oboe) | 0.00 | 8.00 | 4.17 | 2.79 | 7.81 | 6 |

**Table 4**. Collegiate Intonation Responses

The collegiate responses demonstrate a much greater deviation of means. The highest indicated preference for tuning an ensemble down is consistent with practices outlined by the McBeth pyramid of sound. McBeth's pedagogy advocates for building and tuning an ensemble up from the low voices.

The results with the lowest mean included "Tuning each individual with a tuner" followed by "Tuning with a drone." The low average ratings for each of these pedagogical approaches align with an independent, learner-first mindset, as tuning with tuners and drones often detract from allowing students to develop the ability to discern their intonation tendencies with their own ears. "Tuning with a drone" was also the most heavily contested answer, with a mean of 6.83 and the widest standard deviation of 4.41. Responses ranged from rankings of 0 to 10 for this response.

### Balance and Blend

The next category directors were asked to rank pedagogical approaches for was balance and blend. This category aligns in part with the discussion of McBeth's pedagogical approaches and includes mention of the McBeth pyramid of sound. The pedagogical approaches in question, in addition to the responses they garnered from WTSBOA directors, can be seen in **Table 5**.

| # | Field | Minimum | Maximum | Mean | Std Deviation | Variance | Count |
|---|---|---|---|---|---|---|---|
| 1 | Adhereing to the MacBeth pyramid of sound to achieve my ideal ensemble balance | 4.00 | 10.00 | 7.50 | 2.60 | 6.75 | 4 |
| 2 | Having flexible seating based on player ability (ex: Placing the best players in the center of the ensemble instead of in chair order) | 1.00 | 7.00 | 5.00 | 2.35 | 5.50 | 4 |
| 3 | Recruiting with the aim to meet a number quota (ex: More woodwinds than brass, as many people as possible, etc) | 0.00 | 7.00 | 3.50 | 3.04 | 9.25 | 4 |
| 4 | Recruiting quality of students over quantity of students | 3.00 | 10.00 | 6.00 | 2.55 | 6.50 | 4 |
| 5 | Bringing down the upper voices to balance to the lower brass (ex: Having flutes play softer in order to achieve the desired ensemble balance) | 2.00 | 10.00 | 5.00 | 3.08 | 9.50 | 4 |
| 6 | Balancing to the melodic motif (ex: Bringing trombones down to allow a clarinet melody to be heard) | 7.00 | 10.00 | 8.00 | 1.22 | 1.50 | 4 |
| 7 | Balancing the lower sections to the needs of the higher sections (ex: Asking brass to player softer to allow for unforced tone production in woodwinds/ asking brass to play louder to ensure supported sounds in woodwinds without having to sacrifice tone for dynamics) | 3.00 | 7.00 | 5.50 | 1.66 | 2.75 | 4 |

**Table 5**. WTSBOA Balance and Blend Responses

The responses for this category garnered a wider spread of means than in the intonation category, with averages ranging from 3.5 to 8. The idea with the highest average was "Balancing to the melodic motif," with a mean of 8. This statement's low standard deviation of 1.22 further supports that the majority of WTSBOA directors ranked this an 8 in importance, or close to 8. This was closely followed by "Adhering to the McBeth pyramid of sound to achieve my ideal ensemble balance," which received a mean response of 7.50. While not the top response in this category, the high ranking of importance given to the McBeth pyramid of sound further demonstrates its impact and reach in ensembles, decades after it was introduced by Francis McBeth.

The most heavily contested pedagogical approach was "Bringing down the upper voices to balance to the lower brass" with a mean of 5 and the widest standard deviation of 3.08 Answers for this category ranged from rankings of 2 to 10. This is an interesting result, because while this statement supports what McBeth advocated for in his pyramid system, low rankings align with a learner-led approach. This further aligns with the pedagogical approaches outlined in the literature analysis, since the implementation of this approach may prove detrimental to upper woodwinds due to loss of tonal and intonation control due to playing at an unsupported soft dynamic to achieve the desired balance.

The table below now outlines the responses received by collegiate directors in this category.

| # | Field | Minimum | Maximum | Mean | Std Deviation | Variance | Count |
|---|---|---|---|---|---|---|---|
| 1 | Adhereing to the MacBeth pyramid of sound to achieve my ideal ensemble balance | 6.00 | 10.00 | 8.40 | 1.36 | 1.84 | 5 |
| 2 | Having flexible seating based on player ability (ex: Placing the best players in the center of the ensemble instead of in chair order) | 0.00 | 10.00 | 6.57 | 3.16 | 9.96 | 7 |
| 3 | Recruiting with the aim to meet a number quota (ex: More woodwinds than brass, as many people as possible, etc) | 0.00 | 9.00 | 3.50 | 3.35 | 11.25 | 6 |
| 4 | Recruiting quality of students over quantity of students | 1.00 | 10.00 | 6.83 | 3.53 | 12.47 | 6 |
| 5 | Bringing down the upper voices to balance to the lower brass (ex: Having flutes play softer in order to achieve the desired ensemble balance) | 3.00 | 9.00 | 7.33 | 2.21 | 4.89 | 6 |
| 6 | Balancing to the melodic motif (ex: Bringing trombones down to allow a clarinet melody to be heard) | 7.00 | 10.00 | 9.00 | 1.07 | 1.14 | 7 |
| 7 | Balancing the lower sections to the needs of the higher sections (ex: Asking brass to player softer to allow for unforced tone production in woodwinds/ asking brass to play louder to ensure supported sounds in woodwinds without having to sacrifice tone for dynamics) | 4.00 | 10.00 | 7.71 | 1.98 | 3.92 | 7 |

**Table 6**: Collegiate Balance and Blend Responses

The results seen in the WTSBOA responses were reflected in the collegiate responses, with "Balancing to the melodic motif" once again displaying the highest mean and the lowest standard deviation. Similarly to the "Intonation Practices" category, both groups of directors were in agreement for what sub-category held the most importance to them. This specific sub-category demonstrates a deviation from the pedagogy outlined by Francis McBeth in his pyramid of sound, as McBeth identified balance achieved through specific instruments rather than musical phrases or motifs.

### Music Literature

The final category directors were asked to provide rankings pertains to musical literature selection and performance within their ensembles. This category was intended to correspond in part with the discussion of band repertoire and the applications of learner-centered pedagogy when approaching literature with an ensemble. The sub-categories, as well as the responses they received from WTSBOA directors, can be seen in **Table 7**.

| # | Field | Minimum | Maximum | Mean | Std Deviation | Variance | Count |
|---|---|---|---|---|---|---|---|
| 1 | I select my band literature slightly above the needs of my ensemble as a whole | 7.00 | 10.00 | 8.25 | 1.09 | 1.19 | 4 |
| 2 | I select my band literature to expose my ensemble to different styles of music | 7.00 | 10.00 | 9.25 | 1.30 | 1.69 | 4 |
| 3 | I select my band literature to challenge specific individuals in my ensemble and help them grow | 3.00 | 9.00 | 6.00 | 2.12 | 4.50 | 4 |
| 4 | I select my band literature to fit my ensemble to ensure a good sound at all costs | 5.00 | 10.00 | 7.00 | 2.12 | 4.50 | 4 |
| 5 | I select my band literature according to state concert festival rubrics | 0.00 | 3.00 | 1.50 | 1.12 | 1.25 | 4 |
| 6 | I select my band literature based on the interests of the students in my ensemble | 4.00 | 9.00 | 6.50 | 1.80 | 3.25 | 4 |
| 7 | I select my band literature to showcase strong individual players (ex: Selecting a particular piece with an extensive trumpet solo to showcase an All-State trumpet player) | 2.00 | 7.00 | 4.75 | 1.79 | 3.19 | 4 |

**Table 7**: WTSBOA Music Literature Responses

These responses displayed the widest spread of means of any category, with means ranging from 1.50 to 9.25. This demonstrates the greatest explicit ranking of any category, as it displays a clear numeric importance.

The category with the highest mean (9.25) and a standard deviation of 1.30 was "I select my band literature to expose my ensemble to different styles of music." Despite this subcategory receiving the highest mean, it did not receive the lowest standard deviation. The lowest standard deviation (1.09) belonged to the category with the second highest mean (8.25): "I select my band literature slightly above the needs of my ensemble as a whole." Both of these responses indicate pedagogic preference for student-focused approaches to band literature. Selecting music with the intention of exposing students to different styles of music, as well as selecting music to challenge the students within the ensemble, can benefit the individual performers. The most heavily contested answer was "I select my band literature to challenge specific individuals in my ensemble and help them grow" with a mean of 6 and the widest standard deviation of 2.12. Answers ranged from rankings of 3 to 9 in this category. It should be noted that this is less contested than other areas of mixed responses seen in other categories.

Similarly to the WTSBOA results, the collegiate responses demonstrated some of the most clearly defined rankings, with means ranging from 2.25 to 8.5, as seen in **Table 8**.

| # | Field | Minimum | Maximum | Mean | Std Deviation | Variance | Count |
|---|---|---|---|---|---|---|---|
| 1 | I select my band literature slightly above the needs of my ensemble as a whole | 5.00 | 9.00 | 7.60 | 1.74 | 3.04 | 5 |
| 2 | I select my band literature to expose my ensemble to different styles of music | 5.00 | 10.00 | 8.50 | 1.71 | 2.92 | 6 |
| 3 | I select my band literature to challenge specific individuals in my ensemble and help them grow | 1.00 | 8.00 | 5.60 | 2.58 | 6.64 | 5 |
| 4 | I select my band literature to fit my ensemble to ensure a good sound at all costs | 1.00 | 10.00 | 6.20 | 2.99 | 8.96 | 5 |
| 5 | I select my band literature according to state concert festival rubrics | 0.00 | 7.00 | 2.25 | 2.77 | 7.69 | 4 |
| 6 | I select my band literature based on the interests of the students in my ensemble | 0.00 | 7.00 | 4.00 | 2.31 | 5.33 | 6 |
| 7 | I select my band literature to showcase strong individual players (ex: Selecting a particular piece with an extensive trumpet solo to showcase an All-State trumpet player) | 0.00 | 8.00 | 4.20 | 3.19 | 10.16 | 5 |

**Table 8**. Collegiate Music Literature Responses

The highest mean belonged to the same category as seen in the WTSBOA results: "I select my band literature to expose my ensemble to different styles of music."

Once again, the director responses to this category at both levels are congruent with a learner-first approach. The highest ranked responses reflect the importance of student impact when choosing and performing music literature, over responses which reflect ensemble performance goals, such as "I select my band literature according to state concert festival rubrics," which received the lowest ranking for both groups.

### Notable Pedagogic Responses

In addition to being asked to rank pedagogical approaches, directors were also invited to discuss or mention practices they consider unique or alternative in their rehearsals. This question was optional, but resulted in some notable responses, especially from the collegiate level. One WTSBOA director wrote, "We discuss why the pyramid of sound works through looking at the human hearing range, the strongest part of that range, and where the instruments fall within that range. It is what causes the pyramid of sound to work properly." Along with the importance the pyramid received through director rankings, this written statement further indicates the continued relevance of McBeth and his pyramid of sound in the modern band classroom. The continued relevance of this pedagogy further emphasizes

the need for a student-first approach to continue to provide the greatest level of benefit to the students.

A collegiate director wrote, “In marching band rehearsals, I implement some techniques that are tied back to Breathing Gym exercises. For example, playing a phrase on one (usually low in the register) note to encourage more air flow and rehearse elements like sustain or dynamics.” The use of Breathing Gym exercises, which encourage air support and control, directly benefit the performer, which in turn impacts the ensemble as a whole. Improved air support leads to improved tone and intonation on an individual level, as well as dynamic control as indicated by the writer of the response. This improvement made by individual students can then lead to improved ensemble achievement.

#### Survey Conclusions

While it is difficult to quantify subjective pedagogical beliefs, certain pedagogy saw similar responses between both the collegiate and WTSBOA respondents. The continued relevance of the McBeth pyramid of sound in music education was evident through both director rankings and individual written responses. Many responses demonstrated the application of learner-first approaches to pedagogy at both the high school and the collegiate level. The participants for these surveys are practicing directors, many of whom have multiple degrees and decades of experience to support their pedagogical claims and practices.

## Conclusion

This vein of research centered in exploring established high school band pedagogical approaches and their benefits and detriments to individual performers. The history of bands in American schools displayed a shift from a teacher-centered approach to pedagogy towards a learner-centered approach during the late 20th century and into the 21st century. Music education should be an adaptive model. Despite numerous pedagogical developments in recent years, modern music education often still adheres to pedagogy developed in the 1960s or earlier. This does not negate the work of the band pedagogues who provided the foundations for music education during this time, nor does it imply that the pedagogy is ineffective. It is merely a marker of antiquation in an era where there are more effective and pertinent ways that music educators can reach and impact the individuals in their ensembles.

Pedagogical methodologies, such as Social Emotional Learning (SEL), substantiate the use of a more learner-centered approach and its benefits in the classroom. Established sources of literature support this transition from a teacher-led approach to a student-led approach in the music classroom. Benefits of this approach include developing more independent and self-sufficient student musicians who are able to demonstrate self-supported musical decision making in their playing.

Despite this shift in pedagogical methodology through the years, established band pedagogy should not be discarded due to changing pedagogical beliefs and views, rather, adjusting one's pedagogical approach to fit the individual needs of those within the ensemble rather than focusing solely on overall ensemble sound and achievement can provide a greater benefit to individual students. Implementation of approaches such as learner-centered models demonstrate increased individual achievement which, according to established band pedagogues such as David Elliott, leads to increased ensemble achievement. Surveyed directors at both the high school and collegiate levels provided pedagogical responses that further align with this pedagogical shift and a more individual-centric approach to pedagogy.

Pedagogy which directly impacts the individual further benefits students from underprivileged backgrounds as well, as many of these students rely solely on the band classroom to receive any form of music education and to further their musical skills. A pedagogical mindset shift is needed due to a change in the social-learning environment of classrooms across the country and a greater advocacy for individual benefits in the classroom, in addition to the shifting needs of teachers and students alike, especially in the lingering wake of the pandemic.

## References


Baugher, Grace E. "Finding the Sun: An exploration of the band grading system through an original work in three levels for concert band. " Master's Thesis, University of Tennessee, Knoxville, 2019. https://trace.tennessee.edu/utk_gradthes/6064.

Brown, Julie K. "Student-Centered Instruction: Involving Students in their Own Education." *Music Educators Journal* (May 2008): 30–35. https://www.jstor.org/stable/20685476.

Bruns, Robert. "Incorporating Wind Excerpts in the School Band Curriculum." *Music Educators Journal* 96, no. 4 (2010): 43–47. http://www.jstor.org/stable/40666428.

Criswell, Chad. "Brass and Woodwinds: Intonation and the Brass Section." *Teaching Music* 16, no. 1 (2008): 65.

Criswell, Chad. "Brass and Woodwinds: Tuning the Woodwind Section." *Teaching Music* 16, no. 2 (2008): 56–57.

Elliott, David J. *Music Matters: A New Philosophy of Music Education*. Oxford: Oxford University Press, 1995. 241–295.

Everett, Micah. "The Limitations of the Pyramid of Sound." *The Reforming Trombonist,* December 2, 2021. https://thereformingtrombonist.com/2021/12/02/the-limitations-of-the-pyramid-of-sound/.

Fritts, Clarence Nelson Jr. *The historic development of the concept of comprehensive musicianship in school bands*. DMA diss., The Catholic University of America, Washington, D.C., 1991. ProQuest Dissertations & Theses Global.

Gillis, Glen. "The Band Director's Multiple Roles." *Canadian Music Educator* 52, no. 4 (Summer 2011): 35–7, https://www.proquest.com/scholarly-journals/band-directors-multiple-roles/docview/881979663/se-2.

Goolsby, Thomas W. "Assessment in Instrumental Music." *Music Educators Journal* 86, no. 2 (September 1999): 31–50. https://doi.org/10.2307/3399587.

Heidel, Richard Mark. "Sound Advice." *NFHS Music Association Journal*, Vol 30, No. 1 (2013-2014).

Hepner, Jeremy. “Meeting Literacy Goals with a Learner Centered Band.” *Musicien Éducateur au Canada* 51, no. 3, (2010): 39–43.

Hiestand, Daniel Shelley, Jr. “An Evaluation of Recommended Literature for the High School Band.” Order No. EP62034, University of Southern California, 1958. In PROQUESTMS ProQuest Dissertations & Theses Global, https://www.proquest.com/dissertations-theses/evaluation-recommended-literature-high-school/docview/1652525239/se-2.

Koster, Keith. “Revisiting Teaching Strategies for Woodwinds.” *Music Educators Journal* 96, no. 3 (March 2010): 44–52. https://www.jstor.org/stable/20685502.

McBeth, William Francis. *Effective Performance of Band Music*. San Antonio: Southern Music Co, 1972.

McNeil, Brady Glenn. “Aural Skills Pedagogy in the Wind Band: A Survey of Secondary and Collegiate Wind Band Conductors’ Perceptions and Strategies.” Order No. 30272862, Auburn University, 2021. https://www.proquest.com/dissertations-theses/aural-skills-pedagogy-wind-band-survey-secondary/docview/2800162206/se-2. ProQuest Dissertations & Theses Global.

Morrison, Andrew E. “Social Emotional Learning and the Future of Music Education.” *School Band and Orchestra Magazine*, June 12, 2021. https://sbomagazine.com/social-emotional-learning-and-the-future-of-music-education/.

National Arts Education. “National Arts Education Status Report.” Accessed June 2023. https://artseddata.org/national_report_2019/.

Normann, Theodore F. *Instrumental music in the public schools*. Bryn Mawr, PA: Oliver Ditson Co., 1939.

Robinson, Mitchell. “To Sing or Not to Sing in Instrumental Class.” *Music Educators Journal* 83, no. 1 (1996): 17–47. https://doi.org/10.2307/3398989.

Rush, Scott. *Habits of a Successful Band Director: Pitfalls and Solutions*. (Fort Wayne, IN: Focus of Excellence, 2003).

Saucedo, Richard. *Into the Clouds!* Milwaukee, WI: Hal Leonard Corporation, 2007.

Stalter, Todd. "Using Chorales to Teach Intonation, Articulation, and Phrasing." *School Band and Orchestra*, (April 2018). https://sbomagazine.com/commentary-using-chorales-to-teach-intonation-articulation-and-phrasing/.

Stolper, Mary. "Practice Tips for the Piccolo." In *The Flutist's Handbook: A Pedagogy Anthology* (1998):153–160. Chicago: National Flute Association.

Tennessee Bandmasters Association. "TBA Tennessee State Music List." Accessed August 2, 2023. https://tennesseebandmasters.org/concert-band/.

Thornton, Linda C. "The Effect of Grade, Experience, and Listening Condition on the Melodic Error Detection of Fifth- and Sixth-Grade Woodwind Students." *Update: Applications of Research in Music Education* 26, no. 2 (2008): 4–10. https://doi.org/10.1177/8755123308317612.

Wolbers, Mark. "Singing in the Band Rehearsal." *Music Educators Journal* 89, no. 2 (2002): 37–41. https://doi.org/10.2307/3399840.

Worthy, Michael D. "Effects of Tone-Quality Conditions on Perception and Performance of Pitch among Selected Wind Instrumentalists." *Journal of Research in Music Education* 48, no. 3 (2000): 222–36. https://doi.org/10.2307/3345395.

Wuttke, Brian C. "A model describing the effects of equipment, instruction and director and student attributes on wind-band intonation." Order No. 3456375, University of Miami, 2011. https://www.proquest.com/dissertations-theses/model-describing-effects-equipment-instruction/docview/871631429/se-2. ProQuest Dissertations & Theses Global.

Hailey Miller, a recent graduate of the University of Memphis with majors in Biomedical Engineering and Mathematics and minors in Biology and Chemistry, is deeply passionate about cancer research. Raised in Arlington, TN, her interest was sparked during her undergraduate years, leading her to pursue a career in cancer research at St. Jude Children's Research Hospital. Dr. Xiaohua Huang and Alberto Rodriguez played pivotal roles in her academic journey, providing invaluable mentorship and opportunities for research in Dr. Huang's lab. Hailey's achievements include being recognized as an undergraduate research scholar, undergraduate Honors with Thesis, and publishing twice as an author, notably for her work on nanoparticle breast cancer research. Looking forward, Hailey plans to pursue an M.D. and Ph.D. in Cancer Biology, specializing in Pediatric Oncology, to continue her work at St. Jude and advocate for childhood cancer research. Submitting her work to *QuaesitUM*, Hailey aims to inspire local students to pursue research careers. Her paper, "Analysis and Comparison of Hybrid Gold-Based Nanoparticles and Their Potential Use in Optical Spectroscopy and Cancer Nanomedicine," pushes boundaries in cancer treatment, offering a comprehensive perspective on the importance of nanomedicine in battling breast cancer and beyond.

**Hailey Miller & Alberto Rodriguez**

Analysis and Comparison of Hybrid Gold-Based Nanoparticles and Their Potential Use in Optical Spectroscopy and Cancer Nanomedicine

**Faculty Sponsor**

Dr. Xiaohua Huang

## Abstract

Breast cancer, a global health concern, demands innovative solutions. Nanoparticles, with dimensions between 10-100 nm, present a promising avenue for breast cancer diagnosis and treatment. This study focuses on synthesizing and characterizing anisotropic nanoparticles, such as nano popcorns and nanostars, to optimize their potential in enhancing breast cancer detection sensitivity. Rigorous testing, including size measurement and stability assessment, aims to identify optimal nanoparticles for further development. Gold nanoparticles, particularly nanopopcorns and nanostars, exhibit distinct shapes with unique biomedical properties. Finite-Difference Time-Domain simulations aid in understanding their plasmonic properties, crucial for optimizing their performance. Despite promising results, challenges in clinical translation and the need for detailed safety and effectiveness studies underscore the complexity of implementing these nanoparticles in breast cancer therapeutics. Sustained multidisciplinary efforts and advancements in nanotechnology are essential for overcoming hurdles and realizing the transformative impact of nanoparticles in personalized breast cancer management.

## Introduction

Breast cancer is a major public health issue worldwide, affecting millions of women worldwide, accounting for 25% of all cancer cases in women. In the United States alone, it is estimated that over 280,000 women will be diagnosed with breast cancer each year, with over 40,000 deaths [6]. Despite significant advances in breast cancer research, the high mortality rate associated with this disease remains a major challenge. One promising approach for breast cancer diagnosis and treatment involves the use of nanoparticles [5, 2, 11]. Nanoparticles are materials that have dimensions on a nanometer scale, typically between 10-100 nm. These particles have unique properties due to their small sizes, such as increased surface area and reactivity. Additionally, they can be engineered to have specific properties that make them ideal for biomedical applications [2, 7, 12]. They can be functionalized with ligands or antibodies that specifically target cancer cells, allowing for targeted delivery of therapeutic agents or contrast agents for imaging. In addition, nanoparticles can be engineered to have unique optical, magnetic, or thermal properties, making them ideal for various diagnostic and therapeutic applications [3, 1].

One of the key advantages of using nanoparticles in breast cancer diagnosis and treatment is their ability to enhance imaging techniques. Nanoparticles can be designed to serve as contrast agents for imaging modalities such as magnetic resonance imaging (MRI), computed tomography (CT), and ultrasound. These contrast-enhanced imaging techniques offer improved sensitivity and specificity, allowing for the early detection and accurate localization of breast tumors. In the realm of breast cancer treatment, nanoparticles hold great promise for targeted drug delivery. Conventional cancer treatments, such as chemotherapy, often lack specificity, causing damage to healthy tissues along with cancerous ones. Nanoparticles can be tailored to selectively accumulate in tumor tissues, owing to their surface modifications with ligands or antibodies that recognize and bind to specific receptors overexpressed on cancer cells. This targeted drug delivery approach minimizes side effects and enhances the therapeutic efficacy of anticancer agents.

Moreover, the unique physical properties of nanoparticles open up avenues for innovative therapeutic strategies. Some nanoparticles exhibit hyperthermic effects when exposed to certain frequencies of light or magnetic fields, making them suitable for hyperthermia-based cancer treatment. This involves selectively heating the cancer cells, inducing apoptosis or cell death while sparing healthy surrounding tissue. The field

of nanomedicine is also exploring the potential of nanoparticles in monitoring and predicting the response to treatment. By incorporating imaging probes or sensors into nanoparticles, clinicians can track the distribution of therapeutic agents in real-time and assess treatment efficacy. This personalized medicine approach allows for adjustments in treatment plans based on individual patient responses. Despite the considerable promise, challenges remain in the clinical translation of nanoparticle-based approaches. Issues such as biocompatibility, long-term safety, and scalability need to be addressed before widespread clinical adoption. Nevertheless, ongoing research and clinical trials are progressively advancing our understanding of nanoparticle applications in breast cancer, bringing us closer to more effective and targeted diagnostic and therapeutic strategies.

The various nanoparticles synthesized have unique optical and electronic properties that can be tuned by varying their size, shape, and composition. In this study, we focused on the synthesis and characterization of anisotropic nanoparticles—with irregular shapes, which often exhibit distinctive optical and electronic characteristics. Various testing was conducted to determine the synthesized particles' size, shape, and stability. The ultimate goal of this study is to optimize the usage of nanoparticles to increase detection sensitivity. By comparing and optimizing the properties of different nanoparticles, we can identify the most promising candidates for further development and functionalization. It is important to recognize that the size, shape, and composition of nanoparticles play pivotal roles in influencing their behavior and interactions with biological systems.

Our experimental approach involved a series of rigorous tests aimed at comprehensively understanding the key attributes of the synthesized anisotropic nanoparticles. Precise measurements were conducted to determine their size, ensuring accuracy in nanometer dimensions. Shape analysis was undertaken to determine the distinct geometries these nanoparticles adopted. Additionally, the stability of these nanoparticles under various conditions was thoroughly assessed, as stability is a critical factor influencing their performance in biological applications. The overarching objective of our study is to contribute to the optimization of nanoparticle utilization, specifically targeting enhanced detection sensitivity in the context of breast cancer diagnosis. Through systematic comparison and optimization of these properties, we aim to identify the most optimal nanoparticles for further development and functionalization.

By scrutinizing and fine-tuning the characteristics of anisotropic nanoparticles, we strive to unlock their full potential for biomedical ap-

plications, particularly in the early detection of breast cancer. The optimization process involves a meticulous examination of how variations in size and shape impact the nanoparticles' interaction with cancer cells. This nuanced understanding allows us to tailor these nanoparticles to exhibit optimal properties for increased detection sensitivity. Furthermore, the outcomes of our study hold the potential to pave the way for the development of advanced diagnostic tools and targeted therapies. Identifying and optimizing the properties of nanoparticles with superior detection capabilities will contribute significantly to the ongoing efforts to improve the precision and effectiveness of breast cancer diagnosis and treatment.

Gold nanoparticles exhibit distinct shapes, and two intriguing morphologies, namely nano popcorns and nano stars, have gained interest for their enhanced properties in biomedical applications. Nanospheres (NSP) and nanorods (NR) are two distinct forms of nanoparticles with unique characteristics that make them valuable in various scientific and technological applications [12]. Nanospheres are spherical nanoparticles with a uniform structure, and their properties can be precisely controlled by adjusting parameters such as size and composition. Due to their symmetry and predictable behaviors, nanospheres are often employed in drug delivery systems, imaging agents, and as components in sensor technologies. Their regular shape allows for consistent interactions with biological entities and controlled release of therapeutic agents. Nanorods are elongated nanoparticles with a rod-like structure, offering different optical and electronic properties compared to nanospheres [8, 9]. The aspect ratio, or the ratio of length to width, can be fine-tuned to achieve specific characteristics. Nanorods exhibit unique plasmonic properties, making them particularly useful in applications like Surface-Enhanced Raman Spectroscopy (SERS), where their shape enhances the electromagnetic field around them. This property is exploited in various sensing and imaging applications, as well as in the development of photothermal therapy for cancer treatment, where nanorods can efficiently convert light into heat to selectively destroy cancer cells.

Nanopopcorn (NPCs) possesses a unique structure resembling popcorn, with irregular shapes and high surface roughness. This irregularity in shape contributes to their distinctive optical properties, making them valuable for certain biomedical applications. The irregular surface morphology of NPCs enhances their surface area, providing more sites for functionalization and interaction with biological entities[8, 10, 11, 13] . This unique structure can be advantageous for targeted drug delivery, as well as for improving the sensitivity of diagnostic imaging techniques. On the other hand,

nanostars (NSTs) exhibit sharp branches extending from a central core, providing an increased surface area compared to spherical nanoparticles. The enhanced surface area of nanostars is particularly beneficial for applications involving SERS and LSPR. These properties make nanostars attractive for use in biosensing, imaging, and therapeutic applications [7,8,10] .

Hollow nanoparticles, also known as nanocarriers or nanoshells, are a specialized class of nanoparticles characterized by their unique hollow interior structure. Unlike solid nanoparticles, hollow nanoparticles possess voids or cavities within their structures, creating a shell-like morphology. This hollowness can be advantageous in various applications, particularly in drug delivery and imaging. The central void provides an enclosed space that can be utilized to encapsulate therapeutic agents, such as drugs or imaging contrast agents. This encapsulation serves to protect the payload from degradation, enhance its stability, and control its release kinetics. The hollow structure also allows for the incorporation of multiple functionalities, such as targeting ligands or stimuli-responsive elements, further optimizing their performance for targeted drug delivery. Additionally, the hollow interior can serve as a reservoir for drugs and therapies, making these nanoparticles versatile tools in fields ranging from medicine to catalysis. The tunable properties of hollow nanoparticles, such as size, shape, and surface modifications, make them promising candidates for advancing nanotechnology applications with tailored and multifunctional capabilities [1, 2, 11] .

To gain a deeper understanding of the optical characteristics and behavior of gold nanopopcorns and nanostars at the nanoscale, researchers employ advanced computational techniques such as Finite-Difference Time-Domain (FDTD) simulations. Additionally, FDTD computational analysis allows us to model the interaction of light with complex nanostructures, providing valuable insights into their plasmonic properties. In the context of gold nanopopcorns and nanostars, FDTD simulations enable the investigation of their plasmonic properties, scattering and absorption spectra, and electromagnetic field enhancements that occur around these structures [4].

By leveraging FDTD simulations, researchers can predict and understand how these gold nanoparticles interact with light of different wavelengths. This knowledge is crucial for optimizing their performance in various biomedical applications, including imaging and therapy. FDTD simulations enable the fine-tuning of these nanoparticles' optical properties, allowing researchers to design particles with enhanced light-scattering

characteristics or improved absorption in specific wavelength ranges. The distinctive shapes of gold nanoparticles offer unique advantages for biomedical applications. The combination of experimental characterization and computational modeling, especially through techniques like FDTD simulations, allows researchers to unravel the intricate optical properties of these nanostructures, paving the way for their tailored use in advanced diagnostics and therapeutic interventions.

## Methods

### Synthesis and Characterization of Gold Nanopopcorns and Nanostars

The nanoparticles were synthesized using established methods in literature. Briefly, a seed solution containing 1% of Chloroauric acid ($HAuCl_4$) was mixed with an aqueous solution of Sodium Citrate (38.8 mM), which served as the capping and stabilizing agent. Afterwards, 20mM of Sodium Borohydride ($NaBH_4$) was added to the solution dropwise and used as a strong reducing agent to reduce the gold precursor ($HAuCl_4$) from a 3+ charge to a 0, thus initiating a nucleation process between the gold atoms which in terms generate gold seeds with an average size of 5 nm. The solution turned from colorless to red indicating the formation of gold seeds.

After the seed solution preparation, a growth solution containing 200 µL of 10 mM HAuCl4 was prepared and mixed with 5mL of 0.1M CTAB (Hexadecyl trimethyl ammonium bromide), 30 µL of AgNO3 10mM was then injected into the solution and mixed for 5 minutes. It is known that $AgNO_3$ can act as a shape-directing agent by adsorbing onto specific crystal facets of the gold nanostructures during their growth. This preferential adsorption of silver ions on certain facets guides the anisotropic growth of gold, leading to the formation of popcorn with irregular shapes or nano stars with sharp branches. Afterwards, 100mM of ascorbic acid (AA) was used as a weak reducing agent substituting $NaBH_4$ in order to avoid over reduction of the gold precursor. By simply adjusting the ascorbic acid concentration, one can obtain a star (32 µL) or popcorn (90 µL) shape NP. Finally, 350 µL of the previously prepared seeds were injected into the growth solution, acting as catalyst for the creation of the anisotropic NPs (**Figure 2**).

UV-VIS spectrometer (Thermo Fisher, Madison, WI) was used to measure the absorbance spectra of the nanoparticles, which provided information on their plasmonic properties. The concentration and size of the particles was determined through nanoparticle tracking analysis (NTA) utilizing a NanoSight LM10 microscope (Malvern Instruments).

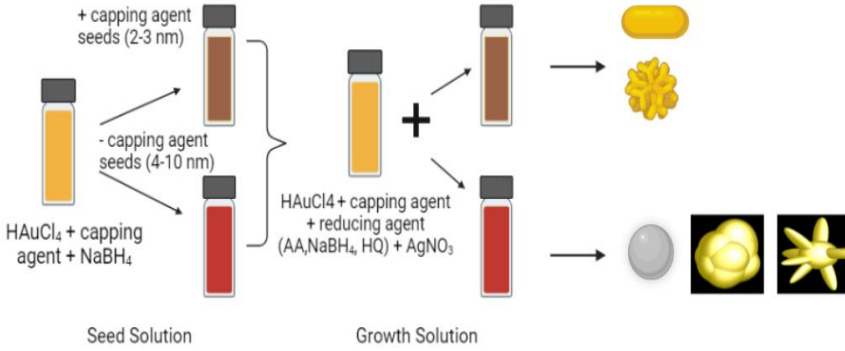



**Figure 1.** Overview of Turkevich seed mediated synthesis of anisotropic gold-based nanoparticles yielding different shapes based on the influence of the capping agent present and seed size.

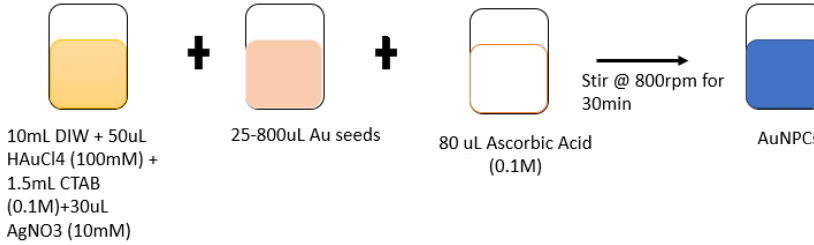



**Figure 2.** Synthesis of Au NanoPopcorns using the Turkevich seed mediated synthesis

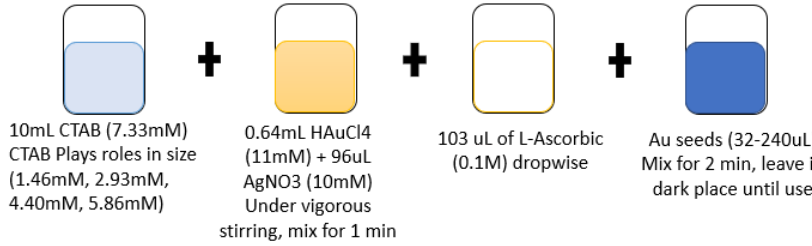



**Figure 3.** Synthesis of Au NanoStars using the Turkevich seed mediated synthesis.

**Synthesis of Hollow Nanoparticles using Galvanic Replacement**

In the synthesis of hollow nanoparticles using the galvanic replacement method, the following detailed steps were undertaken to achieve controlled and efficient formation of the desired hollow structures. First, a sacrificial template of silver nanoparticles was prepared through the reduction of a silver salt, typically silver nitrate, in the presence of a stabilizing agent, such as polyvinylpyrrolidone (PVP). The resulting silver nanoparticles were then washed thoroughly to remove excess reagents and unreacted species. Subsequently, a solution containing the precursor material for the desired shell, often gold chloride ($HauCL_4$), was prepared in a suitable solvent, such as water or ethanol. The concentration of the gold precursor in the solution was carefully optimized to ensure controlled deposition onto the silver nanoparticles during the galvanic replacement reaction. Typically, concentrations ranging from 1 mM to 10 mM were employed, with the specific concentration tailored to achieve the desired shell thickness and morphology.

The silver nanoparticles, acting as sacrificial templates, were immersed in the gold precursor solution under controlled reaction conditions. The galvanic replacement reaction between the silver core and gold precursor took place, leading to the gradual deposition of gold onto the surface of the silver nanoparticles. The silver core was concurrently dissolved into the solution. This process resulted in the creation of hollow gold nanoparticles, where the initial silver template was replaced by the deposited gold shell. To precisely control the reaction kinetics and achieve uniform hollow structures, the temperature and reaction time were rigorously optimized. Commonly, the reaction was carried out at elevated temperatures, often around 60-80°C, for a defined period, typically ranging from 1 to 4 hours. The reaction progress was monitored using techniques such as UV-Vis spectroscopy to observe the characteristic plasmon resonance shift associated with the formation of hollow structures.

After the completion of the galvanic replacement reaction, the hollow nanoparticles were separated from the reaction mixture through centrifugation and thoroughly washed to remove any residual reagents. The resulting hollow nanoparticles were characterized using various analytical techniques, including transmission electron microscopy (TEM) and dynamic light scattering (DLS), to confirm their morphology, size distribution, and structural integrity. By systematically adjusting the concentrations, reaction conditions, and parameters of the galvanic replacement process, this synthesis method enabled the controlled and reproducible fabrication

of hollow nanoparticles with tailored properties. The optimized hollow nanoparticles hold significant promise for applications in catalysis, sensing, and biomedical fields.

#### Synthesis of Gold Core-Silver Shell Nanoparticles

The synthesis of the gold core-silver shell nanospheres involved a seed-mediated growth method, where gold nanospheres (Au NSP) were used as a seed to grow a silver shell around them. The silver shell was grown by adding a silver precursor (silver nitrate) (10 mM) to the 50nm gold nanospheres previously bought from BBI Solutions, along with a reducing agent (ascorbic acid) 100 mM and stabilizing agent (CTAC) 0.2M. The reaction was carried out under close containment of the growth solution due to the nature of the silver to oxidize when it interacts with oxygen. The growth process was initiated and allowed to proceed for 2 hours, during which the silver shell gradually formed around the gold core. This growth was visually monitored, and the distinctive change in color from red to orange indicated the successful deposition of the silver shell onto the gold nanospheres. The rapid alteration in color served as a real-time indicator of the nanomaterial synthesis.

The size of the nanoparticles could be controlled by varying the amount of silver precursor added to the reaction mixture, changing the size of the seeds or the number of seeds injected into the growth solution. This tunability is essential for tailoring the optical and physical properties of the nanospheres to meet specific requirements in applications such as catalysis, sensing, or imaging. Post-synthesis, the gold core-silver shell nanospheres were separated from the reaction mixture, typically through centrifugation, and thoroughly washed to remove any residual reagents. Characterization techniques such as UV-Vis spectroscopy and dynamic light scattering (DLS) were employed to assess the size distribution, morphology, and stability of the synthesized nanospheres.

#### Finite-Difference Time-Domain Modeling

The Ansys Lumerical software was used to conduct different Finite-Difference Time-Domain (FDTD) modeling of the near field of the Au NPCs and NSTs to observe the optical properties. Firstly, an FDTD domain was established with a conformal variant mesh with a size range of 0.25-3 nm generating 100 mesh on different regions of the FDTD model. Generating a large amount of mesh per region increases the accuracy of the test. This is due to the concept of the conformal mesh, which uses an integral solution of Maxwell's equations near interfaces. Following the mesh re-

finement, a scattering cross-section test was introduced near the inner limit region of the FDTD. Additionally, a Frequency-domain Profile and Power monitor was introduced to visualize the electric field enhancement at different wavelengths ranging from 400 to 800 nm. We added a Total-Field Scattered-Field (TFSF) source, which measures scattering and absorbance in plasmonic materials. The TFSF source leads to a separation of the entire simulation region into two parts, the total field region containing both the incident and the scattered fields and the scattered field region containing only the scattered field. The frequency of the test was equivalent to 499 data points which ensures an accurate and clean plot. The electric field patterns in the near field of the nanostructures were evaluated using a Frequency-domain Profile and Power monitor. A perfectly matched layer (PML) was used to block any reflection of the scatter field from going back into the simulation area.

The simulations were conducted for a period of 1000 fs. All the simulations were performed with a background refractive index of 1.33. Lastly, an absorbance cross-section was inserted near the particle analyzed. The dielectric response of gold was taken from Johnson and Christy.[14] This rigorous simulation approach allows for a detailed exploration of the optical characteristics of gold nanoparticles.

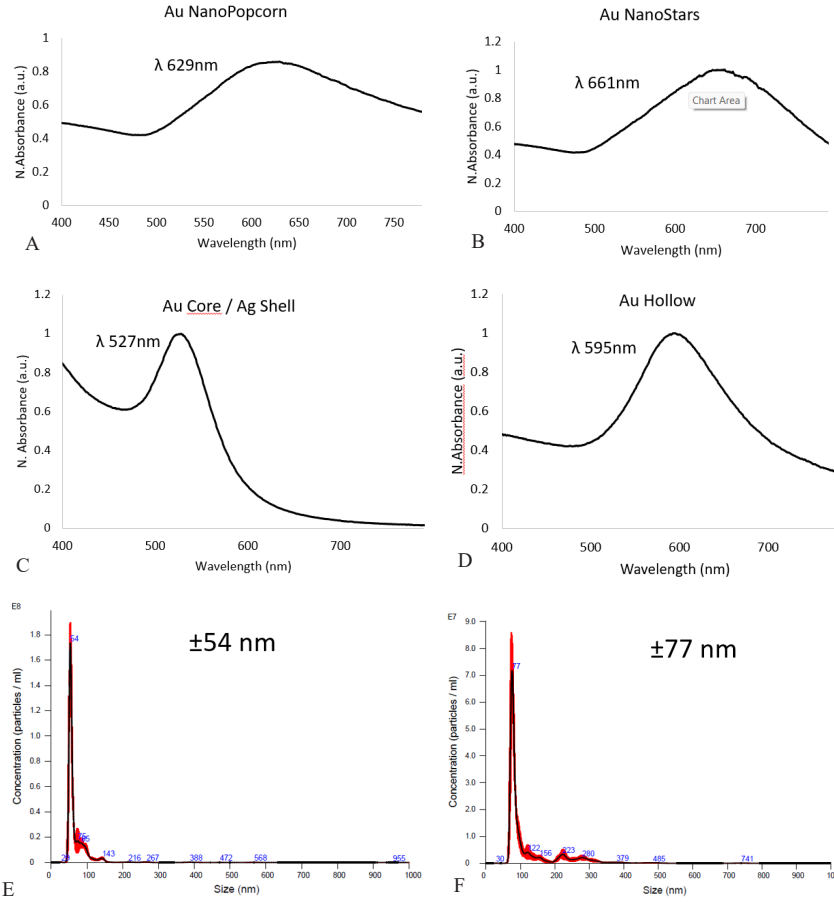
## Results and Discussion

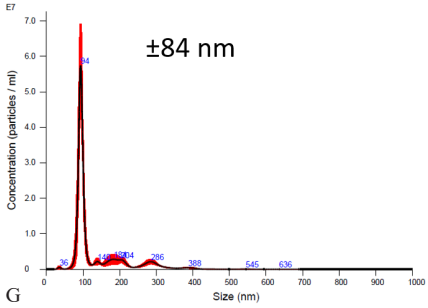
In the course of this study, we achieved the successful synthesis of a diverse array of nanoparticles, deliberately varying their shapes to explore the impact of morphology on their properties. The synthesized nanoparticles underwent a comprehensive characterization process utilizing a range of analytical techniques. UV-Vis spectroscopy provided valuable insights into the optical properties of the nanoparticles, offering information about their absorption and scattering behavior. NTA was employed to precisely determine the size distribution and concentration of the synthesized particles, contributing crucial information about their colloidal stability and uniformity.

Going beyond experimental measurements, FDTD modeling was employed to delve deeper into the electrodynamic behavior of the nanoparticles. This computational approach allowed for a meticulous analysis of the interaction between light and the nanoparticles, providing a detailed understanding of their plasmonic properties and how they respond to different wavelengths. The FDTD simulations were specifically conducted

on a selected nanoparticle size, enabling a focused exploration of the size-dependent optical features and ensuring a nuanced comprehension of the nanoparticles' behavior at the nanoscale.

The integration of multiple characterization techniques offered a multi-faceted examination of the synthesized nanoparticles. This holistic approach not only validated the successful synthesis of nanoparticles with varied shapes but also enriched our understanding of their optical and dynamic characteristics. The synergy between experimental and computational analyses is instrumental in describing the intricate relationships between nanoparticle morphology and functionality, fostering advancements in fields such as nanomedicine, sensing, and catalysis.




E7
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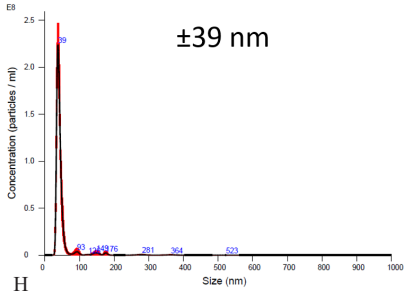
Concentration (particles / ml)
Size (nm)

G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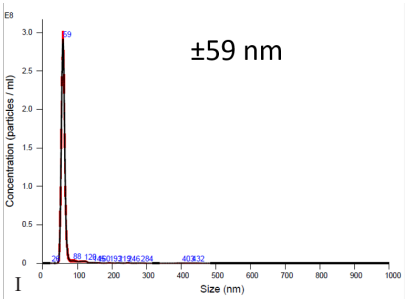
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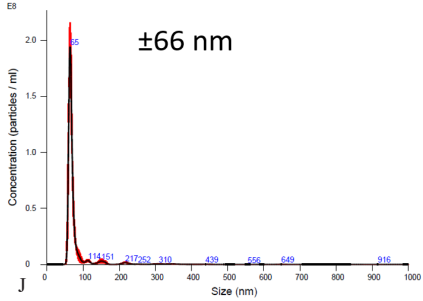
I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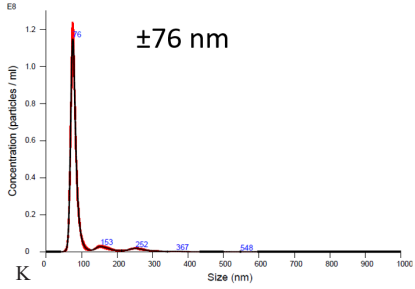
J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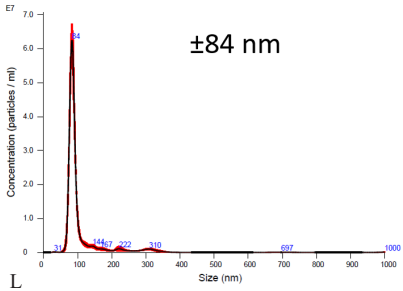
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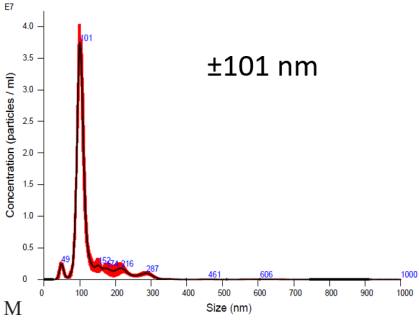
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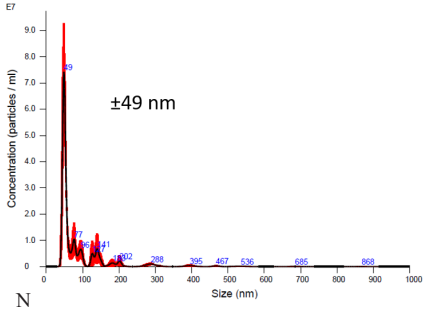
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N

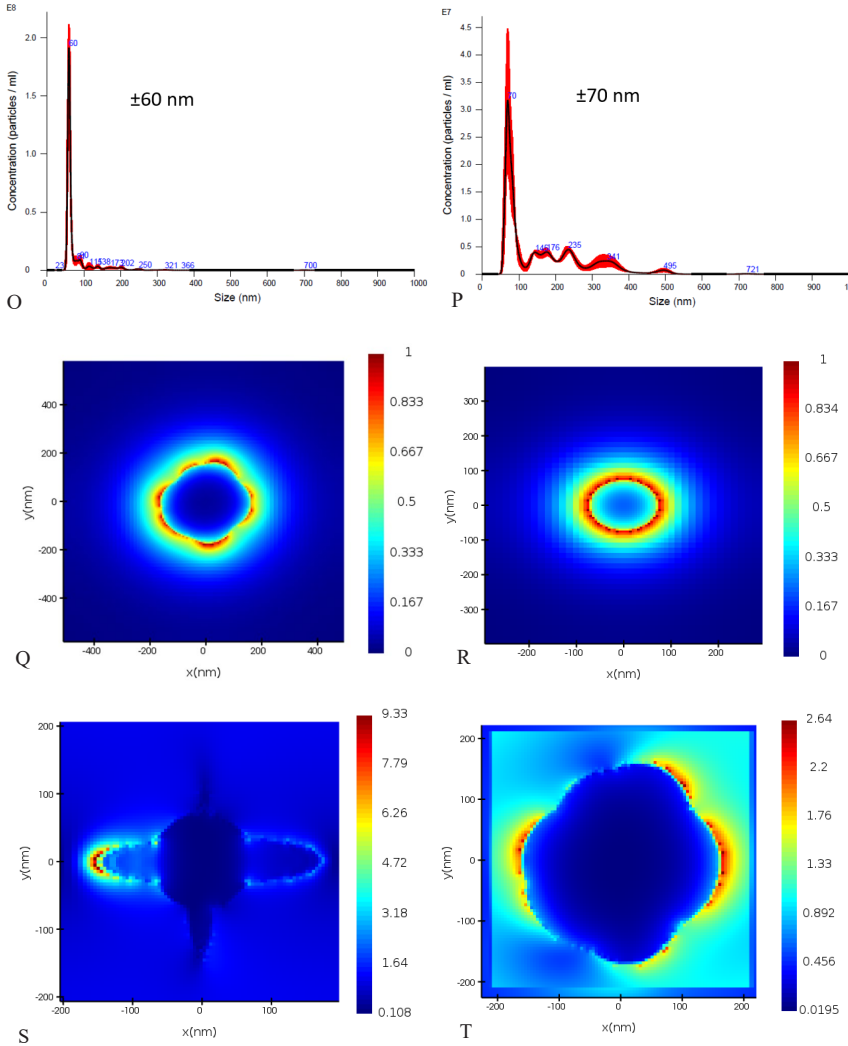



**Figure 4.** (**A-D**) UV-Vis showing the Localized Surface Plasmon Resonance (LSPR) of gold core-silver shell NPs (λ527 nm) and gold nanostars (λ661 nm), and gold nanopopcorns (λ629 nm), and gold hollow nanoparticles (λ595 nm). (**E-P**) NTA results with the average size of the of gold nano-stars (54 nm) found in **E/F/G**, gold nanopopcorns (59 nm) found in **H/I/J/K/L/M**, gold core-silver shell NPs (60 nm) found in **N/O**, and Au Hollow NPs found in **P**. (**Q-T**) FDTD modeling showing the electric field of the gold core-silver shell at (λ527 nm) and nanostar using at (λ661 nm), and the nanopopcorn at (λ529 nm) and (λ629 nm) using Total Field-Scattered Field (TFSF) source injected from the z-plane.

UV-Vis analysis of the synthesized nanoparticles revealed characteristic plasmonic peaks that corresponded to their different shapes and compositions. These plasmonic peaks arise from the collective oscillation for the free electrons in the metal nanoparticles in response to incident electromagnetic radiation. The plasmonic peaks can be used to determine the size, shape, and composition of the nanoparticles. For instance, we observed that the gold nano-popcorns showed a single broad LSPR peak around 629 nm which can either blue or red shift depending on the size, while the gold nano-stars showed a broad LSPR peak around 661 nm which follows the shifting based on the same features as spheres. On the other hand due to the plasmonic nature of the silver, and it being located on the surface of the system, as well as its spherical shape, the LSPR peak is located around 527nm (**Figure 4 A-D**).

NTA results showed that the synthesized nanoparticles had different size distributions, with some particles showing broad distributions and others showing narrow distributions. The gold nano-stars and nano-popcorns both showed a high degree of anisotropy and a narrow size distribution meaning high uniformity for both particles. The same results could be observed in the gold core-silver shell spherical nanoparticles. All particles showed an average size of 54-60 nm (**Figure 4 E-P**).

The Finite-Difference Time-Domain (FDTD) method is a rigorous and powerful tool for modeling nano-scale optical devices that solves Maxwell's equations in complex geometries. We used Anys-Lumerical software to model our anisotropic nanoparticles. FDTD simulation limits were first established followed by the creation of a 3-dimentioanl model of the particle to test. Afterwards, Total Field-Scattered Field (TFSF) source was selected as the recommended source for optical properties characterization based on the company suggestion. We also monitored the frequency-domain field and power to collect the field profile in the frequency domain from simulation results across some spatial region within the simulation in the FDTD. With this monitoring we were able to see the electric field behavior of the nano-popcorns, the bimetal nanoparticle and the nano-stars through a wavelength range from 400-800 nm. The Electric field map was handpicked based on the max LSPR peak location based on their UV-VIS (**Figure 4 Q-T**).

The plasmonic properties of gold nanoparticles are crucial for their applications in cancer nanomedicine. FDTD simulations reveal that both NPCs and NSTs exhibit strong localized surface plasmon resonances (LSPRs), which can be tuned by adjusting their size and shape. These res-

onances play a pivotal role in enhancing light-matter interactions, making these nanostructures ideal candidates for various biomedical applications. Gold nano popcorn and nano stars exhibited enhanced light absorption and scattering compared to spherical nanoparticles. FDTD simulations elucidate the specific wavelengths at which these nanostructures absorb and scatter light most efficiently. This knowledge is crucial for designing targeted therapies, such as photothermal therapy (PTT), where the absorbed light energy is converted into heat, selectively destroying cancer cells.

On the other hand, gold core-silver shell nanoparticles combine the advantageous properties of both gold and silver. The gold core contributes stability and biocompatibility, while the silver shell enhances the plasmonic and catalytic properties. FDTD simulations provide a detailed understanding of the optical response, plasmon resonances, and electromagnetic field enhancements of these hybrid nanostructures. The silver shell can be precisely tuned to manipulate the surface plasmon resonance, making these nanoparticles versatile in applications such as surface-enhanced Raman scattering (SERS) for sensitive cancer biomarker detection.

The FDTD computational analysis of these gold nanostructures provides critical insights into their behavior at the nanoscale, laying the foundation for their applications in cancer nanomedicine. The unique optical properties, plasmonic resonances, and enhanced light-matter interactions contribute to their potential roles in various aspects of cancer diagnosis and treatment. Their applications extend not only for diagnostics, imaging, and therapy, but it also has potential roles in targeted drug delivery, photoacoustic imaging, and synergistic multimodal treatments. The tunable plasmonic properties and enhanced light-matter interactions make these nanostructures versatile tools in the fight against cancer.

In this study, the synthesized NPs demonstrated a wide range of properties, which could be further explored for potential use in breast cancer research. The Au NSTs, with their high degree of anisotropy, have the potential to be utilized as imaging agents to improve the sensitivity and specificity of breast cancer detection. Au NSTs possess a unique surface plasmon resonance (SPR) which produces string localized electromagnetic fields that can enhance the contrast of imaging techniques such as photoacoustic imaging, X-ray computed tomography, and magnetic resonance imaging. By targeting these imaging agents to breast cancer cells, the nano-stars can provide a high level of sensitivity and specificity for cancer detection.

Moreover, the Au core-Ag shell-Au shell nanospheres (NSPs) exhibited a remarkable array of multifunctional properties, positioning them as an enticing option for targeted drug delivery to breast cancer cells. The inherent biocompatibility and stability conferred by the gold (Au) core establish a solid foundation for the overall nanoparticle structure. Simultaneously, the silver (Ag) shell introduces an additional layer of functionality, enhancing the therapeutic potential of the nanoparticles by acting as an antibacterial agent. The outer gold (Au) shell plays a pivotal role in providing a stable and functional surface for the targeted delivery of therapeutics to cancer cells. This outer layer not only contributes to the stability of the nanospheres but also serves as a versatile platform for the attachment of targeting ligands or other functional molecules. The synergistic combination of these three layers, each contributing distinct advantages, results in a nanosphere with multifunctional attributes.

The multifunctional nature of the Au core - Ag shell - Au shell nanospheres makes them a promising candidate for further in-depth investigation in the realm of targeted drug delivery. The potential to harness biocompatibility, stability, antibacterial properties, and targeted functionality in a single nanoparticle structure holds significant implications for advancing the precision and efficacy of therapeutic interventions in breast cancer treatment. Future research endeavors are warranted to explore and optimize the multifaceted capabilities of these nanospheres, paving the way for innovative strategies in personalized breast cancer therapeutics. The gold nanopopcorns showcased in this study exhibit substantial potential for advancing optical and detection sensitivity, primarily attributed to their unique and irregular surface morphology. The irregular surface structure of nanopopcorns, resembling popcorn, contributes to their distinctive op-tical properties. This irregularity enhances their surface area, providing more sites for functionalization and interaction with biological entities. The increased surface area of gold nanopopcorns not only holds promise for targeted drug delivery but also significantly augments their optical sensitivity, making them attractive candidates for applications in breast cancer research.

Furthermore, the nanopopcorns demonstrate superior conjugation efficiency compared to their counterparts, such as nanostars. The nanostar morphology, characterized by sharp branches extending from a central core, presents challenges in achieving efficient conjugation. The sharp peaks of nano-stars may limit the available sites for functionalization, potentially hindering the conjugation process. In contrast, the irreg-

ular and rough surface of gold nano-popcorns offers a more favorable environment for efficient conjugation, providing numerous opportunities for the attachment of functional molecules.

This advantageous feature of enhanced conjugation efficiency positions gold nano-popcorns as promising tools in the development of targeted therapies and diagnostic applications. Their potential to improve detection sensitivity, coupled with efficient conjugation capabilities, makes them valuable assets in the ongoing efforts to enhance precision and effectiveness in breast cancer diagnosis and treatment. Further research and exploration of these unique properties will likely unlock additional opportunities for the utilization of gold nano-popcorns in the realm of biomedical applications, paving the way for innovative advancements in personalized breast cancer therapeutics.

## Conclusion

In the course of this study, we successfully synthesized a diverse array of nanoparticles, deliberately varying their shapes to explore the impact of morphology on their properties. Utilizing UV-Vis spectroscopy, NTA, and FDTD modeling, we comprehensively characterized the nanoparticles, gaining valuable insights into their optical and dynamic characteristics. The integration of multiple characterization techniques facilitated a multi-faceted examination of the synthesized nanoparticles, validating successful synthesis and enriching our understanding of their intricate relationships between morphology and functionality. The synergy between experimental and computational analyses is instrumental in advancing fields such as nanomedicine, sensing, and catalysis.

The plasmonic properties revealed by UV-Vis analysis, NTA results, and FDTD simulations demonstrate the potential applications of gold nanoparticles in cancer nanomedicine. From enhanced light absorption and scattering to tunable plasmonic resonances, these nanoparticles exhibit versatility for various biomedical applications. The unique properties of gold nano-stars make them promising imaging agents for breast cancer detection, while the multifunctional nature of gold core-silver shell-gold shell nanospheres positions them as attractive candidates for targeted drug delivery. Additionally, gold nano-popcorns show potential in increasing optical and detection sensitivity, providing better conjugation efficiency.

The synthesis and characterization of nanoparticles presented in this study demonstrate their potential for breast cancer research. The distinct physical and optical properties of each nanoparticle type provide opportu-

nities for various applications such as imaging, sensing, and drug delivery. The nanoparticles' ability to target cancer cells specifically and their enhanced uptake in tumor tissue make them an attractive option for cancer diagnosis, targeted detection, prognosis, and therapy. However, the study also highlights the challenges associated with translating these nanoparticles to clinical applications. Despite the promising results, there is still a need for more detailed studies to optimize their interaction with cancer cells and to ensure their safety and effectiveness, which will be carried out in future semesters. Furthermore, ensuring the safety and effectiveness of these nanoparticles demands in-depth investigations, a task slated for exploration in upcoming research phases. Efforts to improve the reproducibility and scalability of the nanoparticle synthesis methods are also necessary to facilitate their translation to clinical use.

The findings presented here serve as a foundational stepping stone for future studies aiming to optimize the performance and safety profile of these nanoparticles in cancer research. The complexity of the challenges underscores the need for sustained research efforts, involving multidisciplinary collaboration and advancements in nanotechnology. As these nanoparticles continue to evolve, they hold the potential to reshape the landscape of breast cancer detection, diagnosis, and treatment. With a concerted focus on refining synthesis techniques, understanding cellular interactions, and addressing translational hurdles, nanoparticles emerge as promising candidates that could usher in a new era in personalized and targeted breast cancer therapeutics. The journey towards their clinical integration may be intricate, but the transformative impact on breast cancer management is a goal well worth pursuing through continued research and development.

## References


1. Almehmadi, L. M., Valsangkar, V. A., Halvorsen, K., Zhang, Q., Sheng, J., & Lednev, I. K. (2022). Surface-enhanced Raman spectroscopy for drug discovery: Peptide-RNA Binding. *Analytical and Bioanalytical Chemistry*, *414*(20), 6009–6016. https://doi.org/10.1007/s00216-022-04190-5

2. Bhana, S., Chaffin, E., Wang, Y., Mishra, S. R., & Huang, X. (2014). Capture and detection of cancer cells in whole blood with magnetic-optical nanoovals. *Nanomedicine (London, England)*, *9*(5), 593–606. https://doi.org/10.2217/nnm.13.77

3. Draine, B. T., & Flatau, P. J. (1994). Discrete-dipole approximation for scattering calculations. *Journal of the Optical Society of America A: Optics and Image Science, and Vision*, *11*(4), 1491–1499. https://doi.org/10.1364/JOSAA.11.001491

4. Cheng, L., Zhu, G., & Zhu, L. (2020). FDTD simulation of the optical properties for gold nanoparticles. *Materials Research Express*, *7*(2), 125009. https://doi.org/10.1088/20531591/abd139

5. Ferlay, J., Colombet, M., Soerjomataram, I., Parkin, D. M., Piñeros, M., Znaor, A., & Bray, F. (2021). Cancer statistics for the year 2020: An overview. *International Journal of Cancer*. https://doi.org/10.1002/ijc.33588

6. Hu, H., Tong, K., Tsang, J.Y., Ko, C.W., Tam, F., Loong, T.C., & Tse, G.M. (2024). Subtyping of triple-negative breast cancers: Its prognostication and implications in diagnosis of breast origin. *ESMO Open*, *9*(4) 102993. https://doi.org/10.1016/j.esmoop.2024.102993

7. Freudenberg, J. A.; Wang, Q.; Katsumata, M.; Drebin, J.; Nagatomo, I.; Greene, M. I. (2009). The Role of HER2 in Early Breast Cancer Metastasis and the Origins of Resistance to HER2-Targeted Therapies. *Experimental and Molecular Pathology, 87* (1)*,* 1–11. https://doi.org/10.1016/j.yexmp.2009.05.001

8. Gallego, L., & Ceña, V. (2020). Nanoparticle-mediated therapeutic compounds delivery to glioblastoma. *Expert Opinion on Drug Delivery*, *17*(11), 1541–1554. https://doi.org/10.1080/17425247.2020.1810015

9. Gao, Q., Zhang, J., Gao, J., Zhang, Z., Zhu, H., & Wang, D. (2021). Gold nanoparticles in cancer theranostics. *Frontiers in Bioengineering and Biotechnology*, *9*, 1–20. https://www.frontiersin.org/articles/10.3389/fbioe.2021.647905

10. Gupta, A. K., Naregalkar, R. R., Vaidya, V. D., & Gupta, M. (2007). Recent advances on surface engineering of magnetic iron oxide nanoparticles and their biomedical applications. *Nanomedicine (London, England)*, *2*(1), 23–39. https://doi.org/10.2217/17435889.2.1.23

11. Kwizera, E. A., Chaffin, E., Shen, X., Chen, J., Zou, Q., Wu, Z., Gai, Z., Bhana, S., O'Connor, R., Wang, L., Adhikari, H., Mishra, S. R., Wang, Y., & Huang, X. (2016). Size- and shape-controlled synthesis and properties of magnetic-plasmonic core-shell nanoparticles. *The Journal of Physical Chemistry. C, Nanomaterials and Interfaces*, *120*(19), 10530–10546. https://doi.org/10.1021/acs.jpcc.6b00875

12. Wang, X., Qian, X., Beitler, J. J., Chen, Z. G., Khuri, F. R., Lewis, M. M., Shin, H. J. C., Nie, S., & Shin, D. M. (2011). Detection of circulating tumor cells in human peripheral blood using surface-enhanced Raman scattering nanoparticles. *Cancer Research*, *71*(5), 1526–1532. https://doi.org/10.1158/0008-5472.CAN-10-3069

13. Wu, X., Luo, L., Yang, S., Ma, X., Li, Y., Dong, C., Tian, Y., Zhang, L., Shen, Z., & Wu, A. (2015). Improved SERS nanoparticles for direct detection of circulating tumor cells in the blood. *ACS Applied Materials & Interfaces*, *7*(18), 9965–9971. https://doi.org/10.1021/acsami.5b02276

14. Johnson, P.B., & Christy, R. W. (1972). Optical Constants of the Noble Metals. *Physical Review B*, *6*(12), 4370–379. https://doi.org/10.1103/PhysRevB.6.4370

John Mullen is a student at the University of Memphis majoring in Physics with a minor in Mathematics. John will be graduating in the spring of 2025; he hopes to attend graduate school thereafter. In the summer of 2023, John participated in a research experience program funded by the National Science Foundation at the University of Memphis where he worked under Dr. Firouzeh Sabri. John is grateful for the experience the program provided him and hopes to use the skills that he learned to make the world a better place.

**John Mullen**

Characterization of Collagen Morphology on Aerogel

**Faculty Sponsor**
Dr. Firouzeh Sabri

## Abstract

Type I collagen is the most abundant protein in humans. It is essential to cell attachment and is consequently necessary for cells to thrive. Type I collagen is extensively used in vitro to coat substrates for cell attachment. Aerogel substrates are increasingly being used as medical implants due to their unique physical properties. Therefore, understanding the interaction between collagen and aerogels is important. Despite this, collagen morphology has not been studied extensively on aerogels. This work aims at building a body of knowledge about the dependence of collagen morphology on collagen area-density on two different aerogel substrates. It was observed that collagen fiber length, width, and abundance decreased with increasing collagen area-density on both aerogels tested. Moreover, the collagen film area increased on both substrates with increasing collagen area-density.

## Introduction

Aerogels are a class of solid materials that exhibit many unique properties [1], [2]. First and foremost, aerogels are characterized by their highly porous nature, which causes them to be remarkably light for their size [1]. In addition, the physical, chemical, and other properties of aerogels can be easily optimized for specific applications [3]. Moreover, some types of aerogels—including silica-based, polymer, and hybrid aerogels—have been observed to be biocompatible and to have the ability to mimic biological structures [1]. The combination of all these characteristics makes aerogels very attractive materials for biomedical applications. For example, aerogels are currently being used as nerve and cardiovascular implants, among other biomedical applications [3].

Collagen is a class of proteins that are similar chemically, structurally, and functionally [4], [5]. Collagen plays an essential role in cell attachment and providing support for extracellular matrices [4], [5]. Regarding collagen's importance to cell attachment in vivo, cells attach themselves to collagen structures, often in an indirect interaction involving matrix glycoproteins [6]. However, new research suggests that the coevolution of cell adhesion mechanisms and collagens led to the development of cell receptors that bind to specific motifs in collagens [6]. Of the many types of collagens, Type I collagen is the most abundant type in most human tissues [5]. Regarding its role in providing support, type I collagen has the ability to form large fibers which act as structural elements with high tensile strength and low elasticity [4]. Such fibers are extremely common in major connective tissues and are found in select regions of all internal organs [4].

Hence, understanding the interaction between type I collagen and aerogel substrates in vitro is of great interest since cell attachment—to which collagen is essential—is crucial to cell development in vitro. Studying collagen-aerogel interaction could lead to insights about how to improve aerogels for biomedical applications. The work presented here aims at building a body of knowledge of how different area-densities of type I collagen coatings interact with different types of aerogels in vitro. Both collagen fibers and collagen films were investigated, examples of which can be seen in **Figure 1**. The lengths and widths of the collagen fibers, the percentage of the sample's area covered by the collagen film, and the percentage covered by collagen fibers were all measured.

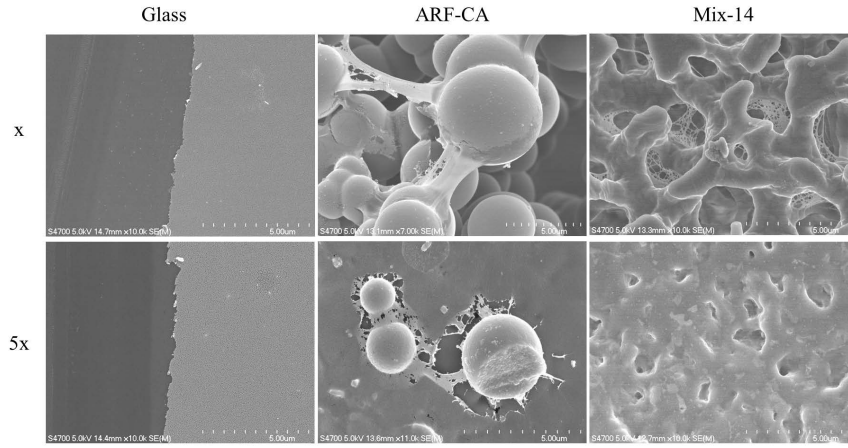



**Figure 1** (left to right). Cover glass, ARF-CA, and Mix-14 coated with both 4 $\frac{\mu g}{cm^2}$ (x) and 20 $\frac{\mu g}{cm^2}$ (5x) collagen area-densities. Cover glass is covered with only collagen film; ARF-CA and Mix-14 substrates display both collagen fibers and film.

## Materials

### Acid-Catalyzed Resorcinol Formaldehyde Carbon Aerogel (ARF-CA)

Carbon aerogels are a subclass of aerogel with extraordinary mechanical, thermal, and electrical properties formed by the organic resorcinol formaldehyde sol-gel process [7]. Resorcinol, formaldehyde, water, and acetic acid were mixed to form the gels from which the samples were made [3]. The gels were cured, soaked in acetone, and super critically dried in liquid $CO_2$; the resulting aerogels were then heated in a tube furnace under a nitrogen atmosphere at 1050 °C for 3 hours [3].

### Superelastic Shape Memory Polyurethane Aerogel (SSMPA) Mix-14

Shape memory aerogels are a new class of aerogel with both the low-density and high-porosity of other aerogels and the characteristics typical of shape-memory materials [3], [8]. Shape memory aerogels have the ability to return to their permanent shape following a temporary deformation. The return to their permanent state is triggered by a stimulus, such as a temperature change. The shape-memory of these aerogels is the result of a triisocyanate core with rigid isocyanurate cross-linking nodes which pull the material back together following deformation [8].

## Methods

### Collagen Coating

The aerogel samples were cut from a larger piece of material. Great care was taken to ensure that the cutting process did not leave marks on the aerogels, altering their surfaces. In all cases, the face of the aerogel that was in contact with the blade during cutting was the face that the collagen was deposited onto. The aerogel samples were all of similar size and shape, being around 0.5 to 0.7 $cm^2$, approximately square when viewed from above, and relatively short in height. While the samples were guaranteed to be significantly larger than the size of the collagen structures being studied, the exact dimensions of the samples were not pertinent to the experiment. This step was performed in the same way for the ARF carbon aerogel and the Mix-14. Uncut cover glass from Propper International was used as a control.

The samples were then glued into petri dishes using clear adhesive sealant from Permatex. This was done to ensure that the aerogel samples would be completely submerged by the various baths in the procedure and that they would not simply float on top of the solutions due to their low densities. The glue was allowed to dry for 24 hours before proceeding. The petri dishes were filled with isopropanol (IPA) and allowed to sit for 1 minute. After removing the IPA, the petri dishes were subjected to UV light (λ=254nm) for 20 minutes using a UV chamber, model 234100, from Boekel Scientific.

In an Eppendorf tube, 3 $\frac{mg}{mL}$ rat tail collagen I from Gibco was mixed with 20 mM acetic acid to make enough solution to cover all of the samples with a 20 $\frac{\mu g}{cm^2}$ (5x) area-density coating of collagen, the appropriate volume of solution was placed onto each sample. Great care was taken to ensure that the solution stayed on top of the samples and did not drain into the considerably larger area of the petri dish. The samples were allowed to sit for one hour before proceeding.

The petri dishes were then gently filled with DI water to the point that the samples were submerged. The DI water was removed using a micropipette, and the petri dishes were again filled with DI water. Drops of 2.5% glutaraldehyde with sodium phosphate buffer from Tousimis were added to the petri dishes. After a drop was added, the petri dish was swirled to ensure that the glutaraldehyde was mixed into the solution. In total, 1mL of 2.5% glutaraldehyde was added into the petri dishes. The DI water and glutaraldehyde solution was removed from the dishes using a 1mL micropipette. The dishes were then filled with 2.5% glutaraldehyde to the

point that the samples were submerged. After 2 hours, the glutaraldehyde was removed from the dishes. Two washes were performed with 0.1M sodium phosphate, waiting five minutes between washes. Lastly, six ethanol washes were performed at increasing concentrations (10%, 30%, 50%, 70%, 90%, and 100%) with ten minutes between washes. The ethanol was removed, and the samples were allowed to air dry for 24 hours.

### SEM Imaging and Analysis

The samples were sputter coated using a HUMMER 10.2 sputter coater with a gold/palladium target. The current was maintained at 4-5 mA, and the samples were coated for 500 seconds. The samples were imaged using a Phenom scanning electron microscope (SEM). On each sample, a 5-by-5 grid of images was taken at 4800x magnification. The images obtained from the SEM were analyzed with the NIH open-source software ImageJ (version 1.54f). The bar scale put on the images by the SEM was used to calibrate the scale of the measurements in ImageJ. The straight-line tool was used to measure the lengths and widths of the collagen fibers. In addition, the brightness threshold tool was used to determine the percent area of each image covered by the collagen film.

## Results

Data is presented for collagen area-densities of both 4 $\frac{\mu g}{cm^2}$ (x) and 20 $\frac{\mu g}{cm^2}$ (5x). Only the data for the 20 $\frac{\mu g}{cm^2}$ area-density is the author's original work.

### Collagen Film Area

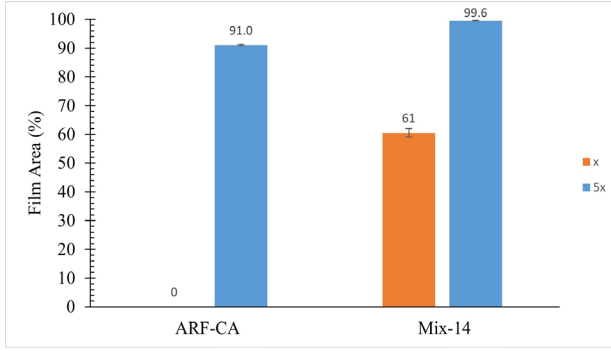



**Figure 2.** Collagen film area on ARF-CA and Mix-14 at both 4 $\frac{\mu g}{cm^2}$ (x) and 20 $\frac{\mu g}{cm^2}$(5x) collagen area-densities. At "x" collagen area-density, the collagen film covered 0% of the ARF-CA and 61% of the Mix-14 samples, while at "5x" the collagen film covered 91% of the ARF-CA and 99.6% of the Mix-14 samples.

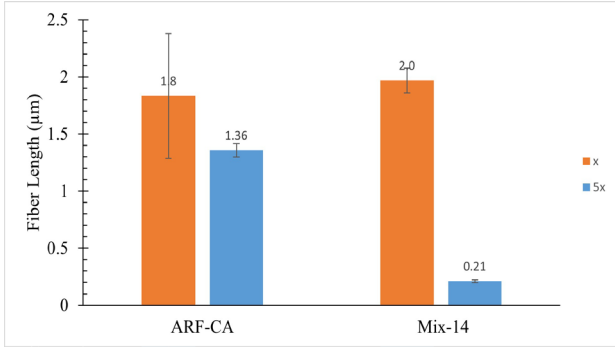



**Figure 3.** Collagen fiber length on ARF-CA and Mix-14 at both 4 $\frac{\mu g}{cm^2}$ (x) and 20 $\frac{\mu g}{cm^2}$ (5x) collagen area-densities. At "x" collagen area-density, the average collagen fiber length was 1.8µm on ARF-CA and 2.0µm on Mix-14. At "5x" collagen area-density, the average collagen fiber length was 1.36µm on ARF-CA and 0.21µm on Mix-14.

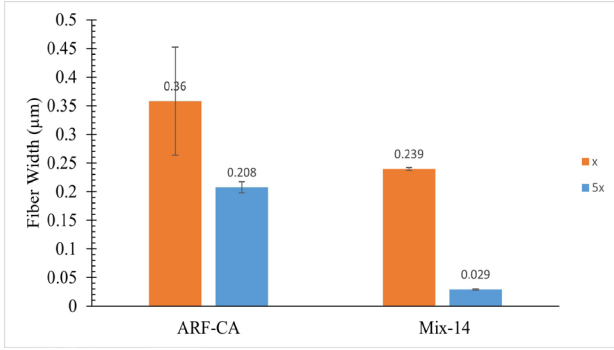



**Figure 4.** Collagen fiber width on ARF-CA and Mix-14 at both 4 $\frac{\mu g}{cm^2}$ (x) and 20 $\frac{\mu g}{cm^2}$ (5x) collagen area-densities. At "x" collagen area-density, the average collagen fiber width was 0.36µm on ARF-CA and 0.239µm on Mix-14. At "5x" collagen area-density, the average collagen fiber width was 0.208µm on ARF-CA and 0.029µm on Mix-14.

### Fiber Area

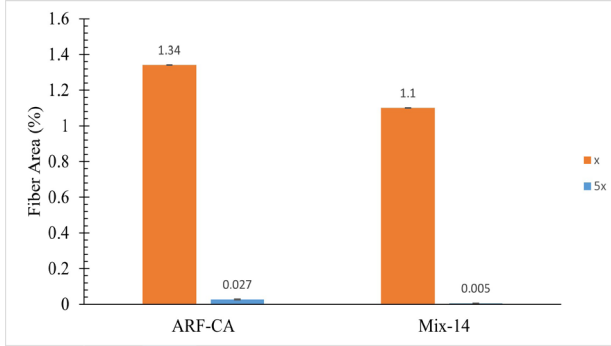



**Figure 5.** Percentage area of collagen fibers on ARF-CA and Mix-14 at both 4 $\frac{\mu g}{cm^2}$ (x) and 20 $\frac{\mu g}{cm^2}$ (5x) collagen area-densities. At "x" collagen area-density, the collagen fibers covered 1.34% of the ARF-CA and 1.1% of the Mix-14 samples, while at "5x" the collagen fibers covered 0.027% of the ARF-CA and 0.005% of the Mix-14 samples.

## Discussion

### Collagen Film Area

**Figure 2** shows that collagen film area increased on both substrates when collagen area-density increased. The collagen film on Mix-14 was more abundant than that on ARF-CA for both collagen area-densities tested.

### Fiber Length and Width

**Figure 3** shows a decrease in collagen fiber length with increasing collagen area-density on both ARF-CA and Mix-14. In addition, although the collagen fibers at 4 $\frac{\mu g}{cm^2}$ were of similar lengths on both ARF-CA and Mix-14, the fibers at 20 $\frac{\mu g}{cm^2}$ were significantly shorter on Mix-14 than on ARF-CA. **Figure 4** shows that collagen fiber width decreased with increasing collagen area-density on both ARF-CA and Mix-14. Moreover, the collagen fibers on Mix-14 were narrower than those on ARF-CA regardless of collagen area-density.

### Fiber Area

**Figure 5** shows that collagen fibers were far more abundant at lower collagen area-densities for both materials. In addition, the fibers on ARF-CA were far more abundant than those on Mix-14 for both collagen area-densities tested.

## Conclusion

In conclusion, it was observed that both collagen fiber length and width decreased with increasing collagen area-density on both ARF-CA and Mix-14. In addition, the percentage of the sample area covered by collagen fibers on both ARF-CA and Mix-14 decreased with increasing collagen area-density. Moreover, the collagen film area increased on both substrates with increasing collagen area-density. Lastly, more work is needed to understand why the two aerogels respond differently to an increase in collagen area-density and why collagen tends to form fewer fibers and more film at higher area-densities on both substrates.

## References


[1] T. Ferreira-Gonçalves, C. Constantin, M. Neagu, C. P. Reis, F. Sabri, and R. Simón-Vázquez, "Safety and efficacy assessment of aerogels for biomedical applications," *Biomedicine & Pharmacotherapy*, vol. 144, p. 112356, 2021.

[2] M. A. Aegerter, N. Leventis, and M. M. Koebel, *Aerogels handbook*. Springer Science & Business Media, 2011.

[3] M. R. Sala, O. Skalli, and F. Sabri, "Optimal structural and physical properties of aerogels for promoting robust neurite extension in vitro," *Biomaterials Advances*, vol. 135, p. 112682, 2022.

[4] S. Gay and E. J. Miller, "Overview: What is collagen, what is not," *Ultrastruct Pathol*, vol. 4, no. 4, pp. 365–377, 1983.

[5] C. Dong and Y. Lv, "Application of collagen scaffold in tissue engineering: Recent advances and new perspectives," *Polymers (Basel)*, vol. 8, no. 2, p. 42, 2016.

[6] J. Heino, "The collagen family members as cell adhesion proteins," *Bioessays*, vol. 29, no. 10, pp. 1001–1010, 2007.

[7] J. P. Lewicki, C. A. Fox, and M. A. Worsley, "On the synthesis and structure of resorcinol-formaldehyde polymeric networks–precursors to 3D-carbon macroassemblies," *Polymer (Guildf)*, vol. 69, pp. 45–51, 2015.

[8] S. Donthula et al., "Nanostructure-Dependent Marcus-Type Correlation of the Shape Recovery Rate and the Young's Modulus in Shape Memory Polymer Aerogels," *ACS Appl Mater Interfaces*, vol. 10, no. 27, pp. 23321–23334, 2018.

Joseph Zeron is a Physics major at the University of Memphis, graduating in the spring of 2025. Joseph plans to pursue a Ph.D. in Astronomy to continue learning about the complicated mechanism that governs our intricate universe. He was originally from Honduras. He migrated to the U.S. in hopes of getting a better life. His interest in astronomy revolves around Black Holes. He first became interested in these celestial objects when he saw a video about them in high school. Their sheer scale helped him see that there was so much more out there. In the summer of 2023, Joseph participated in an NSF-funded research project involving Black Holes. Thanks to the NSF and mentoring from Dr. Ben Keller, he learned a lot about Black Holes and how to perform research. With help from Dr. Keller, he made a manuscript detailing his work and submitted it to the University of Memphis' Undergraduate Research Journal: *QuaesitUM*. Joseph is very thankful for the opportunity to be part of this research and share it with others.

**Joseph Zeron**

AGN Feedback in Galaxy Formation

**Faculty Sponsor**
Dr. Ben Keller

## Abstract

In this paper, we look at the impact of Active Galactic Nucleus (AGN) feedback driven by Supermassive Black Holes (SMBH) on the evolution of a Milky Way-like Galaxy. We do this by running the simulation jsAGN2 (joseph AGN 2), using the Smooth Particles Hydrodynamics code ChaNGa, and comparing it to the simulation MUGS2 (McMaster Unbiased Galaxy Simulations 2). However, the MUGS2 simulation includes only Supernovae feedback, while our simulation also includes AGN feedback. This allows us to look at the effects of SMBHs on the evolution of a Milky Way-like galaxy. We observed how the star formation rate was affected by both forms of feedback and compared the gas properties in these simulations.

## Introduction

Galaxies are enormous collections of gas, stars, and planets all held together by gravity. They formed over cosmic time through gravitational collapse (Ryden & Gunn). Within these galaxies, rotating clouds of gas dynamically collapse to form stars (Shu et al.). Gas can be further accreted from the Circumgalactic Medium (CGM), which serves as fuel for star formation (SF) (Tumlinson).

If left alone, all this gas would collapse. So, there must be a process through which SF is regulated (Gabor J; White & Frenk). Many forms of feedback aid in the process of limiting SF. Stars themselves are one of them; through stellar winds, ionization, radiation, and Supernovae (SNe), gas is pushed away from star-forming regions in turn reducing the efficiency of cooling and SF of the galaxy (Muratov; White & Frenk). AGN feedback from Supermassive Black holes also contributes through radiation, winds, and gas-ejecting jets (Fabian).

Black Holes inhabit most galaxies and have an inherent relationship with the characteristics of their host galaxies, like luminosity (Kormendy and Richstone) and mass (Marconi and Hunt). In this paper, we analyze how AGN feedback from SMBHs interacts with gas and regulates the growth of its host galaxy. We do this by looking at the largest halo of our simulation jsAGN2 and comparing it to the largest halo in the simulation MUGS2. By implementing this feedback from AGN, we expect the SF to be reduced (Fabian; McNamara).

## Methods

Our simulation is run using the N-body + SPH (Smoothed Particle Hydrodynamics) code ChaNGa (Charm N-body GrAvity solver) (Menon et al.). This code can make cosmological simulations with galaxies that interact with each other, and isolated systems. Many of the physics modules used in ChaNGa were originally used in its well-established predecessor, the SPH code GASOLINE (Wadsley et al.)—the code used by the MUGS2 simulation. Some of those physical modules include gas cooling, a cosmic UV background, and SF and SNe feedback. Both simulations use a Barnes-Hut algorithm to calculate the gravitational force exerted on a body.

For the formation of SMBH, an improved Bondi-Hoyle method for the accretion and dynamical friction of SMBHs was implemented. The SMBHs form from Population III stars, which are the stars that were formed in the early stages of the universe when the gas had low metallicity and low fragmentation rates (Bond; Omukai & Nishi). For the seeds of SMBHs to form they must follow these physical criteria:

- Low mass fraction of metals
- Density fifteen times that of the SF threshold
- Temperatures between 9500 K and 10000 K

This allows the gas to collapse quickly and cool relatively slowly (Tremmel). This makes it possible for stars with masses greater than 260 Msol to form, which is the threshold to create a black hole of 100 Msol. (Bond). The AGN feedback used in our code is based on the Keller 2014 Super Bubble model. For the initial conditions, we will use a SMBH initial mass of $1*10^6$ Msol. The SMBHs will achieve this mass by gaining it from the surrounding gas. The simulation is run on 280 nodes on the High-Performance Computing (HPC) supercomputer at the University of Memphis. The simulation is run from $z = 99$ to $z = 0$.

## Results

Once our simulation is over, we proceed with the analysis. **Figure 1** shows a density slice of the biggest halo on our last snapshot, viewed face-on. In **Figure 2** we can see the same snapshot viewed from the side, which offers us a different point of view of where the SMBHs are located. We can see that we were able to form a disk galaxy with SMBHs orbiting it. The arrows represent the velocity vectors. However, none of the SMBHs reached the center of the galaxy. With dynamical friction which occurs both due to large and small-scale perturbations, we expected the SMBH to be forced towards the center of the galaxy (Chandrasekhar). However, this was not the case because the dynamical friction used in this simulation was designed to allow for wide orbits generated from mergers. Another point that helps us further understand this is that some of the SMBHs are moving at speeds around 200 km/s, which helps visualize that some of them have noticeably larger orbits.

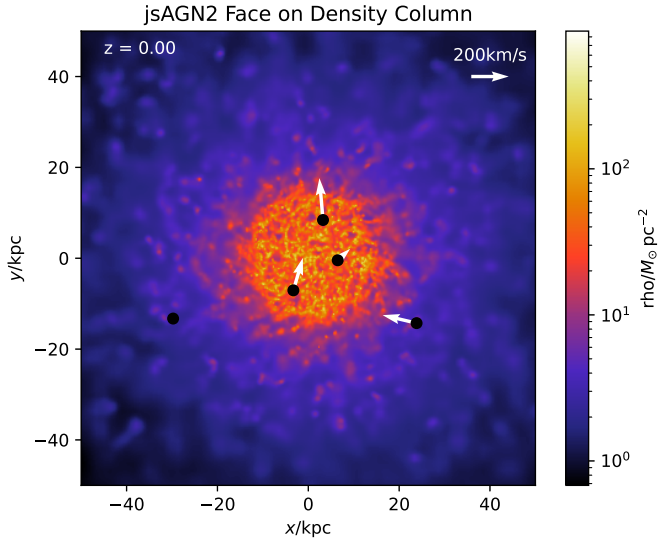



**Figure 1.** Face-on Density Column

**Figure 1** shows the gas column density of a snapshot from the simulation jsAGN2. In the graph, there are five SMBHs, each with their velocity vector. The legend shows an example of a vector that represents 200 km/s. This helps give an idea of how fast each SMBH is moving. Interestingly all the black holes are orbiting the halo, but none are in the exact center.

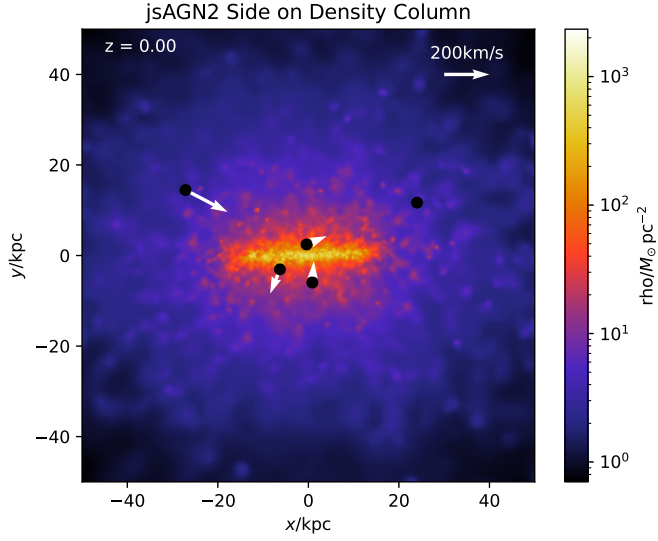



**Figure 2.** Side-on Density Column

**Figure 2** is also a column density plot. However, this plot shows the same halo, as seen in **Figure 1**, but viewed edge-on, which offers another view of the position of the SMBHs. This allows us to see that some of the SMBHs are further from the center than they appeared to be.

We confirmed that SMBHs were formed, now we want to know what their effects are. To do that we look at the star formation history. **Figure 3** shows the star formation rate over time, and it compares the MUGS2 simulation with jsAGN2. We can see that SF is limited by AGN feedback. While in the initial stages of the galaxy, the star formation rate remained similar in both simulations, after 10 Gyr the star formation rate of jsAGN2 subsides and a lower rate is reached by the end. However, that is not the only thing of importance. Throughout the graph, you can see that jsAGN2 has less burstiness than MUGS2. This refers to the sudden peaks in star formation rate that we see throughout MUGS2 history. The star formation history indicates that AGN feedback somewhat suppresses late-time star formation.

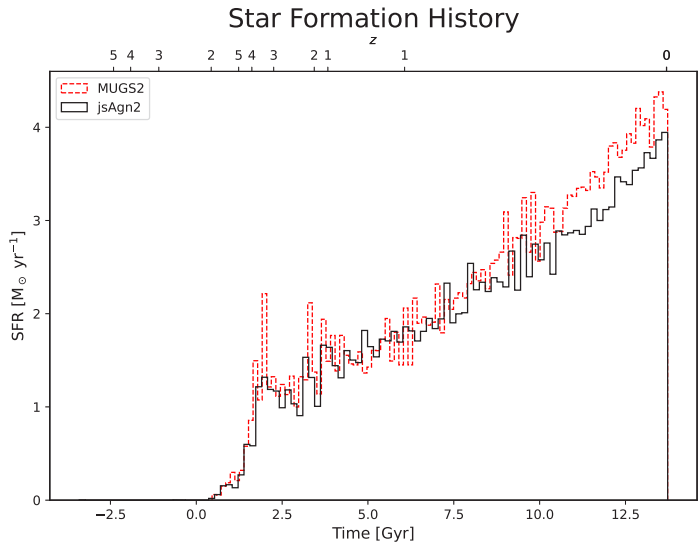



**Figure 3.** Star Formation History

**Figure 3** shows the star formation rate over time in billion years of the simulations MUGS2 and jsAGN2. This graph plots the star formation history of both simulations on top of each other to compare how the implementation of SMBH reduces star formation. The graph shows that the presence of SMBHs regulates the rate and burstiness of the star formation.

To understand why this happened to the SF, the first thing we look at is the gas present. In Figure 4 we plotted the gas, stellar, and total mass of the largest halo in both simulations. We can immediately notice that the gas mass of jsAGN2 is lower than MUGS2 throughout the halo's history. The stellar mass, while not as much, also saw a slight decrease. Yet the total mass of both simulations is almost identical. This is because of Dark Matter (DM) particles, DM particles are unaffected by SNe and AGN feedback. SNe and AGN interact with gas particles by heating them and increasing pressure, this change in pressure causes gas particles to push each other out of the inner CGM. However, DM particles are not affected by electromagnetic forces. So, they do not heat up. Thus, they were not pushed around as much as gas particles; considering that DM particles constitute around 81% of the halo mass, it makes sense that it remained similar in both simulations.

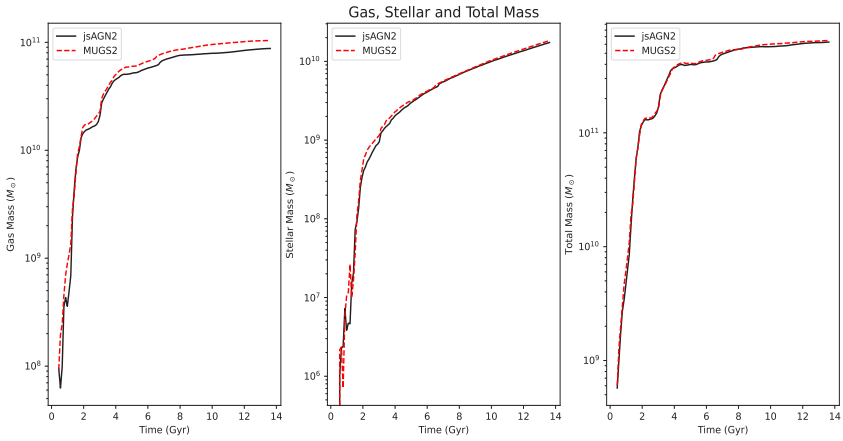



**Figure 4.** Gas, Stellar, and Total Mass

**Figure 4** plots the gas mass, stellar mass, and total mass over time of jsAGN2 and MUGS2. We can see that the gas mass was the most affected by SMBHs. The stellar mass was also affected but to a lesser extent. Due to DM the total mass saw little to no change overall.

This shows that the absence of gas could be why SF was affected by the SMBHs. To confirm this, we have a closer look at the mass and temperature of both simulations' halos. **Figure 5** shows the radial profiles of the mass and temperature of the gas around the halo radius. If you look at the gas mass around 20 to 100 kpcs from the center of the halo, you notice a significant decrease in jsAGN2 compared to MUGS2. Another

interesting thing to notice is that the gas temperature is higher in jsAGN2. This is because of the gas ejected from the halo, the cooling efficiency was reduced resulting in longer cooling times and higher temperatures.

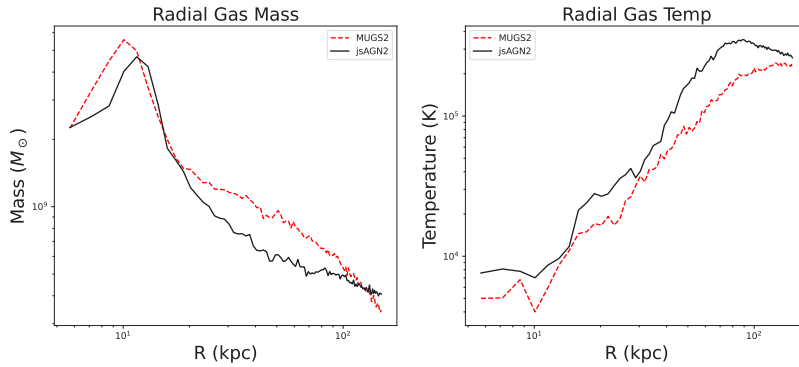



**Figure 5.** Radial Mass and Temp

**Figure 5** gives us a closer look at the state of gas in both simulations. We can see that SMBHs resulted in a decrease in gas mass in the disk and the CGM. This decrease also seems to correlate with an increase in temperature, which can be attributed to longer cooling times due to lower densities.

This effect in the halo's gas mass is caused by AGN jets displacing large amounts of gas from the inner CGM through jets. The CGM is a source of fuel for a galaxy's star formation, so less fuel means fewer stars being formed. If we look at **Table 1**, we can see the gas, stellar, and total mass of the halo at the end of the simulation. By the end of the simulation, jsAGN2 had 16% less gas mass than MUGS2. It also had a lower stellar mass and total mass. The table also contains the SMBHs mass, which amounted to a total of $1.349*10^7$ Msol. This shows that the SMBHs ejected the gas rather than accreting it, because the total gas mass lost was around sixteen billion Msol and the total mass of the SMBHs is not nearly enough to account for all the missing gas mass.

| Halo Final Masses | | | | |
|---|---|---|---|---|
| **Name** | **Gas mass (Msol)** | **Stellar Mass (Msol)** | **Total mass (Msol)** | **Total SMBH Mass (Msol)** |
| **MUGS2** | $1.04*10^{11}$ | $1.86*10^{10}$ | $6.49*10^{11}$ | 0 |
| **jsAGN2** | $8.77*10^{10}$ | $1.77*10^{10}$ | $6.27*10^{11}$ | $1.349*10^{7}$ |

**Table 1.** Halo Final Masses

In **Table 1** here, we can see the different masses of the halo when the simulation concluded at z = 0. The gas mass has the biggest change, decreasing by 16% in jsAGN2. The stellar mass was also affected along with the total mass. We also have the total mass of the SMBHs, which if you compare it to the gas mass lost proves that the gas was ejected and not accreted; because of how small the total mass of the SMBHs is compared to the gas mass lost.

## Conclusion

In this paper, we delve into the mechanisms that limit the SF of a galaxy. We compared two of those mechanisms, SNe and AGN feedback. We did this by running the simulation jsAGN2 using the N-body + SPH code ChaNGa, with feedback from SNe and AGN, and compared it to the previously run simulation MUGS2; which used the code GASOLINE with feedback from SNe only.

We found that AGN feedback noticeably reduces the SFR and burstiness of the simulation. To understand why this happened we looked at the gas in the largest halo of both simulations. We found that throughout the halo history, the gas mass was reduced. This also affected the stellar mass. However, the total mass was unaffected due to DM particles. We then proceeded to analyze the radial profiles of the halo's gas. We discovered that jets, caused by AGN feedback, ejected the gas out of the inner CGM of the halo resulting in lower densities that caused higher temperatures due to longer cooling times. This work is the first of what we are hoping to be a continuing effort to improve our techniques of galaxy simulation, which will aid in our understanding of how galaxies grow and develop.

## Acknowledgments

I would like to extend my sincere gratitude to Dr. Ben Keller for his continuing guidance and support. I would also like to thank the faculty and staff from the REU program at the University of Memphis. The simulation was made possible thanks to the HPC supercomputer at the University of Memphis. Also, I would like to thank Eric Spangler for his advice and help with computing time. Lastly, this would not have been possible without the support and funds from the NSF. Thank you for allowing me to be part of this. My special thanks goes to my mother Angelica Cerrato for always being there for me.

## Works Cited


Bond, J. R., et al. "The Evolution and Fate of Very Massive Objects." *The Astrophysical Journal*, vol. 280, May 1984, p. 825. https://doi.org/10.1086/162057.

Chandrasekhar, S. "Dynamical Friction. I. General Considerations: The Coefficient of Dynamical Friction." *The Astrophysical Journal*, vol. 97, Mar. 1943, p. 255. https://doi.org/10.1086/144517.

Fabian, A.C. "Observational Evidence of Active Galactic Nuclei Feedback." *Annual Review of Astronomy and Astrophysics*, vol. 50, no. 1, 18 Apr. 2012, pp. 455–489. https://doi.org/10.1146/annurev-astro-081811-125521.

Gabor, J. M., et al. "How Is Star Formation Quenched in Massive Galaxies?" *Monthly Notices of the Royal Astronomical Society*, vol. 407, no. 2, 11 Jan. 2010, pp. 749–771. https://doi.org/10.1111/j.1365-2966.2010.16961.x.

Keller, B. W., et al. "A Superbubble Feedback Model for Galaxy Simulations." *Monthly Notices of the Royal Astronomical Society*, vol. 442, no. 4, 28 May 2014, pp. 3013–3025. https://doi.org/10.1093/mnras/stu1058.

Kormendy, John, and Douglas Richstone. "Inward Bound—the Search for Supermassive Black Holes in Galactic Nuclei." *Annual Review of Astronomy and Astrophysics*, vol. 33, no. 1, 1995, pp. 581–624. https://doi.org/10.1146/annurev.aa.33.090195.003053.

Marconi, Alessandro, and Leslie K. Hunt. "The Relation between Black Hole Mass, Bulge Mass, and near-Infrared Luminosity." *NASA/ADS*, May 2003, ui.adsabs.harvard.edu/abs/2003ApJ...589L..21M/abstract.

McNamara, B. R., et al. "The Starburst in the Abell 1835 Cluster Central Galaxy: A Case Study of Galaxy Formation Regulated by an Outburst from a Supermassive Black Hole." *The Astrophysical Journal*, vol. 648, no. 1, 10 May 2006, pp. 164–175. https://doi.org/10.1086/505859.

Menon, Harshitha, et al. "Adaptive Techniques for Clustered N-Body Cosmological Simulations." *Computational Astrophysics and Cosmology*, vol. 2, no. 1, 5 Sept. 2014. https://doi.org/10.1186/s40668-015-0007-9.

Muratov, Alexander L., et al. "Gusty, Gaseous Flows of Fire: Galactic Winds in Cosmological Simulations with Explicit Stellar Feedback." *Monthly Notices of the Royal Astronomical Society*, vol. 454, no. 3, 13 Oct. 2015, pp. 2691–2713. https://doi.org/10.1093/mnras/stv2126.

Omukai, Kazuyuki, and Ryoichi Nishi. "Formation of Primordial Protostars." *The Astrophysical Journal*, vol. 508, no. 1, 20 Nov. 1998, pp. 141–150. https://doi.org/10.1086/306395.

Ryden, Barbara S., and James E. Gunn. "Galaxy Formation by Gravitational Collapse." *The Astrophysical Journal*, vol. 318, 1987, p. 15, https://doi.org/10.1086/165349.

Shu, Frank H., et al. "Star Formation in Molecular Cloud Cores." *Star Forming Regions*, 1987, pp. 417–434. https://doi.org/10.1007/978-94-009-4782-5_137.

Tremmel, M., et al. "The Romulus Cosmological Simulations: A Physical Approach to the Formation, Dynamics and Accretion Models of Smbhs." *Monthly Notices of the Royal Astronomical Society, vol. 470*, no. 1, 15 Sept. 2017, pp. 1121–1139. https://doi.org/10.1093/mnras/stx1160.

Tumlinson, Jason, et al. "The Circumgalactic Medium." *Annual Review of Astronomy and Astrophysics*, vol. 55, no. 1, 2017. pp. 389–432, https://doi.org/10.1146/annurev-astro-091916-055240.

Wadsley, J.W., J. Stadel, et al. "Gasoline: A Flexible, Parallel Implementation of Treesph." *New Astronomy*, vol. 9, no. 2, Feb. 2004, pp. 137–158. https://doi.org/10.1016/j.newast.2003.08.004.

Wadsley, James W., Benjamin W. Keller, et al. "Gasoline2: A Modern Smoothed Particle Hydrodynamics Code." *Monthly Notices of the Royal Astronomical Society*, vol. 471, no. 2, 12 July 2017, pp. 2357–2369. https://doi.org/10.1093/mnras/stx1643.

White, Simon D., and Carlos S. Frenk. "Galaxy Formation through Hierarchical Clustering." *The Astrophysical Journal*, vol. 379, 28 Mar. 1991, p. 52. https://doi.org/10.1086/170483.

## ‘ChaNGa’ References

Menon, H., Wesolowski, L., Zheng, G., Jetley, P., Kale, L., Quinn, T., Governato, F. “Adaptive Techniques for Clustered N-Body Cosmological Simulations”, *Computational Astrophysics and Cosmology*, 2, 1, 2015.

P. Jetley, F. Gioachin, C. Mendes, L. V. Kale, and T. R. Quinn. “Massively Parallel Cosmological Simulations with ChaNGa”. In *Proceedings of IEEE International Parallel and Distributed Processing Symposium* 2008, 2008.

P. Jetley, L. Wesolowski, F. Gioachin, L. V. Kale, and T. R. Quinn. “Scaling hierarchical n-body simulations on gpu clusters”. In *Proceedings of the 2010 ACM/IEEE International Conference for High Performance Computing, Networking, Storage and Analysis*, SC ’10, Washington, DC, USA, 2010. IEEE Computer Society.

Jalyssa Smith is a Biomedical Engineering major at the University of Memphis, graduating in the spring of 2024. She has earned Honors in Biomedical Engineering and will continue her education to earn a master's degree. At the University of Memphis, she has been involved in the track program and the National Society of Black Engineers. The past year she has worked under Dr. Amy L. de Jongh Curry to learn more about Transcranial Magnetic Stimulation (TMS) and its ability to improve the lives of those with neurological disorders. In the future, she will be exploring pediatrics and the developing brain to further the understanding of the effects of TMS and efficacy of treatment.

Jalyssa's paper received a *QuaesitUM* outstanding paper award.

**Jalyssa Smith**

The Identification of the Influence of TMS Parameters on Induced Electric Field and Volume of Activated Cortical Tissue

**Faculty Sponsor**
Dr. Amy L. de Jongh Curry

## Abstract

Transcranial Magnetic Stimulation (TMS) is a noninvasive procedure that utilizes magnetic fields to study brain function, diagnose, and treat neurological diseases. This study investigates the effect of TMS coil location, type, and orientation on induced E-field and volume of activated tissue. SimNIBS, an open-sourced platform, simulated three coil types and orientations, targeting the primary somatosensory cortex. Within the same hemisphere, E-field and volume of activation differed up to 10% and 35%, respectively. Coil orientation altered E-fields up to 11%, and volume of activation by 30%. An inverse relationship was observed between the volume of activation and magnitude of TMS-induced E-field.

## Introduction

Transcranial Magnetic Stimulation (TMS) is a noninvasive procedure utilizing magnetic fields to induce electric currents in the brain. TMS is used to study brain function through functional mapping and is approved by the Food and Drug Administration (FDA) for treatment of depression and obsessive-compulsive disorder. Ongoing research indicates that TMS may also be a viable treatment method for other neurological disorders, such as strokes and chronic pain.

The magnitude of the induced electric field (E-field) is influenced by the type of stimulation coil, orientation of the coil, and coordinates of coil placement [3]. The brain is comprised of white and grey matter and cerebrospinal fluid, which have different conductive properties. In turn, the different composition affects the resulting E-field distribution to neurons during TMS. The type of coil and orientation also affects the E-field distributions and stimulates different regions of neurons. Based on the coil orientation, the induced E-field may be parallel or perpendicular to the cortical columns, which are a group of neurons and alter the effectiveness of TMS. Moreover, the stimulation, or activation, of neurons is dependent on an appropriate induced E-field intensity.

To better understand the effect of TMS parameters, computational modeling of TMS-induced E-fields may be utilized. As an open-source computational platform, SimNIBS [1], was developed to simulate TMS-induced E-fields in physiologically realistic brain anatomy for a variety of clinically relevant stimulation coil types, coil orientations, and coil locations. SimNIBS allows for clinically relevant coil placements utilizing the Montreal Neurological Institute (MNI) brain coordinates and employs the finite element method (FEM) to simulate applied magnetic fields and resulting E-fields in the brain. In this study, we focused on stimulation of the primary somatosensory cortex (SI). Located in the parietal lobe, body surface receptor signals travel through peripheral nerves to the thalamus and relayed to SI to perceive the body and physical environment [2]. SI has been a target location in current TMS research to assist motor and sensory recovery after strokes [3]. The objective of this study was to determine if the induced E-field intensity and volume of activated cortical tissue varied for (1) homologous coil placements on the right and left hemispheres, (2) different coil placements within the same hemisphere, (3) different coil orientations, or (4) different coil types.

## Methods

### E-Field Modeling and Obtaining Volume of Activated Cortical Tissue

The TMS-induced E-field was computed using the free, open-source simulation platform SimNIBS 4 [1]. The head model used in the study was acquired from the example MRI dataset along with default settings. The platform calculates the E-field using a quasistatic form of Maxwell's equations which are [4]

**Eq. 1**
$$\nabla \cdot (\underline{\sigma} \nabla \phi) = -\nabla \cdot \left(\underline{\sigma} \frac{\partial \boldsymbol{A}}{\partial t}\right)$$

**Eq. 2**
$$\boldsymbol{E} = -\nabla \phi - \frac{\partial \boldsymbol{A}}{\partial t}$$

For each coil, SimNIBS simulations determine the magnetic vector potential (A) which is dependent on coil shape, position, and current delivered to the coil [4]. Using Eq. 1, the magnetic vector potential is calculated by relating it to the tissue-specific isotropic conductivity (σ) and electric potential (φ). FEM is implemented to calculate the electric potential and E-field (E) in units of volts per meter (V/m) using Eq. 2. SimNIBS also outputs the volume of cortical tissue with an E-field greater than or equal to 50% and 75% of the maximum E-field. In this study, we report the volume of activated cortical tissue using the E-field equal or greater to 75% as it represents the appropriate threshold in therapeutic applications of TMS [5].

### TMS Parameters

Three electrode placements were chosen within the primary somatosensory cortex on both hemispheres. In the left hemisphere, coil placements at C3 and C5, which are MNI coordinates, and a midpoint between the two were selected. In the right hemisphere, coils were placed at C4 and C6, which are homologous location to C3 and C5, respectively, and a midpoint between C4 and C6. **Figure 1** displays the electrode placements in the left hemisphere.

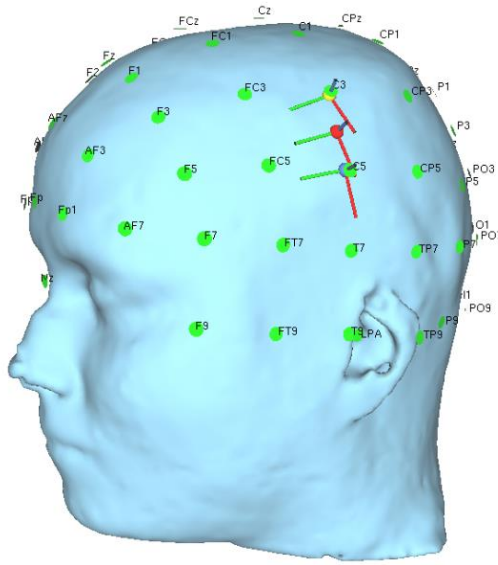



**Figure 1.** Three electrode placements in the left hemisphere, C3 (top), C5 (bottom), and a midpoint between the two. The red and green bars indicate the electrodes x-axis and y-axis, respectively.

At each electrode placement, three different orientations were tested. **Figure 2** displays the orientations, including the coil pointing toward the nose (Nz), occipital (Oz), and vertex (Fcz). Moreover, at each electrode placement and orientation, three coil types were tested including the Magstim 70 mm (Mag70) and Magstim D50 Alpha BI (MagD50), and MagVenture B70 (MagB70). The Mag70 and MagD50 coils are configured in a figure-of-eight shape with a coil diameter of 70 mm and 50 mm, respectively. The MagB70 is configured in a butterfly shape and the two figure-of-eight shaped coils are slightly bent to better conform to the shape of the head. For each simulation, the intensity of the stimulating current delivered to the coil was set to 150 A/μs. The coil was placed 0 mm from the scalp at each location. SimNIBS outputs analyzed were the induced maximum E-field and volume of activated cortical tissue to at least 75% of the maximum E-field. Percent differences were then calculated to identify the effects of coil locations, types, and orientations on the E-field intensity and distribution.

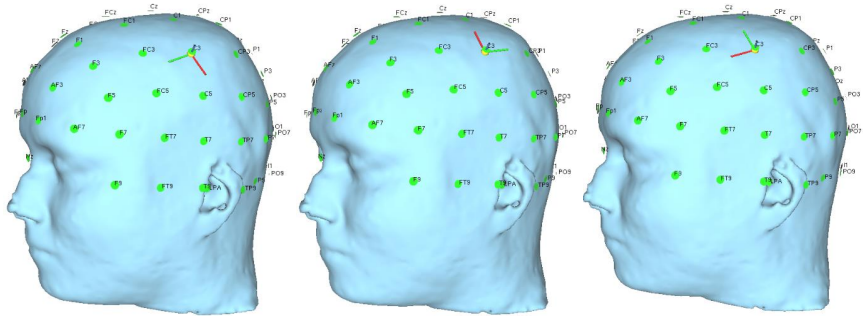


**Figure 2.** Transcranial magnetic simulation coil orientations where the red and green bars represent the x-axis and y-axis, respectively. (A) Current flowing toward the nose (Nz). (B) Coil rotated 180° in the occipital direction (Oz). (C) Coil oriented 60° toward the vertex (Fcz).

## Results

### Difference in Maximum E-Field

We obtained maximum E-Field data for three different electrode placements in the two hemispheres within SI and for different coil types and orientations. An example of the E-field distributions is shown in **Figure 3**. It also demonstrates the different E-field magnitudes and volume of activated tissue with varying coil types.

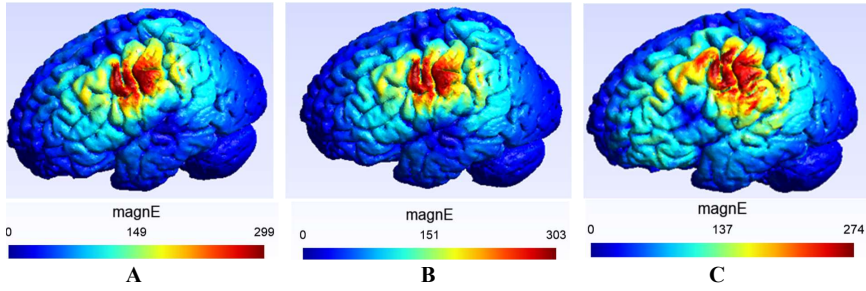
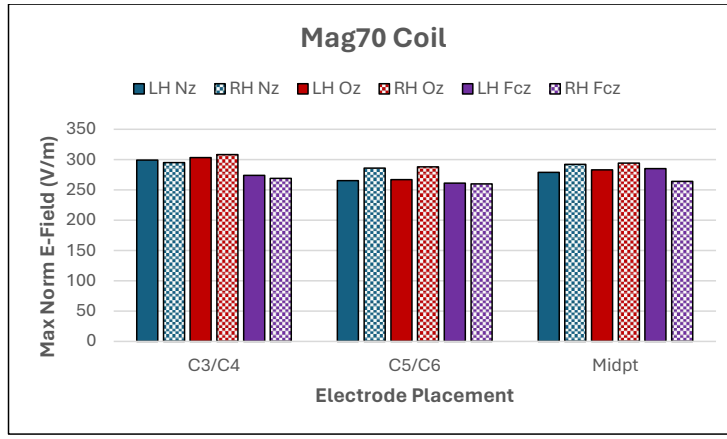
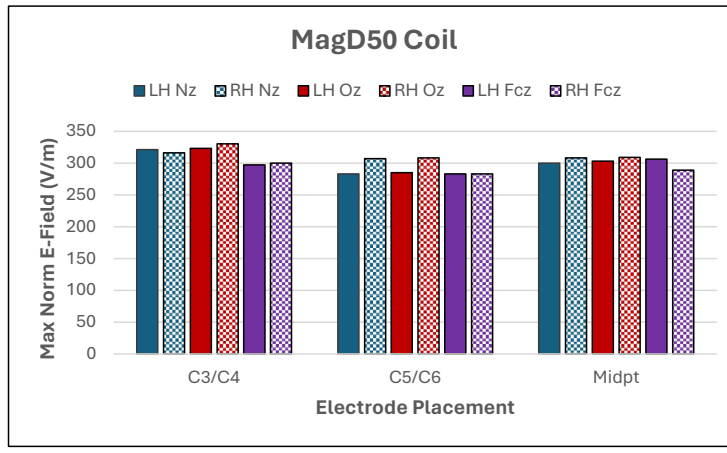



**Figure 3.** E-field magnitudes (V/m) and distributions at C3 using the Mag70 coil pointed toward (A) the nose (Nz), (B) occipital direction (Oz), and (C) the vertex (Fcz).

The maximum E-Field values are shown in **Figure 4** and ranged between approximately 250 to 300 V/m. At homologous regions in the left and right hemisphere, the percent difference between the maximum E-field were between 2–7%. Generally, electrodes C5 and C6 were noted to have the greatest differences compared to the other homologous regions. The differences between coil locations within the same hemisphere, however, was 5–10%. Regarding the coil orientation, the greatest differences were between Fcz and Nz/Oz, with 11% difference in the right hemisphere. In contrast, the difference between Nz and Oz in both hemispheres was only around 1%. Overall, the E-field intensity was greater when pointed toward Nz and Oz versus Fcz. Lastly, the Mag70 coil consistently produced 10% lower E-fields than the MagD50 and MagB70.



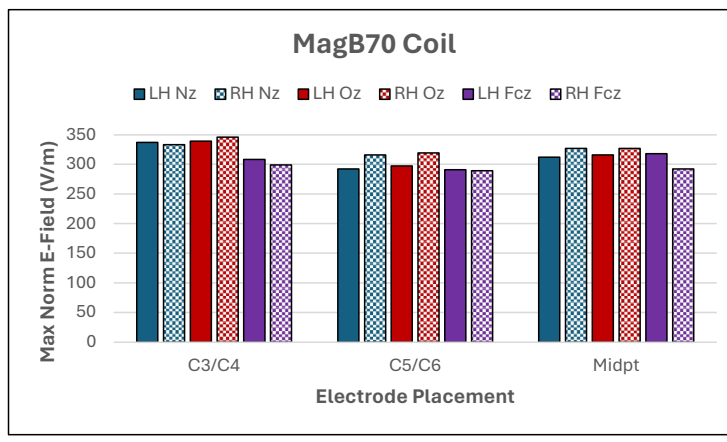




**Figure 4.** The max norm E-field at the electrode placements and orientation for the three different coils, (A) Mag70, (B) MagD50, (C) MagB70.

#### Difference in Activated Volume of Cortical Tissue

We determined the activated volume of cortical tissue for homologous electrode placements, and different coil types and orientations. The values for the activated volume of tissue are shown in **Figure 5**. The activated volume of tissue ranged between approximately 3000 to 5000 . There were 3–20% differences at homologues sites, the greater percentage difference between C5 and C6 and C4 (7% difference). Within the same hemisphere, the activated volume of cortical tissue differed significantly. In the left hemisphere the percent difference was 25% compared to the right hemisphere which was more consistent with a percent difference of 11%. The right hemisphere also experienced greater percent differences in orientations. While there were similar values when the coil is pointed toward Nz and Oz, the values were generally about 30% greater when compared to the Fcz direction. Generally, the Fcz direction had the greatest volume of activated cortical tissue as demonstrated in **Figure 3**. Moreover, the Mag70 produced about 8-10% higher than the MagD50 and MagB70.

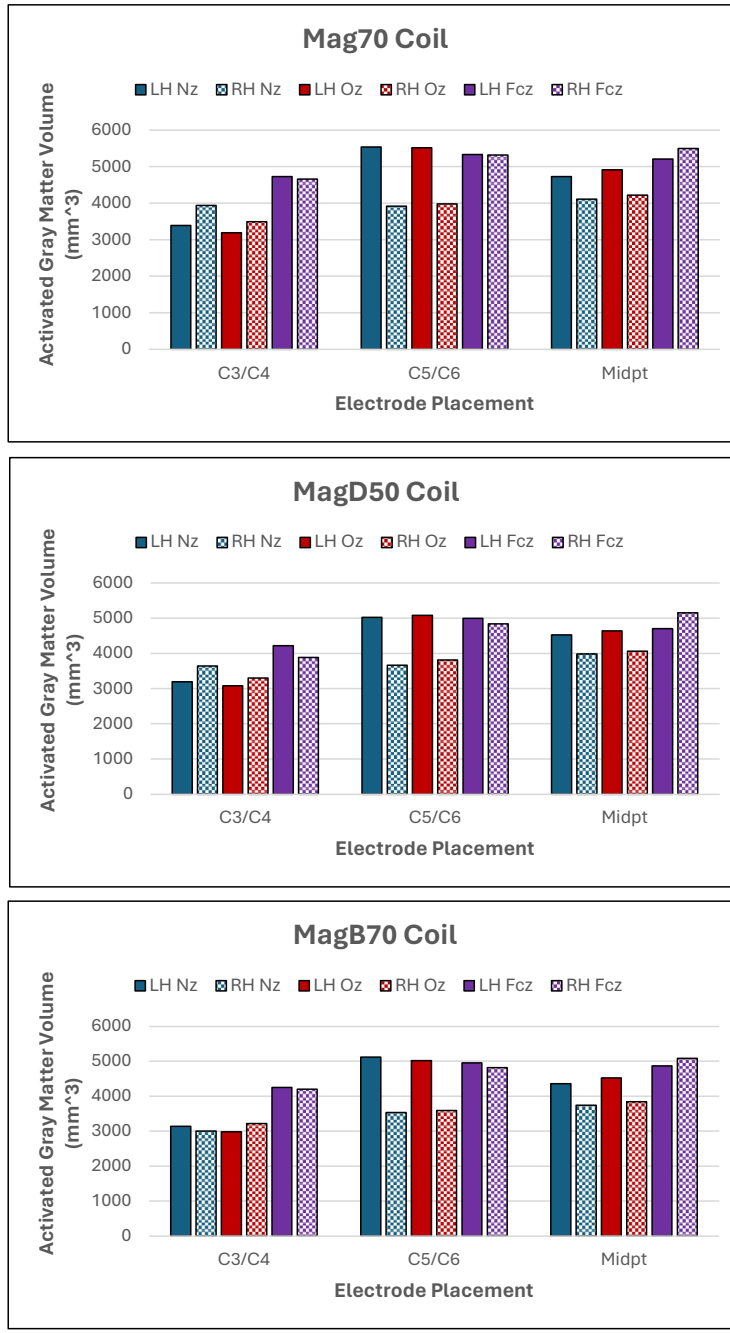



**Figure 5.** The activated gray matter volume at the electrode placements and orientation regarding coils, (A) Mag70, (B) MagD50, (C) MagB70.

## Discussion

The simulations identified that the maximum induced E-field and volume of activated cortical tissue is influenced by the coil's location, orientation, and type. These results were consistent with a previous study [5] that examined the influence of the coil's location on multiple brain areas, including SI, and orientations. Within the same hemisphere, the E-field and volume of activated cortical tissue was more variable than at homologous locations. Due to the difference in tissue conductivity between the gray and white matter and cerebrospinal fluid, the E-field and distribution will be affected. The coil pointed toward Nz and Oz also produced higher E-field, suggesting better alignment with the cortical columns. Thus, further investigation on the alignment of the coil and induced E-field may identify possible relationships. While the Mag70 produced lower E-fields than the MagD50 and MagB70, the volume of activated cortical tissue was higher. This supports the claim that smaller coil diameters and butterfly coils provide more focal magnetic fields but shallower magnetic depths [6].

The difference in induced E-field and volume of activated cortical tissue for coil types also highlights an inverse relationship. Generally, with an increase in induced E-field there is less activated volume in the cortical tissue. The trend was also demonstrated between coil orientations as Fcz produced lower E-fields, but greater activated volume of tissue. Thus, our results indicate there is a tradeoff between the focus and depth of the magnetic fields. In applications such as functional mapping, increased focal fields are desired whereas neurological treatments may require greater magnetic depth.

There were some limitations to the study. The use of isotropic conductivities throughout the brain can affect the resulting E-field distribution and size of the activated volume of cortical tissue. Moreover, due to using one head model, different tissue structures such as tumors cannot be modeled. The model also does not differentiate between neuronal elements, such as interneurons, with a differential response to TMS. Moreover, this study focused on the primary somatosensory cortex and requires additional study on other brain areas to compare and demonstrate the effect of TMS targeting different brain regions. Additional simulations may also support that TMS parameters should be individualized on a patient specific basis.

## Conclusion

Using SimNIBS, we demonstrated the effect of TMS parameters, including coil location, orientation, and type, have on the E-field and volume of activated cortical tissue. We found an inverse relationship between the maximum induced E-field and volume of activated cortical tissue. Thus, it is imperative to understand the TMS application, such as functional mapping and depression treatment, which may require more focal E-field or magnetic depth to optimize TMS diagnosis and treatment.

In future work, we plan to simulate additional head models to identify the influence of TMS parameters on varying model anatomy. Pediatric models of varying ages for TMS simulations will be completed to better understand the effects of anatomical differences in developing brain anatomy on the distribution of TMS-induced E-fields.

## References


1. SimNIBS Developers. SimNIBS 4 [Internet]. 2020. Available from: https://simnibs.github.io/simnibs/build/html/index.html

2. Raju H, Tadi P. Neuroanatomy, Somatosensory Cortex [Internet]. Bethesda: National Library of Medicine; 2022 Nov 7. Available from: https://www.ncbi.nlm.nih.gov/books/NBK555915/

3. De Freitas Zanona, A, Da Silva, ACR, Maciel, A, Shirahige, L, Da Silva, AB, Bolognini, N, & Monte-Silva, K. Somatosensory cortex repetitive transcranial magnetic stimulation and associative sensory stimulation of peripheral nerves could assist motor and sensory recovery after stroke. Frontiers in Human Neuroscience. 2022 April 11;16. https://doi.org/10.3389/fnhum.2022.860965

4. Saturnino GB, Madsen KH, Thielscher A. Efficient electric field simulations for transcranial brain stimulation [Internet]. BioRxiv (Cold Spring Harbor Laboratory); 2019 Feb 5. Available from: https://doi.org/10.1101/541409

5. Konakanchi, D, de Jongh Curry AL, Waters RS, & Narayana, S. Focality of the induced E-Field is a contributing factor in the choice of TMS parameters: Evidence from a 3D computational model of the human brain. Brain Sciences. 2020 Dec 18;10(12), 1010. https://doi.org/10.3390/brainsci10121010

6. Dargavel L. D50 Alpha BI Coil—MagstimTMS [Internet]. MagstimTMS. 2021. Available from: https://www.magstim.com/us-en/d50-alpha-bi-coil/

Noah Molder is a double major in Mathematical Sciences and Film & Video Production at the University of Memphis, graduating in the spring of 2024. He has earned the University Honors with Thesis, Honors in Mathematical Sciences, and Undergraduate Research Scholar designations, among other awards and honors. Following graduation, he will stay at the University of Memphis to complete his second year of the ABM program to earn an MS degree. He is incredibly thankful to Dr. Thomas Hagen, under whom he completed this research, for all the wonderful opportunities and advice he has offered.

**Noah Molder**

The Nontransitive Dice: New Results for a Statistical Paradox in a Game of Chance

**Faculty Sponsor**
Dr. Thomas Hagen

## Abstract

Given three dice, can we place the numbers 1 through 6 on the dice, allowing repetitions, so that after a first player chooses one die of the three, the second player can always choose a die with a higher probability of rolling a greater number from the remaining two? If so, is it possible to optimize the chances of winning? Here, we have discovered the "best" set of so-called nontransitive dice under our conditions and using our specific choice of meaning for "best," which indeed optimizes winning chances. This research project draws on techniques from probability theory, combinatorics, complexity theory, game theory, and scientific computing. The topic falls in the category of nontransitive games, a research area in Mathematics and Economics, and combines theoretical and practical methods. This research was completed in collaboration with Dr. Thomas Hagen and Tyler Owens.

## The Game

Imagine you and an opponent are playing a game consisting of three 6-sided dice. To begin, you will place the numbers 1 - 6 on the three dice in any way you like, allowing repetition. For example, you could create a die that is all ones, denoted as (1,1,1,1,1,1), or perhaps just the even numbers, (2,2,4,4,6,6), or even a random mix, maybe (2,3,3,4,4,5).

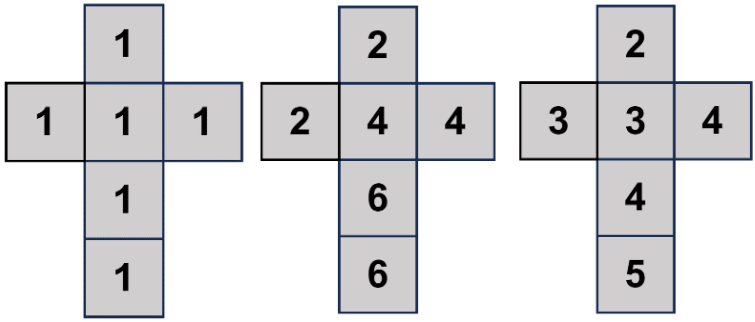



**Figure 1.** Example Dice Nets

It is important to note here that the placement of these numbers on a die does not matter. For example, the two dice (2,2,3,3,3,6) and (3,6,2,3,2,3) are equivalent in our game. To avoid double counting, we only accept dice whose sides are labeled in non-decreasing order. This means we will only accept the first of these two equivalent dice because the numbers do not decrease from left to right as they do in the second. The four dice we have named so far, as well as the other 458 dice that are possible under these conditions, are perfectly valid for the game. Now that you have created the three dice, your opponent will choose one of them, and you will choose one of the remaining two. You each roll your die, and whoever rolls a higher number is the winner.

The game seems quite simple at first, but let us put some money on it. Let us say that you and your opponent both wager a dollar each time you roll the dice. If you just want to make sure you do not lose, you could make all of them normal 6-sided dice, (1,2,3,4,5,6), and things would remain relatively even. But, if you want to really win, you will have to employ some sort of strategy.

So, what might you try? Perhaps you try to create one die that is stronger than the other two. This could work as long as your opponent does not choose the die that is obviously better, which would be unusual. So, perhaps you make two dice that are strong and leave one to be weak. Then you and your opponent both have strong dice, and things are back to being equal again. You may begin to wonder if there is any way you can guarantee that, over time, you will win big or if this all must be left to chance. As it turns out, you can ensure that you will win, no matter the choice of your opponent, thanks to a paradox of probability known as "nontransitive dice".

## Exploring Nontransitivity

Before we take a look at nontransitivity and nontransitive dice, we should first understand transitivity. Transitivity is present in a majority of the relations we see day-to-day, which means it is very intuitive and, by association, is the reason that nontransitivity tends to be counterintuitive. As an example, let us take three people named Adam, Bob, and Charlie, and look at their heights. When we stand Adam next to Bob, we see that Adam is taller. When we stand Charlie next to Bob, we see that Bob is taller. By taking just these two comparisons, we know who of Adam and Charlie will be taller without ever standing them next to each other. Adam is taller than Bob who is taller than Charlie. So, Adam must be taller than Charlie. This is true because "taller than" is what is called in mathematics a 'transitive relation'. If "taller than" were nontransitive, we would not be able to say anything about Adam and Charlie solely through their comparisons with Bob. You may now be thinking, well then, is not every relation transitive? They are not, but to see an example, we will have to do a bit of abstraction.

Considering that we are working with a game of dice, try to think of some sort of game that could be nontransitive. Perhaps a sport comes to mind. Let us take three baseball teams: the Angels, the Braves, and the Cubs. They play three games: the Angels beat the Braves in the first, and the Braves beat the Cubs in the second. We will use the symbol "$\succ$" to denote that one team beats another; that is to say that "$i \succ j$" will mean that $i$ beats $j$. Referring to each team by the first letter of its name, the results of the first two games will look like $A \succ B$ and $B \succ C$. If this relationship were transitive then the Angels would certainly beat the Cubs in the third game, but this is not necessarily the case. $A \succ B \succ C$ may be true, but it does not have to be.

But, there are many variables involved in a sports game. So, let us try something a bit more concrete and familiar. How about a game of Rock, Paper, Scissors? As we all know, rock beats scissors, $R \succ S$, and scissors beats paper, $S \succ P$. If transitivity were true for this relation, we would have $R \succ S \succ P$, but that is not the case (if it were, you could never lose by choosing rock every round). $P \succ R$ is true, meaning that Rock, Paper, Scissors is an example of a nontransitive game. The winning results in the game form a cyclical relationship, which we refer to as a nontransitive loop. This is the relationship we want to replicate with our dice.

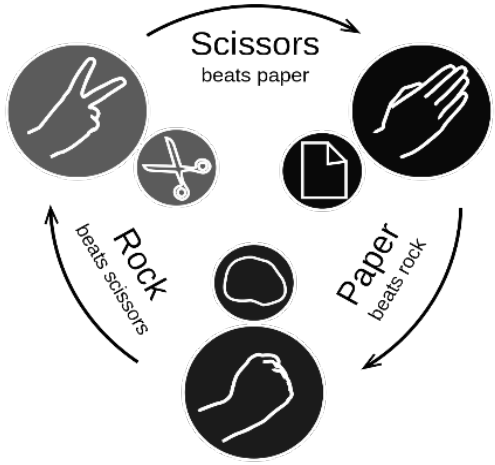



**Figure 2.** Rock, Paper, Scissors Nontransitive Loop
From Enzoklop, [1]

## Nontransitive Dice

While our dice game can be modeled closely after Rock, Paper, Scissors, there is one crucial difference. In Rock, Paper, Scissors, you and your opponent must make your choices at the same time, but in our dice game, this is not how we play. Recall that your opponent will select a die first, and then, knowing what they have chosen, you make your choice. Imagine knowing that your opponent has chosen rock and then getting to pick second. It is up to you to choose paper (in that example), but knowing your opponent's choice should ensure that you never lose. In our game, you will know your opponent's choice. So, as long as you choose your die correctly, you will always come out on top.

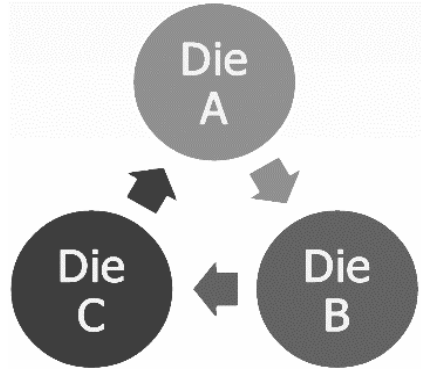



**Figure 3.** Three Dice Nontransitive Loop

With this in mind, we can try to create a set of nontransitive dice. Through the simple but lengthy process of trial and error, the set that I found when the problem was first posed to me contains dice represented by: A - (2,2,3,5,5,6), B - (2,3,4,4,5,5), and C - (3,3,3,4,5,5).

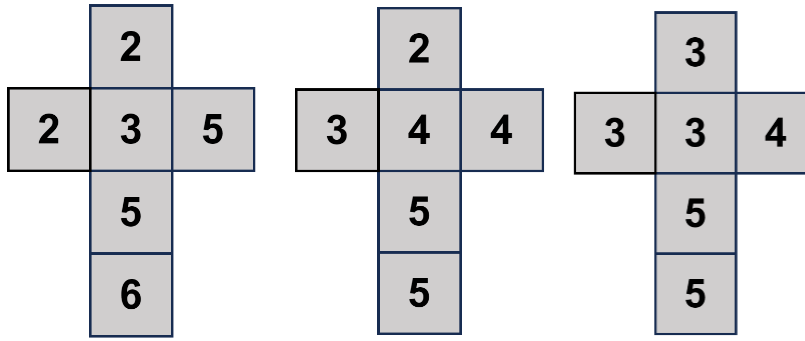



**Figure 4.** Nets of Nontransitive Dice Set

To check that these three dice truly form a nontransitive set, we have to compare each die with every other die. In each comparison, since there are 6 ways one die could land and 6 ways the other die could land, we have 6 x 6 = 36 possible outcomes. We will check what happens in each one of these cases, as in, we will compare one face of a die with each face of another die to see when it wins (when its number is greater than the number on the other die) and then repeat with each face of the first die. The number

of times a face beats a face of the other die will be that face's score, and we will add all of these scores together to get the die's total score. Score here is the same as the number of times out of 36 possibilities that a die will roll a higher number; thus, when we have compared two dice with each other, the one with the higher score will be declared the winner.

In general, the process of comparing two dice is as follows: Consider dice A and B, A with sides $a_i$ and B with sides $b_j$ where $1 \leq i \leq 6$ and $1 \leq j \leq 6$. Compare each $a_i$ with each $b_j$. If $a_i > b_j$: Score(A) increases by 1. If $a_i < b_j$: Score(B) increases by 1. If $a_i = b_j$: no score increases. Then, compare Scores. If Score(A) > Score(B): A wins. If Score(A) < Score(B): B wins. If Score(A) = Score(B), neither wins. It is also true that if Score(A) > 18 or Score(B) > 18: that die will win (since $18 = \frac{36}{2}$, meaning the die wins in over half the cases).

Looking back at my dice set, let us begin with checking A and B. If a 2 is rolled on A, it cannot beat B no matter what happens since there are no 1s on B. The same is true for both 2s on A, so these faces earn scores of 0. If A rolls a 3, it wins in the one case that B rolls a 2, so it receives a score of 1. The two 5s on A beat the 2, 3, and 4s on B, so they get scores of 4. Lastly, since there are no 6s on B, the 6 on A beats all six faces of B, so it gets a score of 6. Adding these scores together: 0+0+1+4+4+6=15, so in the match of A vs. B, A scores a 15.

Now let us see how B stands against A. B's 2 face scores 0, the 3 face scores 2, the 4 faces score 3, and the 5 faces score 3. So, 0+2+3+3+3+3=14, which means B's score is one less than A's score in A vs. B. So, $A \succ B$. Now we have to check B vs. C and A vs. C. The scores from here on will be left for the reader to verify. In B vs. C, B scores a 14 and C scores a 13, so $B \succ C$. In A vs. C, A scores a 14 and C scores a 15, so $C \succ A$. Let us assume this set is transitive and see if it holds. Taking the first two results, $A \succ B$ and $B \succ C$, we would be able to say that $A \succ B \succ C$ which would mean $A \succ C$, but we know that $C \succ A$, so this set is nontransitive.

Another set of nontransitive dice, found by Tyler Owens, consists of A - (1,1,4,4,5,5), B - (2,2,3,3,3,4), and C - (1,2,2,2,6,6). Our verification process for this set will be exactly the same. In A vs. B, A scores a 20 and B scores a 12, so $A \succ B$. In B vs. C, B scores an 18 and C scores a 12, so $B \succ C$. In A vs. C, A scores a 16 and C scores an 18, so $C \succ A$. Again we see that $A \succ B$, $B \succ C$, but $C \succ A$. So, this set is, in fact, nontransitive. While these sets are both nontransitive, they are not equal in all regards. You may notice, the scores in each match are much closer in my set than

in the Owens set. The difference between the two scores in a given match will be called the "win difference". All of the win differences in my set are 1, while the Owens set has win differences of 8, 6, and 2. In theory, playing with either set will result in you winning over time, but my set does so at a far slower rate.

When looking in terms of these win differences, it is clear that the Owens set is better than my set. To say that one set is better than another – and assuming that there are more sets of nontransitive dice under our conditions than the two we have found – raises the question: is there a best solution, and, if so, what is it?

## Searching for the Best Solution

To begin, we must note that there is no one way to define a "best solution," so we need to decide what it is exactly that we are looking for. We chose to look for the solution with the highest sum of win differences as our "best solution". Now, with that in mind, the simplest route forward is to check all the solutions and choose the best one. To find all of the solutions, we will check all of the possible combinations of dice. This will certainly require the aid of a computer program, but even then, there are not unlimited capabilities. We first checked the number of combinations we would have to deal with. Given our conditions, each of the 6 faces of a die can have any one of 6 numbers on it. This means there are $6^6 = 466{,}566$ ways to create one die. Since our game has 3 dice, we compare all possible sets of 3 dice. This makes a grand total of $(6^6)^3 = 101{,}959{,}596{,}668{,}416$ possible games that we would have to check. That is over 100 trillion combinations, which is far too much to run even via program, so, we found a way to simplify.

When using  to calculate the number of dice, we indeed counted them all, but we also counted every permutation of every die. This means that the valid die called (1,1,1,1,1,2) has also been counted under the names (1,1,1,1,2,1), (1,1,1,2,1,1), (1,1,2,1,1,1), (1,2,1,1,1,1), and (2,1,1,1,1,1).

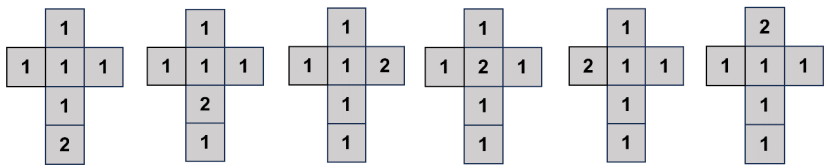



**Figure 5.** Nets of Set of Die Permutations

Recall that only one of these dice, the one with labels in nondecreasing order, is valid. So, we need another way to construct these dice that includes the ones we want to consider and does not include these extraneous permutations.

We can start by setting the first number on a die, denoting the nth number on the die as D(n). When the first number, D(1), is set, we have limited possibilities for the second number, D(2); it must be greater than or equal to D(1). In general, D(n+1) must always be greater than or equal to D(n). Let us use a die that starts with a 4, for example. For D(1) = 4, D(2) could be 4, 5, or 6. If D(2) = 4, then again the next number, D(3), could be 4, 5, or 6, but if D(2) = 5, then D (3) can only be 5 or 6, and if D(2) = 6 then D(3) must be 6. So now, deciding just the first three sides of a die with D(1) = 4, we have 6 possibilities. If we continue this process to its conclusion with D(6), we will see that there are 21 possible dice where D(1) = 4. We must also execute this process for D(1) = 1,2,3,5,6, and then we will add all of these possibilities together. When we do this, we produce 462 total possible valid dice. This means there are only $462^3 = 98{,}611{,}128$ combinations to check. This number (just under 100 million), while still very large, is much more manageable.

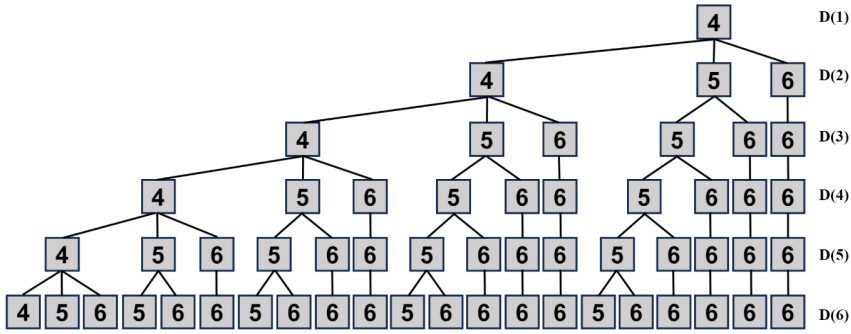



**Figure 6.** Branch Diagram for Dice with D(1) = 4

Next, we needed a strategy for computing the best solution. The first step in writing the program, which can be found in the appendix, was to create the dice. While the way we have named the dice is easy for us to understand, it is not as easy or efficient to program them in the same way. So, instead of naming the dice by the numbers that appear on the faces of the die, we name them by the frequency which each number appears. Because there are 6 numbers that can appear on these dice, each die will become

an array of 6 components, each representing a different number 1 - 6. For example, we will take a die from my set, the one named (2,2,3,5,5,6), and represent it in our new array form. We can start with a blank array (notice the bracket notation instead of parentheses): [-,-,-,-,-,-]. The first component will represent the frequency of ones. This particular die has 0 ones, so we will fill that spot in with a 0: [0,-,-,-,-,-]. For the second component, we note that the die has 2 twos, so we fill in: [0,2,-,-,-,-]. Then 1 three: [0,2,1,-,-,-], and so on until we get the completed array, which in this case is [0,2,1,0,2,1]. Because we are using dice with 6 sides, any die that we rename in this new array form will have the total of its components equal to 6. This allows for much simpler programming.

We wrote the program using a series of "for" loops to give us the dice. Essentially, we loop through the frequencies of each number from 1 to 6, which will result in all of the dice forming in a specific order, which will be useful later. For Die 1, we start with a 6 in the sixes place: [0,0,0,0,0,6], or (6,6,6,6,6,6). Then for Die 2, we have one less six and add a five: [0,0,0,0,1,5], or (5,6,6,6,6,6), followed by having 2 to 6 fives: [0,0,0,0,2,4], [0,0,0,0,3,3], [0,0,0,0,4,2], [0,0,0,0,5,1] and [0,0,0,0,6,0]. Then we add 1 four, beginning with [0,0,0,1,0,5] and looping through the different numbers of fives and sixes until we end with [0,0,0,1,5,0]. We then do the same for 2 to 6 fours and then all possibilities of numbers in this fashion, ending on Die 462: [6,0,0,0,0,0], or (1,1,1,1,1,1). This process outputs a matrix we named "DiceFreq", which is a 462-row matrix (one row for each die) with 6 columns for the different frequencies. Each die array is now a row in this matrix.

We can then use DiceFreq to create a matrix of win differences. It is, in this case, a 462 x 462 matrix where each die is compared with each die, including itself, and the net wins, or win difference, is stored in that position of the matrix. That is to say, in position $(i, j)$ of the matrix (row $i$ and column $j$), the entry, $a_{i,j}$, is net wins of Die $i$ over Die $j$. We do this by multiplying the number of sixes on Die $i$ by the number of faces less than Six on Die $j$ (because each six will win in each of these cases). We add this to the number of fives on $i$ times the number of faces less than 5 on $j$, and so on until we have added the 5 products (we can ignore ones since they never win). This is why it is so beneficial to store the dice by their frequencies as we did in DiceFreq. To do these win difference calculations, we need to know the frequency which each number appears, which is exactly what we have. DiceFreq$(m, n)$ is the number of faces labeled

"$n$" on Die $m$. For example, DiceFreq(289,4) is the number of fours on Die 289. So, when comparing Die 289 with Die 46, we have the fours step in calculating $a_{289,46}$:

DiceFreq(289,4)(DiceFreq(46,3)+DiceFreq(46,2)+DiceFreq(46,1)).

This serves mostly as an intermediary step towards our solution, but there are a couple of interesting things to note. When $i = j$, also known as the entries on the diagonal of the matrix, $a_{i,j} = 0$. This is because we will be comparing a die with itself when $i = j$, and no die will have any advantage when rolled against itself. It is also worth noting that this matrix is skew-symmetric. This means that, $a_{i,j} = -a_{j,i}$, or for example, $a_{64,351} = -a_{351,64}$. This occurs because, in these cases, we are comparing the same two dice; we are just counting the net wins from different perspectives. Taking any dice A and B, if A beats B 12 times, then it must be the case that B beats A -12 times; the negative is also interpretable as denoting net losses.

The final step is writing code that will analyze this win matrix and tell us where any 3 dice – A, B, & C – have the relationship that we are looking for: $A \succ B$, $B \succ C$, $C \succ A$. This will show us all solutions to our problem. From there, we can narrow the results further to find whether there is a best solution.

## Results

We learned several things from running this program. They are as follows: Using only 3 different numbers on the dice (or 1 or 2 different numbers, for that matter, but these are trivial) is not enough to create a set of nontransitive dice. 4 different numbers are the minimum required. Out of the nearly 100 million possible sets, only 121,998 sets are nontransitive. Because of the way we wrote our program, each set appeared in our results 3 times under different permutations, so, as before, we eliminate these extras. Dividing the total by three gives the true number of different sets of nontransitive dice, leaving us with 40,666. Now we look at the win differences of these sets to determine the best. We found that three sets contained the highest minimum win difference, meaning the least of their three win differences was higher than the least win difference in any other set, which was 6. Two of these sets: {(3,3,3,3,4,6), (2,2,2,5,5,5), (1,4,4,4,4,4)} & {(1,3,4,4,4,4), (3,3,3,3,3,6), (2,2,2,5,5,5)}, have win differences summing to 21. The remaining set has the greatest sum of win differences, 26, meaning that, by our definition of "best," this will be the singular, best solution.

The three dice in the best set are A - (3,3,3,3,3,6), B - (2,2,2,5,5,5), & C - (1,4,4,4,4,4).

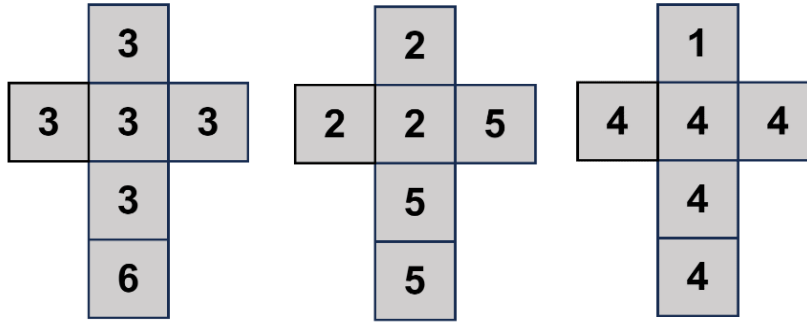



**Figure 7.** Nets of Best Set of Nontransitive Dice

Upon a quick glance at the dice in this set, you will notice a striking symmetry. Picturing the faces as dots above a number line, if we reflect A over a line at 3.5, we get C (and vice versa). B itself has perfect symmetry when reflected over this line at 3.5; it is identical to its own reflection. These symmetries were unexpected, but they are intriguing to explore.

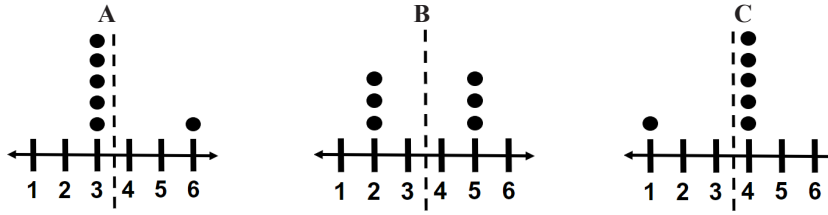



**Figure 8.** Number Line Constructions of Best Set

Looking at the matchups of this set, A ≻ B and B ≻ C both with win differences of 6, and C ≻ A with a win difference of 14. These win differences, particularly in the last case, are far greater than those in the original two sets that we discovered. With this set, if your opponent is unwise enough to choose Die A and you make the right choice of Die C, you will win more than twice as often as them. Even if they make the better choice of Die B or Die C, you will still have all their money in no time.

## Additional Research

Much research has been done on this topic, exploring many related questions. Some examples are: “When can these sets of nontransitive dice exist?”, “How large can the sets be?”, and “Can you create a game for more than two players?” More information and answers to these questions can be found in [2], [3] & [4], and [5], respectively.

## References


[1] Enzoklop.https://commons.wikimedia.org/wiki/File:Rock-paper-scissors.svg

[2] Schaefer, A., & Schweig, J. (2017). Balanced nontransitive dice. *The College Mathematics Journal*, *48*(1), 10–16. https://doi.org/10.4169/college.math.j.48.1.10

[3] Gardner, M. (1970). Mathematical games. *Scientific American*, *223*(6), 110–115. http://www.jstor.org/stable/24927686

[4] Angel, L., & Davis, M. (2017). A direct construction of nontransitive dice sets. *Journal of Combinatorial Designs*, *25*(11), 523–529. https://doi.org/10.1002/jcd.21563

[5] Grime, J. (2017). The bizarre world of nontransitive dice: Games for two or more players. *The College Mathematics Journal*, *48*(1), 2–9. https://doi.org/10.4169/college.math.j.48.1.2

# Appendix

```
% Create all the dice by the frequency of their labels
DiceFreq=zeros(462,6);
counter=0;
for ones=0:6
     for twos=0:(6-ones)
          for threes=0:(6-ones-twos)
               for fours=0:(6-ones-twos-threes)
                    for fives=0:(6-ones-twos-threes-fours)
                         counter=counter+1;
                         DiceFreq(counter,1)=ones;
                         DiceFreq(counter,2)=twos;
                         DiceFreq(counter,3)=threes;
                         DiceFreq(counter,4)=fours;
                         DiceFreq(counter,5)=fives;
                         DiceFreq(counter,6)=6-fives-fours-threes-twos-ones;
                    end
               end
          end
     end
end
% Compare all dice with matrix of Win Differences
W=zeros(462,462);
for i=1:462
     for j=(i+1):462
W(i,j)=DiceFreq(i,2)*DiceFreq(j,1)+DiceFreq(i,3)*(DiceFreq(j,2)+DiceFreq(j,1))+Dice
Freq(i,4)*(DiceFreq(j,3)+DiceFreq(j,2)+DiceFreq(j,1))+DiceFreq(i,6)*(DiceFreq(j,5)+
DiceFreq(j,4)+DiceFreq(j,3)+DiceFreq(j,2)+DiceFreq(j,1))+DiceFreq(i,5)*(DiceFreq(j,
4)+DiceFreq(j,3)+DiceFreq(j,2)+DiceFreq(j,1)) -
(DiceFreq(j,2)*DiceFreq(i,1)+DiceFreq(j,3)*(DiceFreq(i,2)+DiceFreq(i,1))+DiceFreq(j
,4)*(DiceFreq(i,3)+DiceFreq(i,2)+DiceFreq(i,1))+DiceFreq(j,6)*(DiceFreq(i,5)+DiceFr
eq(i,4)+DiceFreq(i,3)+DiceFreq(i,2)+DiceFreq(i,1))+DiceFreq(j,5)*(DiceFreq(i,4)+Dic
eFreq(i,3)+DiceFreq(i,2)+DiceFreq(i,1)));
W(j,i)=-W(i,j);
     end
end
% Find all Nontransitive sets
counter=0;
for i=1:462
     for j=1:462
          for k=1:462
               if (W(i,j)>0) && (W(j,k)>0) && (W(k,i)>0)
                    counter=counter+1;
                    Result(counter,:)=[i,j,k];
               end
           end
      end
  end
  % Calculate all minimum Win Differences
  for index=1:counter
       i=Result(index,1);
       j=Result(index,2);
       k=Result(index,3);
       WinDist(index)=min([W(i,j),W(j,k),W(k,i)]);
  end
  MaxDist=max(WinDist);
  WinLoop=find(WinDist==MaxDist);
  Result(WinLoop,:)
```

# Submission Guidelines

## Eligibility

We consider papers on any research conducted by undergraduates at the U of M. Authors may be current U of M students, participants in U of M summer research programs, or students who have completed their undergraduate programs within the past three semesters. Papers may be single or co-authored, but at least one primary author must have been an undergraduate student at the time the research was conducted. In cases where students are members of a larger research team, the paper should reflect the students' contribution to the larger project.

## Content

Submissions should not be creative manuscripts. Instead, they should present analysis of some type of data. In the case of collaborative research with faculty, papers should focus on the students' contribution to the larger project. While there is no minimum or maximum length for submissions, we understand that different disciplines have different norms, and that the length of submissions will vary. However, 8000 words or less is preferred. Any research involving human subjects should have received approval from the appropriate Institutional Review Board (IRB). Authors (in consultation with their faculty sponsors) are responsible for adhering to IRB guidelines.

## Copyright

Submissions may not be under review for publication elsewhere. Authors retain copyright of their work and may publish their papers elsewhere after their Volume of *QuaesitUM* is published, provided the requirements of all parties are satisfied. Given the hard work that our editorial team puts into each paper prior to publication, if you publish your work elsewhere, we ask that you include an acknowledgement of *QuaesitUM* and its editorial staff.

## Deadline for Submissions

Submissions are accepted anytime. All papers received by the first Friday of the spring semester will be considered for the volume being published in May/June. When possible, late submissions will be published the same year, but if not, they can be considered for the next volume.

## Format

1. **Remove all occurrences of author(s) names** from the manuscript.

2. Submit a cover sheet **as a separate document** that contains the following information:

   (1) name of the author or authors,
   (2) date,
   (3) title,
   (4) citation style,
   (5) faculty sponsor*, and
   (6) your paper's category (according to the groups below)

   - Life and Health Sciences
   - Physical and Applied Sciences
   - Math/Computer Science/Engineering
   - Social and Behavioral Sciences
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   - Professional

   *The faculty sponsor is someone who supervised the research and provided guidance for the paper. They should agree to be contacted to recommend reviewers.

3. Upload an abstract of 150 words or less.

4. **Manuscript Formatting**

   - Upload your manuscript as a *.docx* or *.doc* file. (Let us know if your academic discipline uses a different format.)
   - Use size 12 Times New Roman.

- Include page numbers.
- Include a references page that follows the appropriate citation format for your field of study.
- Please single-space all submissions. Other than that, manuscripts should follow the formatting conventions for your discipline (italics, punctuation, capitalization, footnotes, citation style).

5. **Figues and Tables**

- Tables should be no more than 5 inches wide.
- Avoid extremely small letters/details whenever possible. These can become too small to read if we have to shrink the figure/table to fit within the 5”-page width.
- Provide a number and title for each figure and table.
- Place all figures and tables in your manuscript.
- Files must be a minimum of 300 pixels per inch (ppi).
- Also upload each table and figure in a separate file.
- Files must be a minimum of 300 pixels per inch (ppi).
- Figures should be in PNG, PDF, JPEG, TIFF, or EPS format.

6. Carefully check that each item in your references section follows the **punctuation, capitalization, and italicization** conventions of your citation style (APA, MLA, etc.).

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## Revision Process

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