

AJUR

American Journal of
Undergraduate Research

Volume 23 | Issue 3 | September 2026

www.ajuronline.org

Print Edition ISSN 1536-4585
Online Edition ISSN 2375-8732

AJUR

American Journal of
Undergraduate Research

Volume 23 | Issue 3 | September 2026 | <https://doi.org/10.33697/ajur.2026.176>

- 2 ***AJUR History and Editorial Board***
- 3 ***Adherence to the Photovoice Method in Food Insecurity Research: A Methodological Review***
Victoria R. Braynin, Amy T. Galloway, & Christopher M. Seitz
- 15 ***Examining Barriers to the Application of Modern Construction Technologies in Historic Building Treatments in Metro Detroit***
Alexander F. Okoh & Sooin Kim
- 29 ***Implementation of Buprenorphine After X-Waiver Elimination: A Health System Review of Rural North Carolina***
Madison Wood, Lori Ann Eldridge, Courtney Pope, Beth E. Meyerson, & Christopher Norman
- 45 ***Demographic Influences on Cooperation in One-Shot, Anonymous Prisoner's Dilemma Games***
Peyton Strack & Elana Reiser
- 53 ***Mathematical Models for Coupling Rocket Trajectory with Passive Stability***
Jonathan A. Bartik & Mohammad Mabbubur Rahman
- 73 ***A Comparative Study of MBTI- and Learning Style-Based Grouping for Enhancing Group Effectiveness and Balance in Problem-Based Learning***
Basith Nasik & Shanna Nifoussi

American Journal of Undergraduate Research (AJUR) is a national, independent, peer-reviewed, open-source, quarterly, multidisciplinary student research journal. Each manuscript of AJUR receives a DOI number. AJUR is archived by the US Library of Congress. AJUR was established in 2002, incorporated as a charitable not-for-profit organization in 2018. AJUR is indexed internationally by EBSCO and Crossref with ISSNs of 1536-4585 (print) and 2375-8732 (web).

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Adherence to the Photovoice Method in Food Insecurity Research: A Methodological Review

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<https://doi.org/10.33697/ajur.2026.177>

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ABSTRACT

Introduction: Photovoice is a community-based participatory research tool critical in engaging participants as collaborators to determine the health needs of their communities. The photovoice method is defined by its three major goals: (1) to support participants' use of photos to document community needs, (2) to facilitate participants' group discussion about community issues highlighted in their photos, and (3) to exhibit the photos as a way to reach policymakers and advocate for community change. The purpose of this methodological review was to assess the extent of how photovoice's three major goals were achieved in food insecurity research that used the photovoice method. **Methods:** Peer-reviewed articles were searched for using the search terms "photovoice" and "food insecurity" in the databases PubMed and CINAHL. Additional articles were located using backward and forward chaining of reference lists. Inclusion criteria were defined to determine the articles' eligibility for review. Articles were assessed for their level of achievement of each photovoice goal (e.g., full, partial, none). **Results:** A total of 19 articles were included in the literature review, which described 15 different photovoice projects. Overall, the photovoice projects underachieved the goals of photovoice. Specifically, only two of the photovoice projects fully achieved each photovoice goal, and five projects at least partially achieved each goal. **Conclusion:** In sum, the literature review's findings emphasize the need for projects labeled as "photovoice" to implement all the fundamental goals of the method.

KEYWORDS

Photovoice; Food Insecurity; Community; Participatory research

INTRODUCTION

During the 1990s, Wang and Burris developed the "photovoice" method of research. In their groundbreaking articles, Wang and Burris defined photovoice according to three major goals of the method: (1) to support participants' use of photos to document community needs and assets, (2) to facilitate participants' group discussion about community issues highlighted in their photos, and (3) to exhibit the photos as a way to reach policymakers and advocate for community change.¹⁻³ Wang³ described photovoice as a type of participatory action research, and others have characterized it as community-based participatory research (CBPR).⁴ These research methods view participants as colleagues who are involved throughout the entire research process, including the dissemination of findings and efforts to enact change and improve a community's wellbeing.³⁻⁵ There are several benefits to conducting CBPR, including that a study and its data are relevant to community members, that the health issue being studied is given context by community members' knowledge, and that positive change in the community is an expected outcome.⁵

To help others conceptualize and implement photovoice projects, Wang and Burris provided practical, concrete steps to fulfill photovoice's major three goals.^{2,3} In terms of photovoice's first goal, Wang and Burris recommend that participants be trained on: an introduction of the photovoice method with an emphasis on reaching policymakers, the assignment of what participants should take photos of (which could be determined by the participants), the ethical practices of taking photos (i.e., appropriate ways of approaching and asking others for permission before taking photos), the provision of cameras if participants did not have a camera, and simple tips on taking photos (e.g., lighting, framing). Participants are then given a specific amount of time (i.e., one week) to take photos before meeting again to discuss the photos.^{2,3}

Regarding the second goal of photovoice, a group discussion is facilitated for participants to share, contextualize, and analyze their photos. During the group discussion, each participant selects a few photos that are important to them and then shares their meaning with the other participants. Wang recommends that researchers guide participants through group discussion using the "SHOWeD" mnemonic,⁶ which stands for: What do you See here? What's really Happening here? How does this relate to Our

lives? Why does this situation exist? What can we Do about it? The SHOWeD mnemonic can help participants to provide a critical contextual story behind each photo, which identifies the root of a problem and provides space for discussing potential strategies for improvement. Afterwards, participants qualitatively analyze their photos by categorizing the issues that were discussed into major action-oriented themes.^{2,3}

The third goal of photovoice involves planning how to use the photos to reach policymakers. Based on the group discussion and analysis, researchers should work with participants to plan a format to share photos and stories with community leaders. By doing so, participants have an opportunity to have their voices heard, by using their photos as talking points to address issues in the community and to advocate for change.^{2,3}

The literature suggests that not all studies labeled as “photovoice” have adhered to the method’s defining characteristics, especially in terms of advocacy efforts. The use of photovoice has grown in popularity over the past several decades, with thousands of photovoice studies published in peer-reviewed articles from various fields (e.g., public health, medicine, social work, psychology).⁷ Several literature reviews have been conducted on photovoice studies and have specified where studies have not achieved the three major goals of photovoice. Seitz and Orsini⁸ summarized the limitations mentioned in 15 separate literature reviews, totaling 593 published photovoice studies, including the common critique of photovoice projects not using photo exhibits to give participants an opportunity to speak with policymakers.

Although previous literature reviews have critiqued photovoice projects in general, the purpose of this study was to assess the extent to which photovoice’s three major goals were achieved specifically within food insecurity research that used the photovoice method. Food insecurity is a major public health issue in the United States (U.S.), with 18 million households reporting food insecurity in 2023,⁹ being defined as “a household-level economic and social condition of limited or uncertain access to adequate food.”¹⁰ Several factors can influence food insecurity, including, socioeconomic status, race/ethnicity, disability, neighborhood conditions, and lack of transportation.¹⁰ Food insecurity increases the risk of several negative health outcomes and health disparities, including obesity, malnutrition, chronic diseases, and children’s physical development and mental health.¹⁰

In response to the challenge of food insecurity, Gallegos and Chilton¹¹ suggest there is a major knowledge gap between people who hold positions of power that seek to alleviate food insecurity (e.g., academics, politicians, leaders of non-governmental organizations) and those struggling with the issue, which can result in the exclusion, marginalization, and exploitation of people who are experiencing food insecurity. As such, Gallegos and Chilton¹¹ recommend that scholars collaborate with participants in food insecurity research and practice to co-create an understanding of both the problems and solutions of food insecurity. This recommendation is reflected in the growing body of research in which scholars have used participatory research to address food insecurity in communities.^{12–14}

Photovoice has been one method of participatory research used in several studies on food insecurity; however, a methodological review of those studies regarding adherence to the initial photovoice method goals as defined by Wang and Burris has yet to be conducted. As such, this methodological review of the literature aimed to assess the published studies that used photovoice to address food insecurity to identify if those studies achieved each of the three major goals of photovoice, and to suggest how photovoice methods could be improved in the future.

METHODS AND PROCEDURES

This study was conducted as a methodological literature review. These types of reviews summarize the literature with a focus on methodological practices, which can be used to address uncertain research methods and recommend appropriate methods for future studies.¹⁵ A common type of methodological literature review is a “critical review,” in which the literature on a certain topic is assessed for methodological inconsistencies when compared to a criterion.¹⁵ This review was grounded in Aguinis and colleagues’ systematic review and their checklist of best practices in conducting methodological reviews, which includes: demonstrating the need and value for the review, defining the scope of the review, being transparent in the search process, using seminal sources as the criterion for reviewing articles, organizing the review through a step-by-step methodological guideline, highlighting articles that used exemplary methods, and reporting the review’s findings using simple language.¹⁵

Relevant search terms and databases were used to identify peer-reviewed articles for the literature review. During February of 2026, PubMed and the Cumulative Index to Nursing and Allied Health Literature (CINAHL) were searched using the search terms “photovoice” and “food insecurity.” Additional articles were identified using “berry picking” methods of “backward chaining” (i.e., searching the reference pages of included articles) and “forward chaining” (i.e., searching the articles that cited the included articles)¹⁶ using Google Scholar.¹⁷

The authors used several inclusion criteria to determine article eligibility for the literature review. An article was included in the review if it: (1) was written in the English language, (2) was conducted in the U.S., (3) was published in a peer-reviewed journal,

(4) specified that photovoice methods were used in the study, and (5) described a photovoice project related to food insecurity. If an article did not meet the inclusion criteria, then it was excluded from the literature review. If more than one article was published describing the same photovoice project, those additional articles were included in the review to ensure the full context of the project was assessed.

Each article included in the review was then examined independently by the undergraduate student researcher and a faculty supervisor for several factors to determine the extent to which each major goal of photovoice was achieved. It is important to note here that the information that was analyzed for this literature review was solely based on the methods that were described in each article's text. It is possible, as noted in the limitations below, that the methods to achieve the goals of photovoice were actually used in the photovoice project, but not included in detail within the article's text.

For the first goal of photovoice, the following information was extracted from each article: the number of photovoice trainings, the training content (e.g., overview of the photovoice method, the participants' assignment of what they should take photos of, photo ethics, photo tips), if cameras were provided to participants, and the amount of time provided to take photos. Based on Wang and Burris^{2,3} defining elements of photovoice, the student researcher and a faculty supervisor graded each article's achievement of the first goal of photovoice as: Full (participants were trained in all of the following: the photovoice method, an assignment of what participants should take photos of, photo ethics, photo tips), Partial (the article failed to mention one or more training components), or None (the article failed to mention any training or any components of the training).

Regarding the second goal of photovoice, the following information was extracted from each article: how participants discussed their photos (e.g., group discussion, focus group interviews, individual interviews with researchers), if a type of mnemonic (i.e., SHOWeD) was used to guide group discussion, and if the photo data or discussion/interview data were analyzed by the participants and/or the researchers. The student researcher and a faculty supervisor graded each article's achievement of the second goal of photovoice as: Full (participants discussed their photos as a group or through focus group interviews, the photo data or discussion/interview data were analyzed by the participants), Partial (participants discussed their photos individually with the researchers, and/or the photo data or discussion/interview data were analyzed by the researchers, and/or the participants were only invited to validate the researchers' analysis), or None (the article failed to mention any participant discussion of the photos, or the participants discussed their photos individually with the researchers, and the photo data or discussion/interview data were only analyzed by the researchers).

Finally, for the third goal of photovoice, the following information was extracted from each article: if the photovoice project's findings were shared through the form of an exhibit or other types of display (e.g., print, digital), who planned the exhibit/display, if participants were involved with the exhibit/display, who attended the exhibit/display (e.g., community members, media outlets, policymakers), and if there was any impact as a direct result of the exhibit/display. The student researcher and a faculty supervisor graded each article's achievement of the third goal of photovoice as: Full (the photovoice project's findings were exhibited/displayed, the participants were involved with the exhibit/display), Partial (the photovoice project's findings were exhibited/displayed, but the participants were not involved with the exhibit/display), or None (the article failed to mention any exhibit/display of the photovoice project's findings).

After independently extracting information and grading the methods against the three goals of photovoice, the researchers then met to discuss their assessments. Any inconsistencies between the researchers in the information extracted from the articles or their grading of the methods' achievement of photovoice goals were resolved through discussion.

RESULTS

A total of 19 articles were included in the study **Figure 1**.¹⁸⁻³⁶ Those articles described 15 different photovoice projects, as three projects were described in more than one publication. The photovoice projects ranged in their: location (e.g., rural, urban, region of the US), number and demographics of participants (e.g. age, race/ethnicity), purpose, and participant photo assignments based on the project purpose (**Table 1**). Regarding the first goal of photovoice, the projects varied in achievement, participant trainings, cameras for taking photos, and allotted time for taking photos. Of the 15 projects, eight (53%) had full achievement (**Table 2**). The remaining seven (47%) projects had partial achievement, as they did not mention training components of photo tips and/or photo ethics (**Table 2**). There were 14 projects that used a single training session, and one used two training sessions. To take photos, participants used their cell phones, or were provided with cameras (e.g., digital, disposable). Of the 12 projects that specified the allotted time for taking photos, the time ranged from three days to six weeks, with the most common time being one week (**Table 2**).

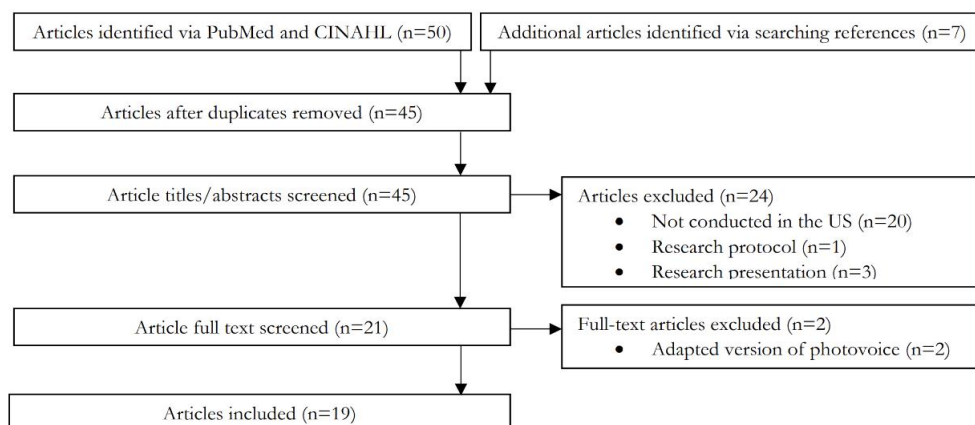


Figure 1. Flow diagram for article inclusion.

First Author	Location, Participants	Study purpose	Photo assignment
Boddie¹⁸	Waco, TX; 5 teens who lived in communities designated as food deserts	To explore teens' views on the barriers, impacts, coping mechanisms, and solutions to food security	Experiences, thoughts, and emotions of food and low food supplies
Burris¹⁹	Five communities in Tampa Bay, FL; 13 teenagers	To understand teenagers' experiences and coping strategies with food insecurity	What teen food insecurity looks like and the participants' ideas for solutions
Chilton,²⁰ Knowles²¹	Philadelphia, PA, Boston, MA, Baltimore, MD, Camden, NJ; 69 caregivers of young children and who use at least one public assistance program	To advocate to policymakers for changes to improve the health issues of young children living in poverty	Experiences with hunger and poverty, and the participants' ideas for change to share with the public, press, and policymakers
Colon-Ramos²²	Two low-income neighborhoods in Washington, DC; 10 African Americans mothers and grandparents	To determine how African-American caregivers living in a food desert provide food for their children	Barriers and facilitators to feeding children
Dailey²³	Adams County, PA; 47 low-income families	To understand the lived experience of food insecurity in a rural community	Experiences everyday with food
Heidelberger²⁴	Urban neighborhood in MN; 29 children	To explore the food environment of low-income adolescents	Foods that are commonly consumed at home, at school, and in the community
Hines²⁵	Baltimore, MD; 24 adults with hypertension	To explore the food environment of Black residents with hypertension	Issues related to food in the neighborhood
Jennings²⁶	Duluth, MN; 18 children experiencing food insecurity and transitional housing	To explore urban, Indigenous children's perceptions about healthy and unhealthy food	Foods that are healthy and unhealthy
Lemp²⁷	A large Midwestern university; 12 students who were food insecure and used the campus food pantry	To assess the impact of food insecurity on the health of college students	Impacts of food insecurity as a college student (e.g., what it looks like, health impacts) and resources used
McMorrow,^{28, 29} Saksena³⁰	Indianapolis, IN; 16 Congolese refugee women	To explore the health and integration experiences of refugee women	Barriers and facilitators of health and health care access
Sohlberg³¹	San Joaquin Valley, CA; 37 parents of K-12 students who participated in a school meal program during COVID-19 school closings	To understand parents' views of school meals during COVID-19 to improve participation in the meal program	Food provided by the school during the COVID-19 school closings
Spear³²	Rural AR; 7 food insecure adult residents	To explore the daily reality of food insecurity	Experiences with food insecurity as individuals, household, or community

Springer³³	Midwest city, USA; 8 teenage refugees from Iraq and Thailand	To understand adolescent refugees' experiences with food access	Representations of food access
Valera³⁴	New York City, NY; 9 low-income mothers	To document low-income women's challenges in accessing healthy food in New York City	Barriers to accessing healthy foods in the neighborhood
Weinstein^{35, 36}	Philadelphia, PA; 8 adult residents	To investigate weight loss factors for overweight/obese adults with serious mental illness	Barriers and facilitators in the environment for losing weight

Table 1. Summary of studies' location, participants, purpose, and photo assignment given to participants.

First Author	Methods for achieving photovoice goal #1	Achievement
Boddie¹⁸	One training on the photovoice method and photo assignment. Participants used their cell phones as cameras. One week was allotted for taking photos.	Partial (missing: photo ethics, photo tips)
Burris¹⁹	One training on the photo assignment. Disposable cameras were provided. The allotted time for taking photos was not mentioned.	Partial (missing: photo ethics, photo tips)
Chilton,²⁰ Knowles²¹	One training on photo assignment, photo ethics, and photo tips. Digital cameras were provided. Three weeks were allotted to take photos.	Full
Colon-Ramos²²	One training (and a take-home guide) on photo assignment and photo tips. Cameras were provided. Four days were allotted to take photos.	Partial (missing: photo ethics)
Dailey²³	One training on the photovoice method and the photo assignment. Digital cameras were provided. One month was allotted to take photos.	Partial (missing: photo ethics, photo tips)
Heidelberger²⁴	One training on the photo assignment, photo ethics, and photo tips. Disposable cameras were provided. The allotted time for taking photos was not mentioned.	Full
Hines²⁵	One training on the photovoice method, photo assignment, photo ethics, and photo tips. Provision of cameras was not mentioned. One week was allotted for taking photos.	Full
Jennings²⁶	One training on the photovoice method, photo assignment, photo ethics, and photo tips. Cameras were provided. Three days were allotted to take photos.	Full
Lemp²⁷	One training on the photovoice method and photo assignment. Participants used their cell phones as cameras. Two weeks were allotted to take photos.	Partial (missing: photo ethics, photo tips)
McMorrow,^{28, 29} Saksena³⁰	Two trainings on the photovoice method, photo assignment, photo ethics, and photo tips. Digital cameras were provided. The allotted time for taking photos was not mentioned.	Full
Sohlberg³¹	One training webinar on the photovoice method and the photo assignment. Provision of cameras was not mentioned. Five days were allotted for taking photos.	Partial (missing: photo ethics, photo tips)
Spear³²	One training on the photovoice method, photo assignment (developed by participants), photo tips, and photo ethics. Disposable cameras were provided. Six weeks were allotted for taking photos.	Full
Springer³³	One training on the photovoice method, photo assignment (developed by participants), photo tips, and photo ethics. Participants used their own camera devices. One week was allotted for taking photos.	Full
Valera³⁴	One training on the photovoice method, photo assignment (developed by participants), and photo ethics. Disposable cameras were provided. Four weeks were allotted to take photos.	Partial (missing: photo tips)
Weinstein^{35, 36}	One training on the photovoice method, photo assignment, photo ethics, and photo tips. Digital cameras were provided. One week was allotted for taking photos.	Full

Table 2. Studies' reported methods and achievement of photovoice goal #1 (training on photovoice method, photo topics, photo ethics, photo tips).

In terms of the second goal of photovoice, the projects varied in their level of achievement. A total of five (33%) projects fully achieved the second goal of photovoice, eight (53%) projects partially achieved the goal (due to lack of participants' involvement with data analysis), and two (13%) projects did not achieve the goal (due to lack of group discussion of photos and participants' involvement with data analysis) (**Table 3**). Of the projects that facilitated group discussion of photos, the SHOWeD mnemonic

was used in six projects, and the “ORID” mnemonic (objective, reflective, interpretive, and decisional questions used to spark discussion)³⁴ was used in one project (**Table 3**).

First Author	Methods for achieving photovoice goal #2	Achievement
Boddie¹⁸	Focus group interviews. Participants and researchers analyzed the interview data and photo data.	Full
Burris¹⁹	Group discussion using the SHOWeD mnemonic. Analysis of photos was not mentioned.	Partial (missing: participant analysis of data)
Chilton,²⁰ Knowles²¹	Individual interviews and group discussion using the SHOWeD mnemonic. Participants and researchers analyzed the photo data, while researchers analyzed the interview and discussion data.	Full
Colon-Ramos²²	Individual interviews and group discussion. Participants and researchers analyzed the photo data, while researchers analyzed the interview and discussion data.	Full
Dailey²³	Group discussion. Researchers analyzed the discussion data.	Partial (missing: participants' analysis of data)
Heidelberger²⁴	Individual interviews. Researchers analyzed the photo data and interview data.	None (missing: group discussion, participants' analysis of data)
Hines²⁵	Group discussion using the SHOWeD mnemonic. Researchers analyzed the discussion data.	Partial (missing: participants' analysis of data)
Jennings²⁶	Group discussion. Participants analyzed the photo data. Researchers analyzed the discussion data.	Full
Lemp²⁷	Group discussion or interviews were not mentioned. Researchers analyzed the photo data.	None (missing: group discussion, participants' analysis of data)
McMorrow,^{28, 29} Saksena³⁰	Group discussion. Researchers analyzed the photo data and discussion data. Participants were invited to validate the analysis.	Partial (missing: participant analysis of data)
Sohlberg³¹	Group discussion. Researchers analyzed the discussion data.	Partial (missing: participants' analysis of data)
Spear³²	Group discussions using the SHOWeD mnemonic. Researchers analyzed the discussion data. Participants were invited to validate the analysis.	Partial (missing: participants' analysis of data)
Springer³³	Group discussions using the SHOWeD mnemonic. Researchers analyzed the photo data and discussion data.	Partial (missing: participants' analysis of data)
Valera³⁴	Group discussion using the ORID mnemonic. Researchers analyzed the discussion data. Participants were invited to validate the analysis.	Partial (missing: participants' analysis of data)
Weinstein^{35, 36}	Group discussion using the SHOWeD mnemonic. Participants and researchers analyzed the photo data and discussion data.	Full

Table 3. Studies' reported methods and achievement of photovoice goal #2 (group discussion of photos, participant analysis of photos).

Regarding the third goal of photovoice, the projects also varied in their level of achievement. Only five (33%) projects fully achieved the goal, two (13%) had partial achievement (due to no participant involvement during the exhibits/displays), and eight (53%) of the projects did not achieve the goal (due to not mentioning any advocacy efforts) (**Table 4**). The exhibits/displays reached policymakers, stakeholders, and the general community, and three projects described the impact of the photovoice exhibit/display (e.g., free meals, food options, politicians' votes) (**Table 4**).

First Author	Methods for achieving photovoice goal #3	Achievement
Boddie¹⁸	Researchers planned several exhibits (two university events, a national conference, a youth council meeting) for various attendees (policymakers, social workers, nonprofit executives, community stakeholders). None of the participants were available to be involved at the exhibits. As a result of the project: the faith-based organization afterschool program that hosted the project began offering meals.	Partial (missing: participants' involvement at the exhibit/display)
Burris¹⁹	It was not mentioned who planned two exhibits (a community event, Juvenile Welfare Board) for various attendees (policymakers, members of the school board, Juvenile Welfare Board, and local hunger organizations). Participants were involved in presenting the exhibit. As a result of the project, school staff improved food handling procedures, eliminated some unhealthy food items, and allowed students to choose which food items they wanted to be served.	Full
Chilton,²⁰ Knowles²¹	Researchers planned 20 exhibits (PA Senate, a MA district, the US Senate, US House of Representatives, and news outlets). Participants were involved in presenting the exhibits. As a result of the project: politicians' votes were impacted on the 2014 cuts to SNAP funding.	Full
Colon-Ramos²²	Not mentioned	None
Dailey²³	Not mentioned	None
Heidelberger²⁴	Not mentioned	None
Hines²⁵	Researchers were planning a future exhibit.	None
Jennings²⁶	Not mentioned	None
Lemp²⁷	Not mentioned	None
McMorrow,^{28, 29} Saksena³⁰	Researchers planned several exhibits (World Refugee Day event, a public presentation at a university, academic conferences). Participants were not involved at the exhibits. Impacts of the exhibits were not mentioned.	Partial (missing: participants' involvement at the exhibit/display)
Sohlberg³¹	Not mentioned	None
Spear³²	Researchers were planning a future exhibit.	None
Springer³³	It was not mentioned who planned an exhibit at an unspecified venue. Participants were involved in the exhibit. Impacts of the exhibit were not mentioned.	Full
Valera³⁴	It was not mentioned who planned two exhibits (a participant letter writing campaign to local policymakers, a university health disparities conference). Participants were involved in the letter writing campaign. Impacts of the exhibit were not mentioned.	Full
Weinstein^{35, 36}	Participants and researchers planned several exhibits (state department of public health, a coalition conference about hunger, a coalition meeting, a demonstration outside a senator's office). Participants were involved with the exhibits. Impacts of the exhibits were not mentioned.	Full

Table 4. Studies' reported methods and achievement of photovoice goal #3 (reach policymakers).

After assessing the methods used for each photovoice goal, only a few projects fully or partially achieved each goal. Of the 15 projects included in this review, there were only two (13%) projects that fully achieved each goal of the photovoice method,^{20, 21, 35, 36} and five (33%) projects that at least partially achieved each goal.^{18, 19, 28–30, 33, 34}

DISCUSSION

The purpose of this methodological review was to determine how photovoice methods were used in research on food insecurity. Specifically, this study assessed if and how projects accomplished each of the three goals that define the photovoice method, as described in the publication text. We found that only two of the 15 projects included in this literature review fully achieved each photovoice goal as outlined by Wang and Burris' foundational articles that defined the method.¹⁻³

It is important to note that nearly half of the photovoice projects included in this methodological review did not mention training participants in the ethics of taking photos. Other literature reviews have also reported a lack of description in how photovoice participants are trained about the ethics surrounding photos.⁸ This finding highlights the need for researchers who are using photovoice to provide detailed training for participants to ethically achieve the goals of photovoice, with specific restrictions on taking photos of the community and the people within it. Oakes and colleagues³⁷ developed a helpful decision tree for photovoice

projects regarding the ethical and legal decision-making process in taking photos (e.g., privacy of person, privacy of place, illegal acts and obscenity, defamation, representation of truth versus actual malice, opinion versus assertion of fact), which could be used during photovoice trainings, group discussions, and exhibit planning.

Regarding the second goal of photovoice (e.g., group discussion of photos and participant analysis of photos), several projects in this review did not involve participants in data analysis. Other literature reviews have also critiqued photovoice projects that did not involve participants in data analysis.⁸ Given the participatory nature of photovoice, and the established outline of the method that specifies including participants in analyzing photos,^{2,3} future food insecurity research that uses photovoice should involve participants when categorizing participants' photos into major themes. Wang & Burris² emphasize the importance of participants taking the lead in analyzing patterns grounded in community data, as they should define the issues and potential solutions within their own communities.

Several studies in this literature review failed to describe if they hosted an exhibit/display, the crucial third goal of photovoice. This finding is reflected in previous literature, where many projects have fallen short of implementing comprehensive photovoice methods.⁸ Hosting an exhibit, or some type of display, creates an opportunity for participants to dialogue with policymakers and stakeholders about community concerns using real forms of evidence through participants' photos and stories.^{2,3} As such, by neglecting to host a photovoice exhibit, the full extent of participants' voices can be silenced.³⁸ In a reflective commentary on the method she created, Wang noted, "All kinds of limits and pressures can get in the way of staying true to the values and integrity of photovoice. Often, the policy component is the first to go. Photovoice organizers, eager to 'analyze' the 'data' on their own, eschew bringing policy makers to the table at the outset, or they neglect to facilitate ways for community people to share their policy recommendations. I want to say, please look in your heart, and may your work be rooted in the goals and core values that underlie photovoice."³⁹

This methodological review of the literature has important implications for future photovoice projects. First, there is a general need for assessing photovoice methods that are specific to each discipline or population of study. Replicating this type of methodological review can help to address the limitations of how photovoice is being used, and how projects could be improved in the future. Second, although completing all three major goals can be time consuming, implementing the basic steps of photovoice is necessary to realize the potential benefits for participants in this unique participatory research method.³⁹ Third, this review underscores the importance of those using photovoice to plan on how they will evaluate and report the impacts of a photovoice exhibit.⁴⁰ Practically, Wang and Burris' defining articles of the photovoice method¹⁻³ and this methodological review can serve as useful guides in planning the basic steps of a photovoice project (e.g., training participants in the photovoice method, providing a photo assignment, providing photo ethics and photo tips, conducting group discussions of photos, involving participants in photo analysis, and working with participants to share the photos with policymakers). Fourth, although the three goals of photovoice as outlined in Wang and Burris' foundational articles may be considered the "gold standard" of photovoice, researchers may modify the method. As such, it is important for researchers to clarify how the method was modified. If participants' photos are only used as an aid for interviews, the method should be classified as "photo elicitation"⁴¹ rather than photovoice. Or, if photovoice was only used to enhance participants' knowledge, skills, attitudes, behaviors, health, or efficacy for change at the individual level (versus at the community or policy level) this could be categorized as a "photovention" type of photovoice.⁴¹ Moreover, if the objective of photovoice was to map community assets or needs (without addressing policymakers), this could be specified that photovoice was used only as a community assessment.⁴¹

There are several strengths and limitations to this study. This study's findings support Gallegos and Chilton's¹¹ recommendation that scholars of food insecurity collaborate with their participants. The studies that achieved each photovoice goal engaged participants as co-researchers to enact change, suggesting that photovoice is a methodology that might be particularly useful for understanding and improving food insecurity without marginalizing participants and their lived experiences. In addition, this review indicates that photovoice can have real impacts on food insecurity. Although policy change can be difficult, three projects described in this review resulted in the availability of meals at an afterschool program,¹⁸ changes to food in a school setting (e.g., improved food handling procedures, elimination of unhealthy food items),¹⁹ and the influence on policymakers' votes on proposed cuts to SNAP funding.^{20,21} Although these impacts do not solve food insecurity in a broad sense, they do indicate that those who study food insecurity with a focus on sparking change in local communities or the national level may want to consider using photovoice as a tool for that work.

In terms of limitations, first, we only included studies that were conducted in the U.S., as food insecurity and advocating for policy change can look different from nation to nation, and we wanted the findings to be comparable by region within the same country. As such, it is possible that photovoice projects conducted outside of the U.S. achieved the three goals of photovoice methodology to a level different than those described in this literature review. Second, by only including photovoice projects that were published in the peer-reviewed literature, it is possible that other relevant photovoice projects (e.g., dissertations, theses,

presentations) could have provided additional insight into how photovoice is implemented within the scope of food insecurity. Third, it is possible that the study's limited search terms and only using the databases of PubMed and CINAHL did not retrieve an exhaustive list of photovoice projects about food insecurity using different terms (e.g., hunger, nutrition, food, grocery) from databases of various fields (e.g., anthropology, sociology, women's studies, economics). Finally, the projects listed in this literature review may have achieved aspects of photovoice goals, even though those details were not mentioned in the articles. This may be due to journal word limits that do not allow enough space for describing specific methodological details. As such, those who disseminate the findings from photovoice projects through peer-reviewed publication may want to use supplemental materials if journal word limits are too restrictive.

CONCLUSIONS

This study conducted a methodological review to assess the extent of how photovoice's three major goals were achieved in food insecurity research that used the photovoice method. A total of 19 articles were included in the literature review, describing 15 different photovoice projects. Overall, the photovoice projects as described in the articles' text underachieved the goals of photovoice. Specifically, only two of the photovoice projects fully achieved each photovoice goal, and five projects at least partially achieved each goal. In sum, the literature review's findings emphasize the need for projects labeled "photovoice" to fully implement the method's fundamental goals.

ACKNOWLEDGEMENTS

The authors thank Appalachian State University's Honors College and the Reviewers.

REFERENCES

1. Wang, C., and Burris, M. (1994) Empowerment through photonovella: Portraits of participation, *Health Educ Behav* 21, 171–186. <https://doi.org/10.1177/109019819402100204>
2. Wang, C., and Burris, M. (1997) Photovoice: Concept, methodology, and use for participatory needs assessment, *Health Educ Behav* 24, 369–387. <https://doi.org/10.1177/109019819702400309>
3. Wang, C. (1999) Photovoice: A participatory action research strategy applied to women's health, *J Womens Health* 8, 185–192. <https://doi.org/10.1089/jwh.1999.8.185>
4. Hergenrather, K. C., Rhodes, S. D., Cowan, C. A., Bardhoshi, G., and Pula, S. (2009) Photovoice as community-based participatory research: A qualitative review, *Am J Health Behav* 33, 686–698. <https://doi.org/10.5993/AJHB.33.6.6>
5. Israel, B. A., Schulz, A. J., Parker, E. A., and Becker, A. B. (1998) Review of community-based research: Assessing partnership approaches to improve public health, *Annu Rev Public Health* 19, 173–202. <https://doi.org/10.1146/annurev.publhealth.19.1.173>
6. Shaffer R. (1984) *Beyond the dispensary: On giving community balance to primary health care*, African Medical Research Foundation.
7. Golden, T. (2020) Reframing photovoice: Building on the method to develop more equitable and responsive research practices, *Qual Health Res* 30, 960–972. <https://doi.org/10.1177/1049732320905564>
8. Seitz, C. M., and Orsini, M. M. (2022) Thirty years of implementing the photovoice method: Insights from a review of reviews, *Health Promot Pract* 23, 281–288. <https://doi.org/10.1177/15248399211053878>
9. U.S. Department of Agriculture. Food security in the U.S. - Key statistics & graphics, <https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-us/key-statistics-graphics> (accessed Feb 2026)
10. U.S. Department of Health and Human Services. Healthy People 2030: Food Insecurity, <https://odphp.health.gov/healthypeople/priority-areas/social-determinants-health/literature-summaries/food-insecurity#cit2> (accessed Feb 2026)
11. Gallegos, D., and Chilton, M. M. (2019) Re-evaluating expertise: Principles for food and nutrition security research, advocacy and solutions in high-income countries, *Int J Environ Res Public Health* 16, 561. <https://doi.org/10.3390/ijerph16040561>
12. Doustmohammadian, A., Mohammadi-Nasrabadi, F., Keshavarz-Mohammadi, N., Hajjar, M., Alibeyk, S., and Hajigholam-Saryazdi, M. (2022) Community-based participatory interventions to improve food security: A systematic review, *Front Nutr* 9, 1028394. <https://doi.org/10.3389/fnut.2022.1028394>
13. Sacca, L., Garba, N. A., Clarke, R. D., Maroun, V., and Brown, D. R. (2023) Using community-based implementation frameworks and strategies to address food insecurity during the COVID-19 pandemic: A scoping review, *J Hunger Environ Nutr* 18, 396–414. <https://doi.org/10.1080/19320248.2022.2136024>
14. Scutts, T., Farnaz, N., Ganbold, G., Bhatti, A. J., Phan, S., Williams, M. J., and Mihrshahi, S. (2025) Co-designing solutions to tackle food insecurity in higher education settings: A scoping review, *Public Health Nutr* 28, 1–17. <https://doi.org/10.1017/S1368980025000485>
15. Aguinis, H., Ramani, R. S., and Alabduljader, N. (2023) Best-practice recommendations for producers, evaluators, and users of methodological literature reviews, *Organ Res Methods* 26, 46–76. <https://doi.org/10.1177/1094428120943281>
16. Booth, A. (2008) Unpacking your literature search toolbox: On search styles and tactics, *Health Info Libr J* 25, 313–317. <https://doi.org/10.1111/j.1471-1842.2008.00825.x>

17. Martín-Martín, A., Orduna-Malea, E., Thelwall, M., and López-Cózar, E. (2018) Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories, *J Informetr* 12, 1160–1177. <https://doi.org/10.1016/j.joi.2018.09.002>
18. Boddie, S. C., Howard, K., Hong, K., Nelms, S., O'Quin, A., Sessa, C., Williams, R., and Carter, S. (2022) Teen food insecurity in a central Texas city: Teen perspectives using photovoice, *J Hum Behav Soc Environ* 33, 232–264. <https://doi.org/10.1080/10911359.2022.2052222>
19. Burris, M., Bradley, S., Rykiel, K., and Himmelgreen, D. (2020) Teen food insecurity: Finding solutions through the voices of teens, *Hum Organ* 79, 13–23. <https://doi.org/10.17730/0018-7259.79.1.13>
20. Chilton, M., Rabinowich, J., Council, C., and Breau, J. (2009) Witnesses to Hunger: Participation through photovoice to ensure the right to food, *Health Hum Rights* 11, 73–85. <https://doi.org/10.2307/40285219>
21. Knowles, M., Rabinowich, J., Gaines-Turner, T., and Chilton, M. (2015) Witnesses to Hunger: methods for photovoice and participatory action research in public health, *Hum Organ* 74, 255–265. <https://doi.org/10.17730/0018-7259-74.3.255>
22. Colón-Ramos, U., Monge-Rojas, R., Stevenson, T. R., Burns, H., Thurman, S., Gittelsohn, J., and Gurman, T. A. (2018) How do African-American caregivers navigate a food desert to feed their children? A photovoice narrative, *J Acad Nutr Diet* 118, 2045–2056. <https://doi.org/10.1016/j.jand.2018.04.016>
23. Dailey, A. B., Hess, A., Horton, C., Constantian, E., Monani, S., Wargo, B., Davidson, K., and Gaskin, K. (2015) Healthy options: A community-based program to address food insecurity, *J Prev Interv Community* 43, 83–94. <https://doi.org/10.1080/10852352.2015.973248>
24. Heidelberg, L., and Smith, C. (2015) The food environment through the camera lenses of 9-to 13-year-olds living in urban, low-income, midwestern households: A photovoice project, *J Nutr Educ Behav* 47, 437–445. <http://dx.doi.org/10.1016/j.jneb.2015.05.005>
25. Hines, A. L., Brody, R., Zhou, Z., Collins, S. V., Omenyi, C., Miller III, E. R., Cooper, L. A., and Crews, D. C. (2022) Contributions of structural racism to the food environment: A photovoice study of black residents with hypertension in Baltimore, MD, *Circ Cardiovasc Qual Outcomes* 15, e009301. <https://doi.org/10.1161/CIRCOUTCOMES.122.009301>
26. Jennings, D. R., Paul, K., Little, M. M., Olson, D., and Johnson-Jennings, M. D. (2020) Identifying perspectives about health to orient obesity intervention among urban, transitionally housed indigenous children, *Qual Health Res* 30, 894–905. <https://doi.org/10.1177/1049732319900164>
27. Lemp, H., Lanier, J., Wodika, A., and Schalasky, G. (2024) Impact of food insecurity on the health and well-being of college students, *J Am Coll Health* 72, 3671–3680. <https://doi.org/10.1080/07448481.2023.2187631>
28. McMorro, S., and Saksena, J. (2021) Evidence from a longitudinal photovoice and interview assessment with Congolese refugee women in the midwestern United States, *Health Equity* 5, 577–586. <https://doi.org/10.1089/hec.2020.0121>
29. McMorro, S., and Saksena, J. (2017) Voices and views of Congolese refugee women: A qualitative exploration to inform health promotion and reduce inequities, *Health Educ Behav* 44, 769–780. <https://doi.org/10.1177/1090198117726572>
30. Saksena J, and McMorro SL. (2020) Through their eyes: A photovoice and interview exploration of integration experiences of Congolese refugee women in Indianapolis, *J Int Migr Integr* 21, 529–549. <https://doi.org/10.1007/s12134-019-00672-1>
31. Sohlberg, T. M., Higuchi, E. C., Ordonez, V. M., Escobar, G. V., De La Rosa, A., Islas, G., Castro, C., Hecht, K., Hecht, C. E., Bruce, J. S., and Patel, A. I. (2023) Parent perception of school meals in the San Joaquin Valley during COVID-19: A photovoice project, *Nutrients* 15, 1087. <https://doi.org/10.3390/nu15051087>
32. Spear, M. J., Vaughan, J. A., Barker, C., Faitak, B., Cole, J., Fleischacker, S., ... and Long, C. R. (2025) Daily reality of food insecurity: A photovoice study of food insecure residents in a rural, southern state, *J Hunger Environ Nutr* 20, 643–659. <https://doi.org/10.1080/19320248.2025.2505951>
33. Springer, P. R., Kang, J. S., Gratopp, E., and Franzen-Castle, L. (2024) Refugee youth's perspective on the role that food insecurity plays in a healthy community: A photovoice project, *IJMHSC* 20, 438–458. <https://doi.org/10.1108/IJMHSC-05-2023-0041>
34. Valera, P., Gallin, J., Schuk, D., and Davis, N. (2009) "Trying to eat healthy": A photovoice study about women's access to healthy food in New York City, *Affilia* 24, 300–314. <https://doi.org/10.1177/0886109909337378>
35. Weinstein, L. C., Chilton, M., Turchi, R., Klassen, A., LaNoue, M., Lamar, S., Yorgey, S., Kramer, L., Smith, I., and Cabassa, L. (2019) Reaching for a healthier lifestyle: A photovoice investigation of healthy living in people with serious mental illness, *Prog Community Health Partners* 13, 371–383. <https://dx.doi.org/10.1353/cpr.2019.0061>
36. Weinstein, L. C., Chilton, M., Turchi, R., Klassen, A. C., LaNoue, M., Silvero, A., and Cabassa, L. J. (2021) 'It's common sense that an individual must eat': Advocating for food justice with people with psychiatric disabilities through photovoice, *Health Expect* 24, 161–173. <https://doi.org/10.1111/hex.13101>
37. Oakes, L. R., Ewald, D. R., Orsini, M. M., and Strack, R. W. (2022) The photovoice decision tree: Legal considerations and ethical implications for photographs and captions, *Health Promot Pract* 23, 250–261. <https://doi.org/10.1177/15248399211053892>
38. Evans-Agnew, R. A., and Rosemberg, M. A. S. (2016) Questioning photovoice research: Whose voice?. *Qual Health Res*

- 26, 1019–1030. <https://doi.org/10.1177/1049732315624223>
39. Wang, C. C. (2022) The Tai Qi of photovoice. *Health Promot Pract* 23, 205–210. <https://doi.org/10.1177/15248399211069905>
40. Teti, M., and Myroniuk, T. (2022) Image to action: Past success, ongoing questions, and new horizons for photovoice exhibits. *Health Promot Pract* 23, 262–266. <https://doi.org/10.1177/15248399211054774>
41. Strack, R. W., Orsini M. M., and Ewald, D. R. (2022) Revisiting the roots and aims of photovoice, *Health Promot Pract* 23, 221–229. <https://doi.org/10.1177/15248399211061710>

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Victoria Braynin will graduate in May 2026 from the Honors College at Appalachian State University with a Bachelor of Science in Psychology and minors in Public Health and Nutrition and Foods. Following graduation, she will continue working on an organic vegetable farm and supporting an NIH grant for Hurricane Helene recovery in Western, NC. Victoria will begin New York University's Master in Public Health and Public Administration program in Fall 2026 and is interested in addressing food insecurity through a sustainable food systems lens.

PRESS SUMMARY

Photovoice is a community-based participatory research tool critical in engaging participants as collaborators to determine the health needs of their communities. The photovoice method is defined by its three major goals: (1) to support participants' use of photos to document community needs, (2) to facilitate participants' group discussion about community issues highlighted in their photos, and (3) to exhibit the photos as a way to reach policymakers and advocate for community change. The purpose of this methodological review was to assess the extent of how photovoice's three major goals were achieved in food insecurity research that used the photovoice method. Based on the authors' anecdotal observations, photovoice has been one method of participatory research used in several studies on food insecurity; however, a methodological review of those studies regarding adherence to the photovoice method has yet to be conducted. As such, this methodological review of the literature aimed to assess the published studies that used photovoice to address food insecurity. In doing so, the review can identify how those studies may have varied in achieving each of the three major goals of photovoice and suggest how photovoice methods could be improved in the future.

Examining Barriers to the Application of Modern Construction Technologies in Historic Building Treatments in Metro Detroit

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ABSTRACT

Modern construction technologies can offer significant potential for historic building treatments by addressing structural deterioration, enhancing safety, improving energy performance, and supporting long-term sustainability. However, integrating these modern construction technologies into historic construction requires a careful balance between preserving historic integrity, complying with contemporary construction standards and advancing technological capabilities. This tension often results in complex managerial and technical challenges for project stakeholders when considering, selecting, and implementing modern construction technologies into historic building treatments. Understanding the perspective and decision-making considerations of key stakeholders is critical to the effective development, utilization, and application of modern construction technologies in the historic construction field. However, there is a lack of empirical understanding of how project stakeholders, including construction engineers and managers, experience, interpret, and address the managerial and technical challenges in practice. In addition, little is known about how such challenges influence technology adoption decisions during historic building treatments. Therefore, it is essential to investigate the lived experiences and perspectives of the project stakeholders to identify the key drivers and challenges shaping modern technology adoption during historic building treatments. To address this research gap and capture nuanced, context-dependent perspectives, the current study employed an in-depth qualitative approach, drawing on detailed interviews with subject matter experts who participated in historic building treatment projects in the Metro Detroit area. Qualitative data were collected and analyzed to examine the lived experiences, interpretations, and professional judgments of stakeholders, which are often shaped by project-specific constraints, regulatory environments, and organizational contexts that cannot be adequately captured through purely quantitative measures. The findings of this research indicate that major barriers to the application of modern construction technologies in Detroit's historic building treatment projects include limited knowledge, technology reluctance, and high costs. The findings of this research advance empirical understanding of how project stakeholders and decision-makers determine the appropriate technologies in historic building treatments. The results identify key factors that contribute to practitioners' and contractors' reluctance to adopt these technologies, including financial constraints, limited technical knowledge, and training gaps among contractors. By revealing the practical considerations that influence technology adoption and implementation, this study provides evidence-based guidance for construction firms, owners, consultants, and historic-building preservation professionals. The findings also inform preservation policy and regulatory decision-making by clarifying the barriers and decision processes associated with modern technology adoption, supporting the more consistent, cost-effective, and context-sensitive application of modern construction technologies in historic building treatments.

KEYWORDS

Historic Integrity; Historic Property; Historic Building Treatments; Preservation; Rehabilitation; Restoration; Reconstruction

INTRODUCTION

The treatment of historic properties includes a range of professional interventions applied to structures in order to conserve, repair, adapt, or rehabilitate them while respecting their cultural, architectural, and historical significance.^{1,2} The treatment of historic buildings has long been shaped by the balance between modern construction demands and the imperative objective of preserving cultural and historic integrity.³ While advances in construction technologies offer opportunities to improve efficiency, sustainability, and affordability, they can often pose the risk of diminishing the historical character of built heritage.^{4,5} There is a persistent risk that construction technologies aimed at improving historic buildings may inadvertently impact their cultural value by compromising their historic integrity.⁴ Many historic properties were built centuries ago and the construction industry has undergone transformative changes in methods and technologies since then. As a result, the gap between historic construction techniques used for historic buildings and modern technologies applied in modern construction projects has continued to widen.⁶

⁷ In addition, historic buildings are often used in ways that differ significantly from their original purpose, creating new occupant needs.⁵ For example, contemporary HVAC requirements are often far more demanding than those in place when historic buildings were originally constructed.⁸ If this gap is not carefully managed, historic properties risk losing their integrity through neglect or hasty modernization, while insufficient adaptation may ultimately render them obsolete.⁹

Historically significant buildings are governed by extensive and complex regulations designed to balance the practical demands of economic use with the preservation of historic integrity and cultural significance.¹⁰ The National Historic Preservation Act (NHPA) requires federal agencies to consider impacts on historic properties, fostering harmony between modern use and preservation.^{11, 12} Historic building treatments are often expensive, time-consuming, and typically require specialized artisanal skills and technical expertise.^{13–15} Hasty or inadequately planned work on historic properties without proper expertise can result in severe, long-term, and often irreversible damage to the properties.^{14, 16} Historic building treatment projects should balance modern construction demands such as functional use, sustainability, environmental performance, energy efficiency and affordability, with the preservation of historic authenticity, aesthetic character, and cultural value of the property.^{17, 18} However, in practice, achieving this balance remains highly challenging.^{19, 20}

Modern construction demands can be addressed through the adoption of modern construction technologies, such as energy-efficient retrofitting methods, smart building materials, and digital building information modeling (BIM) techniques.^{21–24} Historic building treatment projects can similarly leverage such technological interventions to enhance overall project performance. For example, the heritage BIM-based energy retrofit of a historic public building achieved approximately 32% to nearly 100% (up to a net-zero energy balance) annual operational energy savings while preserving the building’s heritage values.²⁵ Identifying a reasonable balance between the application of modern technologies and the preservation of historic integrity is critical in historic building treatment projects, as technological intervention decisions can directly influence both conservation and performance outcomes.^{26–28} In addressing this balance, many Western European countries have adopted more progressive technological interventions in historic buildings, while many Eastern European countries tend to favor more conservative, preservation-oriented approaches to historic building treatments.²⁹ In the United States, this balance manifests differently across regions, reflecting variations in regulatory frameworks, economic conditions, and local construction practices.^{30–32} In legacy post-industrial U.S. cities, such as Detroit, historic building treatments have been particularly challenging. Detroit experienced rapid industrial growth in the early 20th century, followed by significant economic decline and urban transformation.^{33, 34} Detroit’s prolonged economic decline relegated the maintenance and rehabilitation of many historic properties to a lower priority, resulting in widespread abandonment and deterioration.³⁵ At the same time, the city faces pressing economic and social demands that require cost-effective and sustainable renovation solutions.³⁶ As a result, the city of Detroit has recently launched initiatives to promote the restoration and adaptive reuse of historic buildings.³⁶

Despite Detroit’s extensive portfolio of approximately 292 historic properties and districts listed on the National Register of Historic Places, little research has examined the challenges and barriers to integrating modern construction technologies and methods into local historic preservation and rehabilitation practices from an end-user perspective.³⁷ Existing literature tends to focus on general discussions of heritage conservation,^{38, 39} or on the wide variety of modern construction techniques and technologies currently applicable to projects concerning historic properties,⁴⁰ with a lack of grounding in local expert input. It is crucial to understand the context and motivations that lead local contractors and clients to adopt emerging construction technologies for cultural and historic regional heritages. The current research aims to investigate the challenges, perspectives, and key considerations influencing modern technology adoption in historic building treatments. This study employs in-depth qualitative interviews with construction practitioners who participated in Detroit’s historic building projects. The findings of this research are expected to provide empirical evidence and practical insights on balancing modern construction technologies with historic integrity preservation and address the gap in knowledge about the decision-making processes for applying modern construction technologies to historic building treatments.

LITERATURE REVIEW

The literature review is conducted to synthesize the current state of modern construction technologies and techniques applicable to historic building treatments. Important terms are defined based on the literature review in **Table 1** to ensure conceptual clarity, promote consistency across qualitative interviews, and support the validity and transparency of this study.

Term	Definition
Property Preservation	Historic building and property preservation is the process of maintaining, repairing, and restoring historic properties in a manner that preserves them in a state as close as possible to the one in which the building was initially built while still keeping up to as many modern safety, accessibility, and environmental standards as possible. ⁴¹

Historic Property	As stated by (NHPA [54 U.S.C. § 300308]) “Historic property” will be defined as any prehistoric or historic district, site, building, structure, or object included on, or eligible for inclusion on, the National Register, including artifacts, records, and material remains relating to the district, site, building, structure, or object. ⁴²
Historic Building Treatments	When working with historic properties, it is important to understand and remember the four historic building treatments: preservation, rehabilitation, restoration, and reconstruction. ⁴¹
Preservation	Preservation is defined as applying the necessary measures to stabilize a historic property and maintain it in its current state. ⁴¹
Rehabilitation	Rehabilitation is defined as repairs, additions, or alterations to a property while still keeping the features of the property that convey its cultural, architectural, or historic values. ⁴¹
Restoration	Restoration consists of depicting the form and character of a property as it used to be at a specific point in time. This may include reconstruction of missing features or the removal of added features that do not fit the intended time period. ⁴¹
Reconstruction	Reconstruction is applicable in situations where there is little existing material left. In such cases, a total rebuilding of the property is required. This treatment has a substantial risk due to the potential for historic inaccuracies. ⁴¹

Table 1. Definitions of terms.

A summary of the literature review is presented in **Table 2**. Previous studies explore the applications of modern technologies in historic building treatments, such as the utilization of a deep learning AI algorithm to classify Athenian architecture into appropriate categories.⁴³

Study	Modern Technology	Findings
Prokop <i>et al.</i> 2021 ⁴⁴	Laser scanner Faro Focus 3D modeling	A 3D Historic Building Information Model (HBIM) provides reliable documentation and finite element analysis of historic structures, supporting visualization, diagnosis, and conservation of architectural heritage such as St. Hubert's Chapel in Rzeszów.
Garbett <i>et al.</i> 2021 ⁴⁵	The combination of building information modeling (BIM) and augmented reality (AR) into a unified product	A framework has been designed for the use of BIM and AR together. This resulted in a prototype system (BIM-AR) being developed that allows geographically split teams to work together in the AR space.
Siountri & Anagnostopoulos 2023 ⁴³	AI deep learning classification of historic buildings	By utilizing a You Only Look Once (YOLO) algorithm and deep learning AI, the classification of Athenian architecture since 1830 into its various categories can be accomplished automatically.
Perret 2025 ³	The coherent acceptable low emission cultural heritage efficient renovation (CALECHE) project	This literature review legitimizes and backs the continued utilization of the CALECHE project to pioneer sustainable energy and renovation projects for historic buildings, demonstrating its effectiveness through four demonstration sites, for example, the former Musée-Bibliothèque de Grenoble in France.
Cabeza <i>et al.</i> 2018 ²⁹	The deployment of modern energy efficiency solutions to historic buildings	Using a variety of modern renewable technology solutions, such as high-efficiency heating, ventilation, and air conditioning (HVAC) systems, solar energy, and geothermal energy to raise the energy efficiency of historic buildings, helping mitigate their impact on the environment.
Xu <i>et al.</i> 2017 ⁴⁶	The use of 3D scanning and 3D printing to recreate historic building ornamental components	By combining the usage of three-dimensional scans and mortar-based cement, 3D printing reproduction of certain ornamental components of historic buildings is possible when such components are difficult to achieve through historic methods. For a feasibility demonstration, a cup-shaped plinth was recreated at the Huazhong University of Science and Technology in China.
Krajnikova <i>et al.</i> 2025 ⁴⁷	Using AI for digital diagnostics and predictive modeling in historic monuments.	AI can greatly benefit the prediction of the condition of historic monuments and can reduce the need for interventions by providing automated damage detection and degradation analysis.
Cascone <i>et al.</i> 2016 ²⁰	Fiber-reinforced polymer nets	Fiber-reinforced polymers (FRPs) are greatly effective at providing reinforcement to masonry structures: they are compatible with lime mortars and suitable for integration into existing buildings and can thus be used to great effect in historic buildings. An example provided is their use in a prominent historic building in Catania, Spain, originally built in 1883.
Orlenko <i>et al.</i> 2020 ⁴⁸	Hydrodynamic methods for the treatment of walls in historic buildings	By utilizing new-to-the-industry hydrodynamic methods and special abrasives historic walls can be cleaned and prepared for restoration. Chemical methods like ammonium fluoride preparations and hydrofluoric acids can also be used.
Khaleghi & Governa 2025 ⁴⁹	Smart city application to historic buildings	The interaction of interconnected smart building systems such as digital heritage tools, data-driven urban management tools, BIM, etc. are in a delicate relationship with the cultural and historic value of many buildings. This relationship must be balanced carefully to preserve collective memory in a swiftly changing world.
Tejani 2021 ¹⁹	Integration of modern HVAC systems into historic buildings	By retrofitting HVAC systems that are energy-efficient into historic properties they are able to continue functioning as important

		buildings that serve not only a cultural function but a practical one. However, the implementation of these systems presents a large number of challenges in preserving the historic sanctity of the building.
Grinzato 2012 ⁵⁵	Use of infrared (IR) thermography for historic building analysis	Thermal non-destructive testing can be effectively applied for historic building treatments. IR thermography can inspect large surfaces with no physical contact or damage. The use of IR thermography allows for the detection of structural cracks, fresco detachment sizing, and understanding the moisture content of structures.

Table 2. Description of the applications of modern construction technologies in historic building treatments that have been documented in previous studies.

When technologies concern material replacement, it is critical to maintain a careful balance between the perceived practicality of the replacement material and understanding if the material is realistically applicable as a replacement for the original material, avoiding the common misconception that new material is always better.⁵⁰ An example of such technological balance is the utilization of externally bonded composite material in masonry structures,⁵¹ such as fiber-reinforced polymer.⁵² The visual impact of these composite materials can be minimal in certain applications, particularly when they are carefully designed and strategically placed on less visible areas such as the extrados of an arch.⁵¹ However, their visual integration is application-dependent and may vary based on geometry, exposure, and design constraints. Despite this variability, these materials can significantly enhance the safety and structural stability of historic buildings. This is especially important in earthquake-prone regions where additional reinforcement is critical.^{20, 51} When preparing historic walls for other treatments and restoration efforts, hydrodynamic and chemical methods such as ammonium fluoride or hydrofluoric acids may be used.⁴⁸

The use of 3D scanning and 3D printing are two emerging technologies in construction that are beginning to see more frequent use.⁵³ There are two primary reasons for the utilization of these 3D techniques in historic building treatments. Many decorative flourishes in historic buildings have substantial amounts of detail, of which there may be limited existing drawings and blueprints. Due to the fragile nature of certain building components and the possibility of their corrosion and erosion from contact with measuring equipment or oils from human skin, it may, as a result, become impossible to effectively measure and survey them without employing 3D laser scanning.⁴⁶ The second major reason is the scope of work involved in manually copying certain elements. As the quantity of artisanal craftsmen goes down, and prices skyrocket for some projects, it becomes increasingly difficult to use entirely manual labor to recreate complex work such as decorative masonry, frescoes, and wood carvings.¹⁴ Utilization of 3D scanning to obtain a highly detailed 3D image of the work can allow recreation with far more accurate results, especially if this is done preemptively before severe damage or deterioration takes place.⁵⁴ Evaluation of historic buildings can also be conducted using thermal non-destructive testing. IR thermography can allow for the effective investigation of material weakness and its causes, as well as identify structural cracks.⁵⁵

An overarching technology that has become of pressing importance in the construction management industry as a whole is BIM.⁵⁶ BIM allows for significantly easier project management and limits waste.⁵⁷ As historic building treatments in particular involve so many fine details, as well as environmental constraints when adapting to modern standards,⁵⁸ the usage of BIM has been imperative in maintaining control of every element of a project.⁵⁹ During retrofitting projects, energy-efficient HVAC system implementation can be beneficial to historic buildings as they often rely on older HVAC systems leading to significant energy usage.⁶⁰ As the modern world continues evolving, it becomes increasingly necessary for historic buildings to remain usable and compliant in modern circumstances. Modern HVAC systems can achieve that while maintaining the historic value of the properties.¹⁹

A crucial factor necessary for successful projects in the context of construction management is customer involvement.⁶¹ The employment of virtual reality (VR) allows companies to clearly demonstrate to their clientele and other high-importance stakeholders concepts that may be difficult for them to grasp without seeing an image-based representation.⁶² In addition, VR employment during the construction phase can significantly increase safety awareness of contractors.⁶³ Usage of VR also allows for the minimization of paper usage in the planning process of projects, which allows easier visualization of concepts and leads to increased accessibility and cohesion of efforts.^{64, 65} Many of these technologies can be applied at the same time, often leading to an even further streamlined and optimized process. For example, BIM and augmented reality (AR) can be integrated to deliver a seamless viewing process for both contractors and clients.⁴⁵ A full bundle of modern technologies can lead to smart-city solutions, with integration of BIM, digital heritage tools, data-driven urban management tools, and other innovations.⁴⁹ As artificial intelligence (AI) technology has risen to prominence in recent years, it has become increasingly relevant and commonplace in the historic construction industry.⁴⁷ AI has broad practical and theoretical applications, from the utilization of deep learning techniques to classify buildings,⁴³ to improving worker safety during high-risk tasks.⁶⁶

Approval from the historical discourse community and other stakeholders is critical to the success of modern technology applications for historic building treatments and is often difficult to secure.³⁸ Historians are often cautious about attempting new preservation strategies.⁶⁷ This difficulty is especially pronounced with technologies that can be seen by the surrounding community as minimizing the historic integrity of the property.^{39, 68} For example, 3D printing technology can reproduce certain decorative elements of buildings; however, it can rarely do it with the original material and must be done with a replacement, such as a cement mixture or plastic.⁴⁶ Use of certain modern technologies is only considered in severe cases of dilapidation.⁵⁸ In addition, the deployment of certain smart systems often aligns with speculative redevelopment and the transformation of historic spaces into commodities, separating them from their function as spaces communities see as their cultural heritage and identity.⁴⁹ Despite the significant amount of research devoted to the topic of the application of modern technology to historic treatment projects, the majority of the research that has been done is either quantitative in nature, resulting in less detailed professional opinions or is focused on an individual case study, often in Europe, resulting in a narrow scope of study. Prior research generally gives little attention to how clients and contractors evaluate whether to integrate modern technology into their projects or not. This research strives to address the existing research gap of the application of modern construction techniques, methods, and technologies for historic building treatments by utilizing qualitative research methods to provide a more in-depth understanding of how industry professionals and owners of historic properties decide what techniques and technologies are appropriate for their circumstances, as well as what prior knowledge they have of modern construction technology.

METHODS AND PROCEDURES

This research seeks to answer the following questions: (1) What are the factors that can assist in understanding whether a client or contractor is willing and likely to employ modern and emerging construction technologies for a historic building treatment project? (2) What often prevents individuals from deciding to use these technologies? (3) What incentives or methods can be used to motivate and encourage the appropriate usage of modern construction technologies for historic building treatments?

This research focused on identifying common challenges, strategies, and considerations in the selection process of applying modern construction technologies and techniques to historic building treatments in Detroit, Michigan. Five semi-structured expert interviews were conducted with professionals directly engaged in historic building treatments in Detroit, including virtual design construction (VDC) specialists, construction project managers, engineers, and historic preservation specialists. Four of the interviewees worked as contractors.

In qualitative research, expert interviews are a widely accepted technique for eliciting in-depth knowledge about specialized practices, unresolved issues, or gaps in existing literature.³⁷ In the context of historic building treatments, many of the most relevant insights about historic building preservation requirements and modern construction technologies are not readily accessible through formal documents or published studies. Semi-structured expert interviews address this limitation by offering a systematic yet flexible way to capture practitioners' reasoning, decisions, and implicit professional judgments. Semi-structured interviews differ from explanatory interviews in that they rely on a carefully designed question set to ensure consistency and comparability across responses, while still allowing space for clarification and elaboration. This approach makes it possible to capture both the breadth and depth of challenges encountered in Detroit's historic renovation projects. Reliability in qualitative interviews refers to the consistency of data collection and interpretation processes.⁶⁹ To enhance reliability, a semi-structured interview protocol was developed and applied across all participants, reducing variation in question framing and sequencing. Additionally, conducting multiple interviews with professionals from different roles improved the robustness of findings by triangulating perspectives.⁷⁰ Validity is defined as the extent to which the research captures what it intends to capture.⁶⁹ The validity of expert interviews in this study was strengthened through deliberate interviewee selection. The approach provides both an empirical contribution to preservation literature and practical guidance for professionals engaged in balancing heritage values with modern construction demands and technologies.

To ensure ethical standards, the Institutional Review Board (IRB) at Wayne State University was contacted. It was determined that this study was exempt from being considered as human participant research as it constituted an evaluative study and did not require IRB review. Interviewees were selected from a variety of companies and universities and were contacted either by e-mail, telephone, or in-person conversations.

This interview process employs non-random selection of interviewees as presented in **Table 3**, focusing on a variety of historic building treatments in the Detroit area done by a multitude of companies and contractors. The purpose of these interviews was to understand the decision process of contractors and clients as to whether they choose to use certain emerging technologies or not in the scope of historic building treatment projects, to present to the reader a brief summary of some modern technologies used in building restoration in Detroit and surrounding suburbs, as well as to gain insight into the thought process of industry professionals and how they perceived the existing issues in the industry. For the satisfaction of this purpose, semi-structured interviews were used with five subject matter specialists who were involved in a variety of projects in various roles such as project managers, project engineers, or members of historical boards. Care was taken to ideally select interviewees who were close to the

project and had a familiar relationship with contractors and sub-contractors involved. Historic properties important to the historic building landscape of Detroit, such as Central Michigan Station, shown in **Figure 1**, were discussed as part of the interviews.

Interview Number	Title	Years of Experience	Relevant Projects
Interviewee #1	Electrical Engineer, Contractor	30+	Packard Proving Grounds
Interviewee #2	Project Manager, Contractor	8	Central Michigan Station, Buhl Building
Interviewee #3	VDC Coordinator, Contractor	7	Central Michigan Station
Interviewee #4	Vice-Chair of Historical Committee	11	More Than 42 Residential Properties
Interviewee #5	Project Manager, Contractor	37	Freer House

Table 3. Interviewee information



Figure 1. View on Central Michigan Station from below.

RESULTS

Five interviews were conducted with experts representing a combined total of over 93 years of experience in construction and pre-construction project phases. The interview responses generally aligned with insights identified in the literature review, including the risks and benefits of material replacement, the advantages of adopting modern technologies during the pre-construction phase, and the importance of evaluating project-specific needs prior to implementing such technologies. The inclusion of practitioner and end-user perspectives provides contextual support for the literature findings and offers applied insights that help ground the discussion in real-world construction practice. At the same time, the interviews revealed novel findings and provided nuanced perspectives, particularly regarding the sparse application of modern technologies, which warrant further elaboration in this section. Two major categories of reasons for the lack of modern construction technology deployment were pointed out during the interviews.

Financial Barriers

The most obvious barrier to the adoption of modern construction technologies is financial concern. Many of the recently emerging technologies are still in the experimental phase and thus quite expensive. This issue is especially relevant to smaller construction firms as well as clients possessing residential properties. For them, the risk of utilizing a costly technology that may not necessarily “pay itself off” is not worth the risk.

Knowledge Barriers: Lack of Knowledge and Awareness

However, even when prices are reasonable, the second major barrier corroborated by interviewees was the simple lack of knowledge and awareness of the technology in question. An example of this lack of knowledge and awareness is the use of infrared (IR) scanning in the pre-construction phase. Using an IR scan can aid in diagnosing the condition of the historic building, allowing the contractor to be prepared for the scope of work instead of being surprised by the poor condition of certain elements, such as severe leakage, structural cracks, or insulation issues.⁵⁵ Being aware of these conditions before building treatments begin

can allow for proper methodologies to be applied for these issues, thus resulting in minimized further damage to the building and reduced costs. IR scanners are quite affordable to use, with a scan generally costing as little as 200-300 dollars. However, one of the major barriers to IR scanner application is that clients or contractors are simply unaware of it as an option for identifying issues with the building. The concern of clients being unaware of approaches was noted by an interviewee, mentioning how often he encounters owners of historic residential properties that are unaware of some of the modern construction technologies that could be available and fit the needs of their property. According to interviews, contractors often fail to provide adequate information to the client in this regard, despite being aware of the technology. A suggested solution was to utilize information pamphlets to distribute to potential clients, ensuring that they would be aware of all options regarding their property. A summary of interviewee suggestions is provided in **Table 4**.

Recommendation	Reasoning
Produce media involving the usage of modern construction techniques and technologies.	Spread knowledge of a variety of modern construction techniques and technologies to lay people, resulting in a higher rate of them asking for such technology to be used on projects.
Distribute information slips describing modern construction techniques and technologies to potential clients and owners of historic properties.	Raise awareness of such technologies, resulting in increased interest and knowledge among people not directly involved in the field.
Improve the user interface (UI) of products and reduce the amount of necessary equipment for utilization.	Many products remain underutilized due to how complicated they are to gain competence with. If companies lowered the knowledge level required to use modern solutions through improvements to the user experience, these technologies would see more use.

Table 4. Interviewee recommendations

Knowledge Barriers: Technology Reluctance

Even when contractors are aware of certain new technologies, they can often be reluctant to employ them. Construction as an industry is a field that evolves slowly, particularly in comparison with others.⁷¹ Construction managers can be very doubtful about the use of new technologies due to a lack of understanding and exposure to them, and thus, have a lack of trust towards them.⁷² This absence of trust and willingness to adopt new things is particularly noticeable with smaller construction firms for whom the risk of a poor financial decision is greater.⁷³ Smaller construction companies are often concerned about employing new construction techniques and technologies on projects.⁷³

A method of disseminating knowledge of modern construction techniques and technologies noted by an interviewee was the production of media involving the implementation of modern construction technologies in the context of historic building treatments.

Also, improving the user-friendliness and UI of software and digital tools could significantly increase the frequency of use of modern technologies in historic building treatments.

Deciding what level of modern technological intrusion is acceptable is a challenging task. Interviewees agree that as many modern methods as possible should be used in the pre-construction phase. One of the biggest general factors in historic building work is unknown problems that are hidden by the building until work begins. Emerging technologies may be utilized to expose some of these potential faults, saving both money for the client and time for the contractor, and preventing decisions that may lead to further damage to the property. For example, an interviewee mentioned the need to detect water leaks as early as possible. When such issues are detected early in the planning phase, further damage can be prevented, and existing damage can be repaired more easily. In addition, careful pre-construction efforts and planning utilizing technology can help to understand the building's history and thus lead to accurate and historically appropriate choices in later phases of the construction process. For example, layers of paint may be analyzed, thus providing a better picture of what time period additions and renovations occurred in the building. Similar techniques can be used to analyze the mortar used on brick and masonry. However, once construction begins, knowing where it is acceptable to use modern methods becomes a lot more challenging. Most interviewees were quite opposed to any ahistorical material replacement. However, to quote an interviewee: "There is a place for it [modern construction methods and materials] to a point".

One of the most frequently cited factors influencing the successful application of modern construction technologies in historic preservation projects was the knowledge and training of contractors. Interview participants emphasized that modern technologies and materials are merely tools whose effectiveness depends on how appropriately they are applied. As one participant explained, using an unsuitable technology in a historic building is "like using a hammer to drive in a screw." While modern materials can improve efficiency and performance, their misuse can compromise both the historic integrity and structural condition of a building.

The Freer House restoration project provides a clear example of these risks. **Figure 2** shows the Freer House, which is currently undergoing restoration work that includes the replacement of the incompatible mortar with historically appropriate lime mortar. The Freer House, a historic masonry structure, was originally constructed using lime mortar, which is flexible enough to accommodate natural building movement. Because such historic structures typically lack modern expansion joints, compatible lime mortar is essential for preventing cracking and deterioration. During previous repair efforts, however, a modern cement-based mortar was used instead of lime mortar. Although the cement mortar was perceived as stronger and more durable, its rigidity prevented the masonry from flexing as intended. As a result, the building experienced significant cracking, mortar joint failure, and masonry spalling, creating additional deterioration that continues to require remediation today. This example illustrates how inadequate knowledge of historic construction methods can lead to the inappropriate application of modern materials, ultimately causing greater damage and increasing long-term repair costs.



Figure 2. A view of the Freer House undergoing rehabilitation

DISCUSSION

Despite the limited interview sample size and the geographic focus on the Detroit metropolitan area, this research provides insight into how project stakeholders and decision-makers determine the appropriate technologies in historic building treatments. The major barriers to applying modern construction techniques and technologies to historic building treatments can be grouped into two categories: financial barriers and knowledge barriers, which are often interrelated.

Financial barriers emerged as a primary constraint, indicating that the high cost of adopting modern technologies frequently discourages implementation, particularly for smaller firms or projects with limited budgets. In such contexts, cost considerations tend to dominate decision-making processes and reduce the likelihood of adopting innovative approaches. Smaller companies and clients are effectively restricted to letting large companies bear upon them the brunt of experimentation with modern techniques and technologies and must wait until the new technology becomes tested and readily available on the market for a lesser price.

Knowledge barriers represent a broader range of knowledge-based challenges, including the lack of knowledge and awareness and technology reluctance. The findings indicate that clients and contractors are often unfamiliar with available technologies, which limits consideration of their use in practice. Even when contractors are aware of emerging technologies, they may still be reluctant to adopt them, reflecting the generally slow rate of technological evolution in the construction industry compared to other sectors.⁷⁰

This hesitancy is often associated with limited understanding and exposure, which can contribute to reduced trust in new technologies among construction managers.⁷¹ In some cases, stakeholders may also be unaware of the potential benefits these new technologies could offer compared to traditional approaches.

One key intersection between financial and knowledge barriers is risk-aversion. When technologies are perceived as both costly and unfamiliar, stakeholders are more likely to favor established construction practices that are perceived as lower risk. This interaction reinforces conservative decision-making patterns in the adoption of new technologies in historic building contexts. This absence of trust and conservative adoption behavior is particularly evident among smaller construction firms, where the perceived risk of poor financial decisions is greater.⁷² Smaller firms are therefore more likely to be cautious in adopting new construction techniques and technologies.⁷² The interview findings suggest that financial constraints and perceived risk play a central role in shaping adoption decisions, particularly in contexts where project budgets are limited.

The most commonly proposed solution to alleviate these challenges, mentioned in almost every interview, is to increase industry-wide awareness of these technologies among both potential clients and contractors. Contractors and clients should be as aware as reasonably possible of all potential technologies available during a historic building treatment. This could be achieved through structured training programs, informational resources, as well as gradual exposure to emerging technologies as they become more widely adopted in practice. A potential strategy is to bring these modern technologies into common knowledge via the use of various media entertainment programs, such as television programs or online channels. Television programs, such as *Houses With History*, focus on historic building treatments. However, these existing programs usually focus on the aesthetic decisions during the historic building treatments, rather than discussing the potential use of modern technologies. Highlighting modern technologies and techniques that can be used to achieve the desired aesthetic outcome could significantly increase public awareness of these possibilities.

Increasing the user-friendliness of software and digital tools could significantly improve the frequency of use of modern technologies in historic building treatments. Construction projects have an inherently complex and unpredictable nature.⁷⁴ This inherent complexity makes the usability and ease of implementation of modern technology critical considerations in historic building projects.

An important point to emphasize is that before the application of modern technologies, methods, or materials is considered, the contractor must be highly familiar with the historic methods, and more importantly, understand the rationale of why they were used. By doing so, contractors can more accurately decide where the use of modern technologies in historic building treatments is appropriate, and where it is not. This understanding of historic methods, or lack thereof, is the most important factor to consider when applying modern construction techniques and technologies in the context of historic building treatments.

The research found that financial barriers, knowledge barriers, and usability limitations collectively reinforce risk-averse behavior of practitioners, hindering their adoption of modern technologies. This dynamic is particularly important in historic building treatments, where decision-making must balance innovation with preservation requirements. The successful integration of modern technologies, therefore, requires emphasis on both technological accessibility and historical competency. While interviewees highlight that these emerging technologies should become accessible to end-users as quickly as possible and that access to the technologies should be democratized, they also emphasize the need for coordinated efforts to strengthen training in historic construction methods. In combination, these approaches may enable the benefits of modern innovation to be realized without compromising the cultural and historical integrity of heritage structures.

CONCLUSIONS

This research was undertaken to address the research gap in the decision process of key project stakeholders when deciding whether to utilize modern construction technologies in historic building treatments and factors impacting this decision-making process. The findings of this research provide qualitative empirical insight into the opportunities and challenges associated with the applications of modern construction technologies in historic building treatment projects. Drawing on in-depth expert interviews with industry professionals involved in historic building projects in Detroit, Michigan, the study identifies several key concerns influencing adoption decisions, including the high cost of implementing modern technologies, lack of knowledge and awareness, and technology reluctance among project stakeholders.

Among these, financial constraints emerged as a primary and recurring concern, particularly given the perceived expense of emerging technologies and the budget limitations often faced by smaller firms and projects. These financial considerations frequently interact with knowledge-related constraints, reinforcing cautious and risk-averse decision-making. At the same time, the results also underscore the potential benefits of modern construction technologies in historic building treatments, particularly in mitigating

long-term deterioration and enabling more effective intervention strategies, especially in cases where historic methods are infeasible or impractical.

A key contribution of this research lies in its identification of knowledge gaps as a central constraint on the responsible adoption of modern technologies in historic building treatments. The findings of this research show that uncertainty, limited familiarity, and lack of knowledge about modern construction technologies, among both project owners and contractors, often drive overly conservative decision-making or, conversely, inappropriate technological applications. By foregrounding practitioner perspectives, this study advances existing literature by linking technology adoption in historic building treatments not only to material or regulatory considerations, but also to workforce training, professional education, and communication practices. Workforce training programs, targeted professional education, and the strategic documentation and dissemination of successful case studies can be utilized to address existing knowledge gaps and improve knowledge transfer across project teams, thereby supporting the effective application of modern technologies in historic building projects.

This research provides empirical insights for project stakeholders in the historic construction industry by illuminating the complexities of technology-related decision-making, discussing financial and knowledge-based constraints, and identifying actionable strategies to support more effective application of modern technologies in historic building projects. This research opens several avenues for future research. The interview sample size was limited, which may constrain the breadth of perspectives represented. Moreover, the geographic focus on the Detroit metropolitan area restricts the generalizability of the findings. Future research would benefit from a larger and more geographically diverse sample of expert interviews, enabling analysis across different climatic conditions, regulatory frameworks, and regional preservation practices. Expanding the research scope in this manner would further refine the understanding of how modern technologies can be responsibly adapted to diverse historic building contexts.

ACKNOWLEDGMENTS

The authors thank all the interviewees that so graciously provided their time and expert input into this research, as well as Drs. Okoh and Mr. Xie for all their aid with the submission process.

REFERENCES

1. Arzac, Sergio, Nancy Volkman, Charles A. Birnbaum, and Christine Capella Peters. 1998. *The Secretary of the Interior's Standards for the Treatment of Historic Properties*. APT Bulletin 29: 54. <https://doi.org/10.2307/1504550>.
2. Grimmer, Anne E., and Kay D. Weeks. 2017. *The Secretary of the Interior's Standards for the Treatment of Historic Properties*. APT Bulletin: 172.
3. Perret, Noëlle-Laetitia, Elodie Héberlé, and Laure-Emmanuelle Perret. 2025. Multi-Benefit Decision-Making Process for Historic Buildings: Validation of the Caleche Hub Conceptual Model Through a Literature Review. *Heritage* 8: 45. <https://doi.org/10.3390/heritage8020045>.
4. Yixin, Jin, and Hu Shen. 2024. Historical building protection and modern functional renovation practice. Edited by A.-S. Nizami and B. Wang. *E3S Web of Conferences* 490: 02011. <https://doi.org/10.1051/e3sconf/202449002011>.
5. Garau, Giorgio, and Marco Rosa-Clot. 2017. Supplying historic buildings with energy, without impinging on their historic and cultural values. *Energy Procedia* 134: 244–255. <https://doi.org/10.1016/j.egypro.2017.09.614>.
6. Siman, Siman, and Nugraha Nugraha. 2024. Comparison Of Traditional And Modern Construction Methods In Civil Engineering Projects. *Innovative Research in Civil and Environmental Engineering* 1: 15–22. <https://doi.org/10.70134/ircee.v1i1.43>.
7. H. 2005. *The Oxford encyclopedia of economic history*. Edited by Joel Mokyr. Oxford reference Online Oxford Digital Reference Shelf. Oxford: Oxford Univ. Press. <https://doi.org/10.1093/acref/9780195105070.001.0001>.
8. Hegazi, Yasmine Sabry, Heidi Ahmed Shalaby, and Mady A. A. Mohamed. 2021. Adaptive Reuse Decisions for Historic Buildings in Relation to Energy Efficiency and Thermal Comfort—Cairo Citadel, a Case Study from Egypt. *Sustainability* 13: 10531. <https://doi.org/10.3390/su131910531>.
9. Penića, Milja, Golovina Svetlana, and Vera Murgul. 2015. Revitalization of Historic Buildings as an Approach to Preserve Cultural and Historical Heritage. *Procedia Engineering* 117: 883–890. <https://doi.org/10.1016/j.proeng.2015.08.165>.
10. Lanciotti, Alessandra. 2024. Preservation of Historical Buildings through the Lens of International Law. *Real Estate* 1: 198–211. <https://doi.org/10.3390/realestate1020010>.
11. Advisory Council on Historic Preservation. 1966. National Historic Preservation Act | Advisory Council on Historic Preservation. October 15.
12. Park, Sharon C., and S. M. Escherich. 1996. Affordable housing and historic preservation. *CRM- Washington* - 19. National Park Service: 20–23.
13. Karakul, Özlem. 2015. “An Integrated Methodology for the Conservation of Traditional Craftsmanship in Historic Buildings. *International Journal of Intangible Heritage* null: 121–129. <https://doi.org/10.35638/IJIH.2015..10.016>.

14. Squassina, Angela. 2022. From Intangible to Tangible Artisan Skills and Traditional Crafts for Preserving Venice's Built Heritage. In *Proceedings Heritage 2022 - International Conference on Vernacular Heritage: Culture, People and Sustainability*. Universitat Politècnica de València. <https://doi.org/10.4995/HERITAGE2022.2022.15716>.
15. Zhao, Peng, Xiuzhi Zhang, Lei Qin, Yunsheng Zhang, and Lizhi Zhou. 2019. Conservation of disappearing traditional manufacturing process for Chinese grey brick: Field survey and laboratory study. *Construction and Building Materials* 212: 531–540. <https://doi.org/10.1016/j.conbuildmat.2019.03.317>.
16. Nowogońska, Beata. 2020. Consequences of improper renovation decisions in a 17th century half-timbered building. *Scientific Review Engineering and Environmental Studies (SREES)* 29: 557–566. <https://doi.org/10.22630/PNIKS.2020.29.4.48>.
17. Gregg, Andrew W. 2025. The Legal Intersection of Historic Preservation and Modern Development | Bean, Kinney & Korman.
18. Grimmer, E. A., and D. K. Weeks. 2021. Preservation brief 14: new exterior additions to historic buildings: preservation concerns. 2013—07—11]. <http://www.nps.gov/tps/how-to-preserve/briefs/14-exterior-additions.htm>.
19. Tejani, Ankitkumar. 2021. Integrating Energy-Efficient HVAC Systems into Historical Buildings: Challenges and Solutions for Balancing Preservation and Modernization. *ESP Journal Of Engineering & Technology Advancements* 1: 83–97. <https://doi.org/10.56472/25832646/JETA-V1I1P111>.
20. Cascone, Santi, Vincenzo Sapienza, Irene Lioni, and Simona Porto. 2016. Fiber-Reinforced Polymer Nets for Strengthening Lava Stone Masonries in Historical Buildings. *Sustainability* 8: 394. <https://doi.org/10.3390/su8040394>.
21. Anireddy, Abhiram Reddy. 2024. Impact of Technology on Construction: The Role of Building Information Modeling (BIM) in Modern Construction Project. *Int. J. Innov. Res. Eng. Multidiscip. Phys. Sci* 12. <https://doi.org/10.5281/zenodo.14005348>.
22. Emmanuel, Igba, Edwin Osei Danquah, Emmanuel Adikwu Ukpoju, Jesutosin Obasa, Toyosi Motilola Olola, and Joy Onma Enyejo. 2024. Use of Building Information Modeling (BIM) to Improve Construction Management in the USA. *World Journal of Advanced Research and Reviews* 23: 1799–1813. <https://doi.org/10.30574/wjarr.2024.23.3.2794>.
23. Kallayil, Aiswarya, Jigar Patadiya, Balasubramanian Kandasubramanian, Aleksey Adamtsevich, Mohamed Kchaou, and Faisal Khaled Aldawood. 2025. Adaptive Smart Materials in Architecture: Enhancing Durability and Sustainability in Modern Construction. *ACS Omega* 10: 22305–22322. <https://doi.org/10.1021/acsomega.4c04943>.
24. Sodangi, Mahmoud, and Alaa Salman. 2024. Analyzing the Critical Impediments to Retrofitting Historic Buildings to Achieve Net Zero Emissions. *The Open Construction & Building Technology Journal* 18: e18748368357448. <https://doi.org/10.2174/0118748368357448241118063403>.
25. Younis, Ahmad, and Muhieddin Tawalbeh. 2024. Innovative Energy Retrofit Approach of Historical Buildings Using HBIM Process: The Guest House of Al-Karak Greater Municipality in Jordan a Case Study. *Civil Engineering and Architecture* 12: 1219–1234. <https://doi.org/10.13189/cea.2024.120239>.
26. Cluver, John H., and Brad Randall. 2012. Saving energy in historic buildings: balancing efficiency and value: energy modeling and life-cycle costing can help identify simple steps to make a historic building more energy efficient, addressing both preservation and sustainability concerns. *Planning for Higher Education* 40. Society for College and University Planning: 13–25.
27. Gnaba, Hela Ahmad, Faizah Mohammed Bashir, Nedhal Al-Tamimi, Mohammed J Alshayeb, Nadia Hasen Rassas, Yaser Khaled Al-Sakkaf, and Yakubu Aminu Dodo. 2025. Balancing heritage preservation with sustainability through interior design strategies and technological interventions in adaptive reuse projects. *Energy and Buildings* 346: 116234. <https://doi.org/10.1016/j.enbuild.2025.116234>.
28. Yuk, Hyeonseong, Ji Yong Choi, Sungwoong Yang, and Sumin Kim. 2024. Balancing preservation and utilization: Window retrofit strategy for energy efficiency in historic modern building. *Building and Environment* 259. Elsevier: 111648. <https://doi.org/10.1016/j.buildenv.2024.111648>.
29. Cabeza, Luisa F., Alvaro De Gracia, and Anna Laura Pisello. 2018. Integration of renewable technologies in historical and heritage buildings: A review. *Energy and Buildings* 177: 96–111. <https://doi.org/10.1016/j.enbuild.2018.07.058>.
30. Dattel, Robin E., and Dennis J. Dingemans. 1988. Why Places Are Preserved: Historic Districts in American and European Cities. *Urban Geography* 9: 37–52. <https://doi.org/10.2747/0272-3638.9.1.37>.
31. Frank, Karolin, and Patricia Petersen, ed. 2002. *Historic Preservation in the USA*. Berlin, Heidelberg: Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-662-04767-5>.
32. Heintzelman, Martin D., and Jason A. Altieri. 2013. Historic Preservation: Preserving Value? *The Journal of Real Estate Finance and Economics* 46: 543–563. <https://doi.org/10.1007/s11146-011-9338-8>.
33. Heins, Matthew. 2020. Two Views on Abandonment and Blight in Detroit SaraSafransky. *The City After Property: Abandonment and Repair in Postindustrial Detroit*. Durham, NC: Duke University Press, 2023. Alesia Montgomery. *Greening the Black Urban Regime: The Culture and Commerce of Sustainability in Detroit*. Detroit: Wayne State University Press, 2020. *Journal of Planning History* 24: 58–61. <https://doi.org/10.1177/15385132231222948>.
34. Boyle, Kevin. 2001. The Ruins of Detroit: Exploring the Urban Crisis in the Motor City. *The Michigan Historical Review* 27: 109. <https://doi.org/10.2307/20173897>.

35. Herstad, Kaeleigh. 2017. "Reclaiming" Detroit. *The Public Historian* 39: 85–113. <https://doi.org/10.1525/tpb.2017.39.4.85>.
36. Citywide Historic Preservation Plan. 2024. City Of Detroit.
37. National Register Database and Research. 2026. Excel Spreadsheet. National Park Service U.S. Department of the Interior. <https://www.nps.gov/subjects/nationalregister/database-research.htm>. Accessed June 14.
38. Kelly, David, and Hyun Jeong Koo. 2024. Challenges Managing Large Historic Building Renovations: Lessons Learned from Detroit, Michigan. *Journal of Construction Engineering and Management* 150: 05023015. <https://doi.org/10.1061/JCEMD4.COENG-13555>.
39. Vafaie, Fatemeh, Hilde Remøy, and Vincent Gruis. 2023. Adaptive reuse of heritage buildings; a systematic literature review of success factors. *Habitat International* 142: 102926. <https://doi.org/10.1016/j.habitatint.2023.102926>.
40. Chmielewski, Ryszard, and Leopold Kruszka. 2015. Application of selected modern technology systems to strengthen the damaged masonry dome of historical St. Anna's Church in Wilanów (Poland). *Case Studies in Construction Materials* 3: 92–101. <https://doi.org/10.1016/j.cscm.2015.08.001>.
41. OHP001 Module 2 - Understanding the Four Treatments for Historic Properties. California State Office Of Historic Preservation.
42. National Historic Preservation Act. 2026. Advisory Council On Historic Preservation. <https://www.achp.gov/digital-library-section-106-landing/national-historic-preservation-act>. Accessed February 8.
43. Siountri, Konstantina, and Christos-Nikolaos Anagnostopoulos. 2023. The Classification of Cultural Heritage Buildings in Athens Using Deep Learning Techniques. *Heritage* 6: 3673–3705. <https://doi.org/10.3390/heritage6040195>.
44. Prokop, Anna, Piotr Nazarko, and Leonard Ziemiański. 2021. Digitalization of historic buildings using modern technologies and tools. *Budownictwo i Architektura* 20: 083–094. <https://doi.org/10.35784/bud-arch.2444>.
45. Garbett, James, Thomas Hartley, and David Heesom. 2021. A multi-user collaborative BIM-AR system to support design and construction. *Automation in Construction* 122: 103487. <https://doi.org/10.1016/j.autcon.2020.103487>.
46. Xu, Jie, Lieyun Ding, and Peter E.D. Love. 2017. Digital reproduction of historical building ornamental components: From 3D scanning to 3D printing. *Automation in Construction* 76: 85–96. <https://doi.org/10.1016/j.autcon.2017.01.010>.
47. Krajnikova, Katarina, Rastislav Ručinský, Jana Smetanková, and Maria Grazianova. 2025. Using AI in the Restoration of Historic Buildings: Digital Diagnostics, Predictive Modelling and Ethical Challenges. In *2025 IEEE International Conference on Engineering, Technology, and Innovation (ICE/ITMC)*, 1–11. Valencia, Spain: IEEE. <https://doi.org/10.1109/ICE/ITMC65658.2025.11106628>.
48. Orlenko, Mykola, Yulia Ivashko, Justyna Kobylarczyk, and Dominika Kusnierz-Krupa. 2020. Ways of revitalization with the restoration of historical industrial facilities in large cities. The experience of Ukraine and Poland. *International Journal of Conservation Science* 11: 19. ISSN: 2067-533X.
49. Khaleghi, Neshat, and Francesca Governa. 2025. Smart City and the Adaptive Reuse of Historic Buildings: Preserving Cultural Identity and Mitigating Gentrification in Urban Regeneration. Politecnico di Torino.
50. Jester, Thomas C. and The Getty Conservation Institute, ed. 2014. *Twentieth-century building materials: history and conservation*. Los Angeles, Calif: Getty Conservation Institute.
51. Valluzzi, Maria Rosa, Claudio Modena, and Gianmarco De Felice. 2014. Current practice and open issues in strengthening historical buildings with composites. *Materials and Structures* 47: 1971–1985. <https://doi.org/10.1617/s11527-014-0359-7>.
52. Sivaraja, S. Saileysh, T.S. Thandavamoorthy, S. Vijayakumar, S. Moses Aranganathan, and A.K. Dasarathy. 2013. Preservation of Historical Monumental Structures using Fibre Reinforced Polymer (FRP) - Case Studies. *Procedia Engineering* 54: 472–479. <https://doi.org/10.1016/j.proeng.2013.03.043>.
53. Hager, Izabela, Anna Golonka, and Roman Putanowicz. 2016. 3D Printing of Buildings and Building Components as the Future of Sustainable Construction? *Procedia Engineering* 151: 292–299. <https://doi.org/10.1016/j.proeng.2016.07.357>.
54. Siu, S. L. K. 2021. Application of 3D scanning technology in restoration of heritage site damaged by natural disaster.. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLVI-M-1–2021*: 685–691. <https://doi.org/10.5194/isprs-archives-XLVI-M-1-2021-685-2021>.
55. Grinzato, Ermanno. 2012. IR Thermography Applied to the Cultural Heritage Conservation. In . Durban, South Africa.
56. Nguyen, Tuan Anh, Tu Anh Nguyen, and The Van Tran. 2024. Building Information Modeling (BIM) for Construction Project Schedule Management: A Review. *Engineering, Technology & Applied Science Research* 14: 13133–13142. <https://doi.org/10.48084/etasr.6834>.
57. Likita, Ayuba Jerry, Mostafa Babacian Jelodar, Vishnupriya Vishnupriya, James Olabode Bamidele Rotimi, and Nimesha Vilasini. 2022. Lean and BIM Implementation Barriers in New Zealand Construction Practice. *Buildings* 12: 1645. <https://doi.org/10.3390/buildings12101645>.
58. Brahmi, Bani Ferial, Souad Sassi Boudemagh, Ilham Kitouni, and Aliakbar Kamari. 2022. IPD and BIM-focussed methodology in renovation of heritage buildings. *Construction Management and Economics* 40: 186–206. <https://doi.org/10.1080/01446193.2021.1933557>.

59. Olawumi, Timothy O., and Daniel W. M. Chan. 2019. Building information modelling and project information management framework for construction projects. *Journal of Civil Engineering and Management* 25: 53–75. <https://doi.org/10.3846/jcem.2019.7841>.
60. Gleń, Piotr, Jan Wrana, Wojciech Struzik, and Katarzyna Jaromin-Gleń. 2024. Dedicated HVAC Technology in the Renovation of Historic Buildings on the Example of the Marshal Pilsudski Manor in Sulejówek. *Energies* 17: 5946. <https://doi.org/10.3390/en17235946>.
61. Chigangacha, Theo C Haupt, and T C Haupt. 2017. Effectiveness of client involvement in construction projects: A contractor perspective. In , 249–266. Durban.
62. Ozcan-Deniz, Gulbin. 2019. Expanding applications of virtual reality in construction industry: A multiple case study approach. *Journal of Construction Engineering, Management & Innovation* 2: 48–66. <https://doi.org/10.31462/jcemi.2019.02048066>.
63. Monla, Ziad, Ahlem Assila, Djaoued Beladjine, and Mourad Zghal. 2023. Maturity Evaluation Methods for BIM-Based AR/VR in Construction Industry: A Literature Review. *IEEE Access* 11: 101134–101154. <https://doi.org/10.1109/ACCESS.2023.3281265>.
64. Wang, Xiangyu. 2007. Using Augmented Reality to Plan Virtual Construction Worksite. *International Journal of Advanced Robotic Systems* 4: 42. <https://doi.org/10.5772/5677>.
65. Waly, Ahmed F, and Walid Y Thabet. 2003. A Virtual Construction Environment for preconstruction planning. *Automation in Construction* 12: 139–154. [https://doi.org/10.1016/S0926-5805\(02\)00047-X](https://doi.org/10.1016/S0926-5805(02)00047-X).
66. Badhan, Sharmin Jahan, and Reihaneh Samsami. 2025. Artificial Intelligence (AI) in Construction Safety: A Systematic Literature Review. *Buildings* 15: 4084. <https://doi.org/10.3390/buildings15224084>.
67. Okba, M. Okba, and E. Embaby Mohga. 2013. Sustainability and Heritage Buildings. *International Journal of Engineering Research & Technology* 2: 1682–1690.
68. Yildirim, Mücahit. 2012. Assessment of the decision-making process for re-use of a historical asset: The example of Diyarbakir Hasan Pasha Khan, Turkey. *Journal of Cultural Heritage* 13: 379–388. <https://doi.org/10.1016/j.culher.2012.01.018>.
69. Leedy, Paul D., and Jeanne Ellis Ormrod. 2010. *Practical Research: Planning and Design*. 9th ed. Perason.
70. Dorussen, Han, Hartmut Lenz, and Spyros Blavoukos. 2005. Assessing the Reliability and Validity of Expert Interviews. *European Union Politics* 6: 315–337. <https://doi.org/10.1177/1465116505054835>.
71. Regona, Massimo, Tan Yigitcanlar, Bo Xia, and Rita Yi Man Li. 2022. Opportunities and Adoption Challenges of AI in the Construction Industry: A Prisma Review. *Journal of Open Innovation: Technology, Market, and Complexity* 8: 45. <https://doi.org/10.3390/joitmc8010045>.
72. Arabshahi, Mona, Di Wang, Junbo Sun, Payam Rahnamayiezekavat, Weichen Tang, Yufei Wang, and Xiangyu Wang. 2021. Review on Sensing Technology Adoption in the Construction Industry. *Sensors* 21: 8307. <https://doi.org/10.3390/s21248307>.
73. Sexton, Martin, Peter Barrett And, and Ghassan Aouad. 2006. Motivating small construction companies to adopt new technology. *Building Research & Information* 34: 11–22. <https://doi.org/10.1080/09613210500254474>.
74. Jahan, Shah, Khurram Khan, Muhammad Thaheem, Fahim Ullah, Muwaffaq Alqurashi, and Badr Alsulami. 2022. Modeling Profitability-Influencing Risk Factors for Construction Projects: A System Dynamics Approach. *Buildings* 12: 701. <https://doi.org/10.3390/buildings12060701>.
75. CBS. (2021, September 27). Plympton Couple Starring In New HGTV Show On Repairing Historic Homes. CBS Boston.73.

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PRESS SUMMARY

Modern construction technologies have notable potential in their application to historic properties important to the cultural heritage of Detroit by addressing structural deterioration, enhancing safety, improving energy performance, and supporting long-term sustainability. However, integrating these modern construction technologies into historic construction requires a careful balance between preserving historic integrity and complying with contemporary construction standards and advancing technological capabilities. Understanding the perspective and decision-making considerations of key stakeholders is critical to the effective development, utilization, and application of modern construction technologies in the historic construction field. Therefore, it is essential to investigate the lived experiences and perspectives of key project stakeholders to identify the primary drivers and challenges shaping the adoption of modern technology used during historic building treatments.

Implementation of Buprenorphine After X-Waiver Elimination: A Health System Review of Rural North Carolina

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<https://doi.org/10.33697/ajur.2026.179>

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ABSTRACT

Background: Increasing accessibility of buprenorphine among individuals with opioid use disorder (OUD) is essential to decreasing the prevalence of overdose-related deaths. In January 2023, the Federal Mainstreaming Addiction Treatment (MAT) Act eliminated the X-waiver requirement for clinicians to prescribe buprenorphine to increase treatment provision. Prescriber-level behaviors following this policy change are not well understood in rural areas. This study investigates how buprenorphine prescribing practices changed in one North Carolina health system after the elimination of the X-waiver. **Methods:** Data were obtained through a convergent mixed-methods online survey conducted from February-July 2025. Survey items included structured survey questions and free response opportunities. Clinicians from the East Carolina University (ECU) Health System were identified from the North Carolina Medical Board (NCMB) Roster and from an ECU Health advanced practice provider email network (N = 978). Buprenorphine prescribing behaviors were analyzed using descriptive statistics. Barriers and facilitators to buprenorphine prescription were identified using thematic analysis. **Results:** Fifty clinicians responded to the survey for a response rate of 5.1%. Prior to the MAT Act, 42% reported prescribing buprenorphine; following the MAT Act, only 28% did so. Prescribing was shaped by (1) individual clinician factors; (2) health systems-level factors; and (3) community-level factors. **Conclusions:** Findings suggest that federal policy change alone may be insufficient to increase buprenorphine prescribing in this rural health system. Implementation of evidence-based strategies addressing factors at the community, health system, and individual level can potentially strengthen institutional support, reduce community-level barriers, and enhance clinician engagement in providing medication for OUD.

KEYWORDS

Buprenorphine; X-waiver; Medication for Opioid Use Disorder (MOUD) Policy; CFIR; Rural; North Carolina; Physician Assistant; Nurse Practitioner

INTRODUCTION

Opioid misuse and opioid use disorder (OUD) are significant public health concerns in the US. People who misuse opioids have a higher mortality rate and a substantially shorter life expectancy.¹⁻³ In 2024, 4.8 million people ages 12 and older reported OUD in the past year.⁴

Access to medication for opioid use disorder (MOUD), including buprenorphine or methadone, is the most effective OUD treatment.⁵ MOUD reduces the risk of opioid overdose death by 60%.⁶ The CDC (Centers for Disease Control and Prevention) estimated that although 4% of Americans needed OUD treatment, only 25% received recommended medication.⁷ There are myriad reasons why MOUD is not accessed or utilized, including insufficient availability of MOUD prescribers,^{8,9} patient and provider stigma, lack of knowledge, inadequate prescribing resources, and federal or state regulations.¹⁰

As of January 2023, any clinician with a narcotics license in the US can prescribe buprenorphine. Until then, prescribers were required to complete 8 hours of training and obtain a Drug Addiction Treatment Act (DATA) waiver, or X-waiver, through the Drug Enforcement Agency (DEA).^{11,12} Waivered clinicians were historically limited in the number of patients they could treat.¹³ Despite the X-waiver requirement and associated incentive (federal loan forgiveness) obtaining the waiver did not ensure clinicians would initiate or sustain buprenorphine prescribing.¹⁴ Federal policy created unintended barriers, such as scope of practice restrictions, that reduced treatment access, as highlighted in a 2019 study reporting that only 6% of physicians, 2% of physician assistants (PA), and 3% of nurse practitioners (NP) held X-waivers.¹⁵

In April 2021, X-waiver requirements were relaxed, allowing clinicians to apply for training exceptions to prescribe buprenorphine for fewer than 30 patients.¹⁶ A state-level analysis, of four states, showed modest increases in waived clinicians after training exemption thought effects varied by state; one state experienced a 0.5% decrease.¹⁷ In 2022, the Mainstreaming Addiction Treatment Act (MAT Act), removed restrictions surrounding MOUD.¹⁸ Effective January 2023, the MAT Act eliminated the X-waiver requirement (including patient limits) and introduced a universal training requirement for clinicians treating OUD.¹⁸ The change allowed any clinician with an active DEA registration number that includes schedule III (e.g., Oxycodone, Adderall) authority to prescribe buprenorphine. However, state-specific restrictions (i.e., prior authorizations, patient limits, special state registration) still applied.¹⁹

Impact of the X-waiver Elimination

The MAT Act eliminated the X-waiver in 2023, yet few studies have examined the impact of this regulatory change on prescribing. Two national studies found that while the number of clinicians prescribing buprenorphine increased following the elimination, the number of patients with buprenorphine prescriptions decreased.^{20,21} Additionally, Guy et al. observed a diminishing rate of buprenorphine prescribing nationally the year following previous policies to expand MOUD, which could be due to lower prescribing frequency amongst newly initiated prescribers.²² This suggests that policy change is necessary but may not be sufficient to expand patient access to buprenorphine treatment.

Rural Buprenorphine Treatment & CFIR

National data show persistent rural–urban disparities in buprenorphine treatment.^{23,24} Roughly one-third of rural residents live in counties without buprenorphine access compared with about 2% of urban residents, and many rural counties remain markedly undersupplied.²⁵

Rural communities face barriers across multiple dimensions, including availability barriers (few clinics and providers),²⁶ acceptability barriers (greater stigma and negative clinician attitudes toward OUD and MOUD),²⁷ and accessibility barriers (transportation, cost, and long waitlists).²⁸ Across settings, intervention characteristics, inner-setting dynamics, and individual factors, including stigma, diversion concerns, and limited time or support, shape prescribing, though attitudes often improve with real-world experience.²⁹⁻³²

The Consolidated Framework for Implementation Research (CFIR) is a framework used to identify multidimensional factors influencing intervention implementation.³³ The CFIR has guided understanding of why buprenorphine delivery succeeds or stalls across multiple dimensions within health care settings.³⁴⁻³⁶ CFIR has been applied to emergency department (ED)–based buprenorphine programs. A recent scoping review mapped barriers and facilitators across all five CFIR domains, identifying strategies such as multidisciplinary teams, co-located low-barrier services, and harm-reduction services, while also pointing to challenges related to structural stigma, complex patient needs, and a complex drug supply landscape.³⁷

North Carolina MOUD Access

In 2024, the North Carolina Department of Health and Human Services (NCDHHS) reported roughly 3,025 overdose deaths statewide.³⁸ During the period in which the X-waiver governed buprenorphine prescribing, multiple system-level barriers constrained access to treatment in North Carolina (NC). A 2023 study with NPs highlighted how federal and state regulations, limited institutional support, and persistent stigma toward OUD shaped clinicians' willingness and ability to prescribe buprenorphine.¹⁰ Downstream barriers in the dispensing process were also identified. Although most NC pharmacies carried buprenorphine, restrictive order practices and pharmacists' refusal to dispense created inconsistent access for patients seeking care.³⁹ These challenges illustrate that structural (CFIR domains: outer and inner setting) and attitudinal (CFIR domains: individuals) barriers can become embedded barriers interrupting the treatment continuum during the X-waiver era. Despite the X-waiver removal and implementation of the MAT Act, it is unknown if these concerns continue to influence buprenorphine availability and uptake today in NC.

It is important to specifically focus on rural community access to MOUD, as 80 of the 100 counties within NC are considered rural.⁴⁰ NC rural communities experience higher overdose rates compared with their urban and suburban counterparts.⁴¹ Yet, no studies within NC explored rural MOUD treatment access post MAT Act. Access to MOUD is imperative to reduce overdoses in rural NC communities.

There have been no studies on the impact of the MAT Act in NC. The purpose of this study is to characterize buprenorphine prescribing among clinicians in a NC health system that serves 25 rural counties in eastern NC.⁴² The study will provide information on how buprenorphine prescribing behaviors changed within a health system after the MAT Act and explore barriers and clinicians' attitudes toward buprenorphine prescribing. We hypothesize that buprenorphine prescription increased following

the implementation of the MAT Act. Findings will guide the development and implementation strategies to enhance buprenorphine access and support utilization of MOUD treatment in rural areas.

METHODS AND PROCEDURES

Study Design and Participants

This cross-sectional study used a convergent mixed-methods design. East Carolina University (ECU) Health System serves 29 counties in eastern NC, 25 of which are rural and medically underserved.^{40,43,44} ECU Health has a substantial rural footprint and a mission to advance rural health.⁴⁵ The system includes nine hospitals, more than 105 clinics, and over 1,200 physicians and advanced practice providers across multiple specialties.⁴⁶ It was selected as the study setting because it is the fifth-largest NC health system and provides care to a large, predominantly rural patient population.⁴⁷

Eligible participants were ECU Health clinicians practicing as medical doctors (MDs), doctors of osteopathic medicine (DOs), physician assistants (PAs), or nurse practitioners (NPs). Clinicians working exclusively in administrative medicine or specialties unlikely to provide MOUD such as pediatrics/neonatology, anesthesiology, dermatology, ophthalmology, physical medicine, plastic surgery, pathology, and radiology were excluded. This study was approved by the ECU Institutional Review Board (UMCIRB 24-001094).

Procedures

Participant recruitment occurred in two phases. In phase one, clinicians were identified using the North Carolina Medical Board (NCMB) Roster, which provides a full listing of clinicians practicing in NC. A new roster report is run monthly, providing the most up-to-date list of licensees. The roster was obtained in December 2024. Clinicians practicing within ECU Health were identified from the NCMB Roster. It was thoroughly sorted to exclude specialties listed above. Duplicate entries were removed. The roster was separated into two separate lists for PAs (n=81) and MDs (n=438). Provider emails were obtained through ECU Health database.

Due to NPs not being included in the NCMB roster, phase two focused on NP recruitment. An advanced practice provider leader within ECU Health system emailed NPs and PAs (n=459) working within ECU health. Due to using a mixed-discipline email group, we were unable to determine discipline-specific recruitment numbers for NPs and PAs in Phase 2.

An adapted Dillman Method was used for email recruitment timing.⁴⁸ A total of three emails were sent in the early morning (430-6 am). Recruitment emails contained a URL and QR code, directing participants to a Qualtrics portal with study information. Informed consent was required before participants could answer survey questions; those who declined were redirected and could not proceed. At survey completion, participants could enter a drawing to win one of 55 \$15 Amazon gift cards. Participation was voluntary and anonymous and for research purpose only; data were securely stored on ECU's restricted-access OneDrive.

Measures

The CFIR informed *a priori* implementation barriers and facilitators for measurement.⁴⁹ Measures focused on three domains: Outer Setting, Inner Setting, and Individuals. These domains were chosen due to alignment with survey measures. Items were adapted from publicly available CFIR constructs and tailored for OUD treatment (**Table 2**). The Outer Setting captured external factors influencing buprenorphine prescribing, including policies, community resources, and system- or patient-level barriers. The Inner Setting assessed organizational infrastructure, culture, and processes shaping implementation within the ECU Health system. The Individuals domain reflected clinician or patients' attributes (personal beliefs, knowledge, confidence, and motivations) that influence buprenorphine prescribing.⁵⁰

Outcome variables addressed in the 27-item survey include infrastructure, practice context, attitudes toward buprenorphine prescription, buprenorphine prescription prevalence, methadone prescribing practices, and personal and employment demographics (**Table 1**).

Domain / Variable	Description	Question Type	Items / Response Options	Source
Infrastructure	Organizational capacity to deliver MOUD	Two Quantitative Items; One Qualitative Item	1. Resources needed to administer buprenorphine (Likert: Strongly Agree–Strongly Disagree) 2. PDMP use (Before determining any medication; Before prescribing narcotic; Before treating OUD; After prescribing; Seldom; Not familiar). Qualitative response option of Other – please list. 3. Identify sources for OUD treatment guidance (qualitative response).	Integrating Medications for Addiction Treatment (IMAT) index Chokron Garneau et al., 2021
Practice Context	Clinical environment and patient population	Three Quantitative Items	1. % of patient using opioid analgesics for chronic pain 2. What proportion of patients does the clinician directly prescribe (0%–100%) 3. Primary population includes SUD (Yes/No/Not assessed)	Damschroder et al., 2022b; McCracken et al., 2012; Wertheimer et al., 2021
Clinician Attitudes Toward Buprenorphine Prescribing	Perceptions influencing prescribing	Two Quantitative Items; One Mixed-Method Item	1. Importance of prescribing buprenorphine (Likert: Strongly Agree–Strongly Disagree) 2. Influence of X-waiver on prescribing (Don't know; No effect; Minor effect; Major effect) 3. Previous MOUD training (Fellowship; CE training; Mentoring; UNC ECHO; None); Qualitative response option of Other – please list.	Chokron Garneau et al., 2021; Damschroder et al., 2022b
Buprenorphine Prescribing Practices	Current and historical prescribing behaviors	Six Quantitative Items	1. Clinic volume (<100 – >1000) 2. History of prescribing buprenorphine (Yes/No) 3–4. Patients prescribed buprenorphine before vs. after X-waiver elimination (0; 1–3; 4–8; >8) 5. Comfort prescribing buprenorphine (Needs training; Difficult to discuss; Strongly against) 6. Comfort teaching peers about MOUD (Comfortable; Needs training; Not comfortable; Difficult to discuss)	Jones et al., 2023; Jones & McCance-Katz, 2019; Meyerson et al., 2019; Perez et al., 2004; The Physician's Foundation, 2012
Methadone Practices	Willingness to prescribe methadone	Two Quantitative Items	1. Likelihood of prescribing methadone 2. Likelihood if regulations allowed office-based prescribing (0–10 scale: 0 = very unlikely, 10 = very likely)	Damschroder et al., 2022b; Jones & McCance-Katz, 2019
Barriers to MOUD Treatment	Barriers hindering MOUD accessibility	One Mixed-Method Item	1. Select barriers hindering MOUD accessibility (Table 4).	Speight et al., 2023
	Barrier elaboration	One Qualitative Item	2. Suggested changes to improve buprenorphine access.	Damschroder et al., 2022
Demographics	Participant characteristics	Four Quantitative Items	Race/ethnicity; Gender; Age	U.S. Census Bureau, 2020
Employment Characteristics	Professional background	Four Quantitative Items	Degree; Years in practice; Specialty; County of practice	The Physician's Foundation, 2012

Table 1. Summary of Survey Outcome Variables and Measurement Items.

Data AnalysisQuantitative Data

Quantitative data were analyzed by examining the distribution of responses for each answer choice provided in a frequency table for each item (**Table 1**). Descriptive statistical analyses were performed using Statistical Package for the Social Sciences (SPSS v.30).

Qualitative Data

Qualitative data were collected through free response items embedded within a quantitative survey. Data were analyzed using a deductive and inductive approach. Responses were coded based on *a priori* CFIR domains.⁵⁰ Constructs from the outer setting, inner setting, and individual domains were utilized to assess factors such as local attitudes and conditions, partnerships and connections, incentive systems, access to knowledge and information, available resources, and characteristics of innovation deliverers and participants, such as compatibility and motivation (**Table 2**). A related stigma construct was developed and incorporated into the coding framework.

Domain	Construct	Exemplar Quote
Outer Setting	Financing	"Lack of insurance coverage"
	Local Attitudes	"Remove the stigma/judgement from healthcare professionals and media"
	Local Conditions	"Rural location"
	Partnerships and Connections	"I would have counselors, LCSW, support groups, a way to do drug testing and two extra nurses"
Inner Setting	Incentive Systems	"Incentivize providers for identifying and treating patients with substance abuse issues"
	Access to Knowledge and Information	"Increase non-biased education to health care providers about SUD"
	Available Resources	"More providers/clinics and easier communication between EHR so we can follow treatment plans"
Individual	Innovation Deliverers	"More education for providers"
	Innovation Recipients	"Patient cooperation and willingness to try buprenorphine"
	Compatibility	"A special clinic of providers that can specialize in MAT"
	Motivation	"More providers willing to prescribe/manage"
Stigma	Stigma Prevalence	"The stigma"
	Reducing Stigma	"Remove the stigma/judgement from healthcare professionals and media"

Table 2. Buprenorphine prescribing practices by Consolidated Framework for Implementation Research (CFIR).

Convergence of Data

We integrated findings using a convergent mixed-methods approach.⁵¹ After separately analyzing the data, we compared results through a structured side-by-side examination to identify areas of convergence, expansion, and divergence. Quantitative indicators were aligned with qualitative themes describing contextual barriers and facilitators concerning prescribing practices following the X-waiver elimination.

RESULTS

Data collection for Phase 1 occurred from February - April 2025 (**Figure 1**) and for Phase 2 June - July 2025. Email invitations were distributed to 519 clinicians in Phase 1 and 459 clinicians in Phase 2, yielding a sampling frame of 978 clinicians. A total of 50 surveys were completed, 32 in Phase 1 and 18 in Phase 2, resulting in an overall response rate of 5.1%.

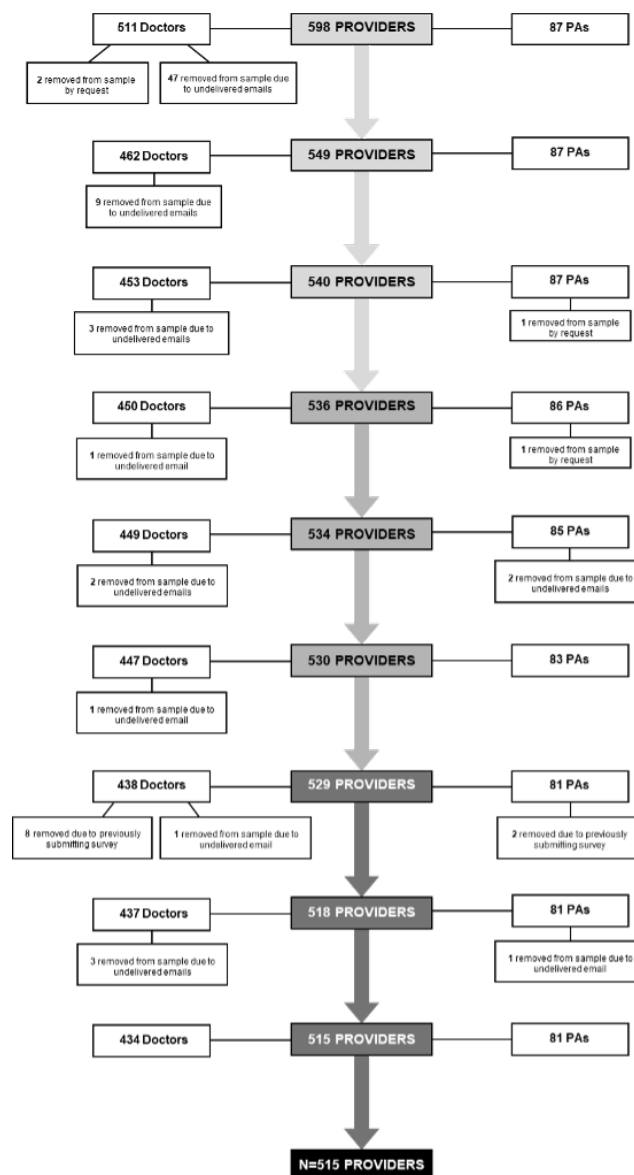


Figure 1. Sample for Phase 1 Recruitment.

Respondents included 24 MDs (48%), 1 DO, (2%), 10 PAs (20%), and 15 NPs (30%). Most practiced in Pitt County (80%), as the primary ECU Health Center is in Pitt County. The sample was relatively evenly split between male (48%) and female (52%) (Table 3).

Sample Characteristic	Full Sample	
	<i>n</i> = 50	Percentage
Professional Title		
Medical Doctor (MD)	24	48%
Doctor of Osteopathic Medicine (DO)	1	2%
Physician Assistant (PA)	10	20%
Nurse Practitioner (NP)	15	30%
Specialty		

Primary/General Care (Family Medicine, Internal Medicine)	9	18%
Woman & Infant Health (OBGYN, Neonatology)	6	12%
Behavioral & Supportive Care (Addiction Medication, Palliative Care)	12	24%
Surgical & Acute Care (Surgery, Emergency Department)	14	28%
Specialty Care (Neurology, Oncology, Cardiology)	9	18%
Practicing County		
Pitt	40	80%
Wilson	1	2%
Edgecombe	2	4%
Duplin	1	2%
Hertford	1	2%
Halifax	2	4%
Chowan	1	2%
Dare	1	2%
No response	1	2%
Age		
20-29	2	4%
30-39	15	30%
40-49	7	14%
50-59	8	16%
60-69	6	12%
No response		
Gender		
Male	23	46%
Female	26	52%
No response	1	2%
Race		
Asian (Chinese, Indian, Filipino, Vietnamese, Korean, Japanese)	3	6%
Black or African American	2	4%
White	39	79%
Other	4	8%
No response	2	4%
Ethnicity		
Hispanic, Latino, or Spanish origin	3	6%
Not Hispanic, Latino, or Spanish origin	43	86%
Prefer not to say	3	6%
No response	1	2%

Table 3. Clinician Demographics.

Survey participants (N=50) indicated prior to the MAT Act, 42% (N=21) prescribed buprenorphine compared with 28% (N=14) after. Among Phase 1 respondents (N=32), 72% (N=23) reported no change in prescribing habits following the MAT Act, 12% (N=4) reported increasing their buprenorphine prescribing, and 16% (N=5) reported being unsure whether their habits had changed. In Phase 2 (N=18), when asked how many patients they currently manage on buprenorphine for OUD, 17% (N=3)

reported treating 0 patients (typically referring to specialty treatment), 11% (N=2) managed 1-3 patients, 5% (N=1) managed more than 8 patients, and 67% (N=12) did not answer due to skip logic within the survey.

Participants identified multilevel determinants shaping buprenorphine prescribing. Barriers and facilitators spanned the outer setting, inner setting, and individual levels (Figure 2). These preliminary findings suggest that prescribing is influenced by intersecting structural, organizational, and individual factors, emphasizing the need for multilevel implementation strategies to expand MOUD in rural health systems.

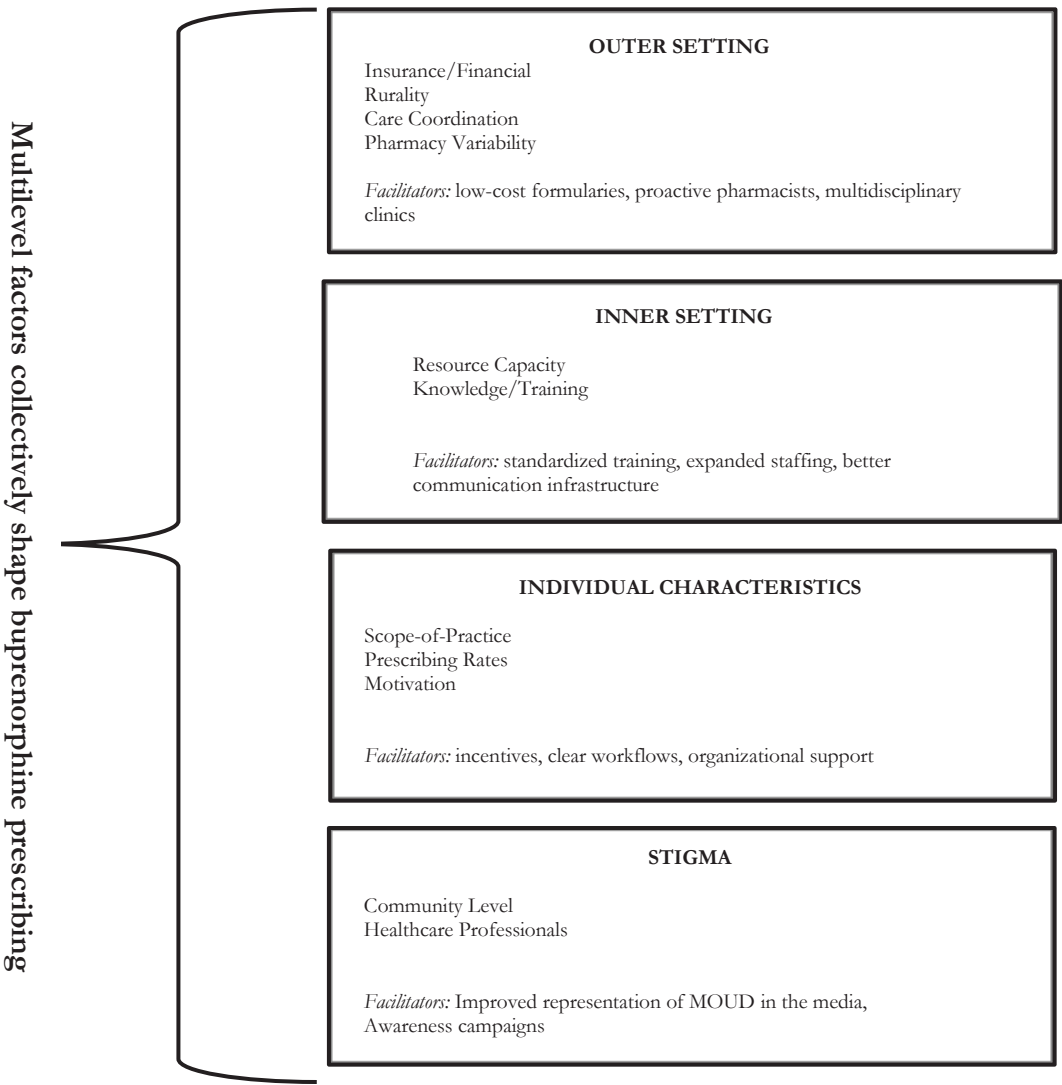


Figure 2. Multilevel Determinants of Buprenorphine Prescribing in a Rural Health System.

Outer Setting

Participants identified several community-level factors outside of ECU Health System that influenced their ability to prescribe buprenorphine. To assess perceived system-level constraints, respondents indicated current barriers and facilitators they believed to affect buprenorphine prescribing (Table 4). Every respondent indicated at least one barrier influencing MOUD treatment.

Barrier	Prevalence by Discipline				Prevalence Total
	MD N = 24	DO N = 1	PA N = 10	NP N = 15	
Rural location	16 (32%)	0 (0%)	8 (16%)	8 (16%)	32 (64%)
Stigma	13 (26%)	0 (0%)	6 (12%)	9 (18%)	28 (56%)
Lack of providers willing to utilize MOUD treatment	19 (38%)	1 (2%)	5 (10%)	10 (20%)	35 (70%)
Patient transportation	10 (20%)	0 (0%)	6 (12%)	5 (10%)	21 (42%)
Patient MOUD education	8 (16%)	0 (0%)	5 (10%)	3 (6%)	16 (32%)
Lack of insurance coverage	11 (22%)	0 (0%)	5 (10%)	9 (18%)	25 (50%)
Job instability	5 (10%)	0 (0%)	4 (8%)	3 (6%)	12 (24%)
Patient motivation	13 (26%)	0 (0%)	6 (12%)	8 (16%)	27 (54%)
Pharmacies not offering buprenorphine or other MOUD treatment	8 (16%)	0 (0%)	4 (8%)	1 (2%)	13 (26%)
Lack of long-term recovery support	12 (24%)	0 (0%)	5 (10%)	9 (18%)	26 (52%)
Other	2 (4%)	0 (0%)	1 (2%)	3 (6%)	6 (12%)

Table 4. Barriers to Buprenorphine Prescribing.

Insurance/Financial

Participants emphasized that financial instability and insurance related barriers limit access to buprenorphine, noting that gaps in insurance coverage and high out of pocket costs restrict treatment. Several suggested that access would improve if buprenorphine were included in low-cost retail plans, with one proposing it be made “*available on the \$4 formulary*,” to reduce patient burden. Others stressed the need for broader no cost options and fewer insurance approval requirements, and one respondent highlighted the need for “*lower cost, [and] less insurance approval process*,” which reflects how administrative hurdles worsen financial strain. Participants linked these challenges to patients’ overall “*financial security*,” describing limited resources that affect appointment attendance, prescription adherence, and navigation of insurance systems.

Rurality

Participants emphasized that rurality, including limited local treatment options, long travel distances, and unreliable transportation, remained a primary barrier to consistent MOUD access. These constraints were often described in terms of “*patient transportation*,” with one participant noting that if additional services were available locally, “*access to care and ability to follow up would be a non-issue*.” Several highlighted how job instability and broader community level socioeconomic strain further undermined patients’ ability to initiate and sustain treatment.

Limited Services

Several participants identified restricted long-term recovery support as a barrier, noting limited external programs offering sustained counseling, case management, or group-based recovery services. The absence of accessible psychiatric services in eastern NC further constrained integrated care. In contrast, participants emphasized the critical role of strengthened partnerships in facilitating buprenorphine treatment. Clinicians described the value of increased outpatient support and follow up options, including access to multidisciplinary clinics that provide counseling, nursing support, drug screening, and care coordination. One respondent explained that an ideal service environment would include “*counselors, LCSWs, support groups, a way to do drug testing, and two extra nurses*,” underscoring the need for robust cross-disciplinary collaboration. Participants identified implementation facilitators that could mitigate structural challenges, including more outpatient and multidisciplinary support, development of specialized MOUD clinics, and expanded referral pathways to ensure timely follow up and ongoing recovery support.

Pharmacy Variability

Respondents described challenges collaborating with pharmacies that do not consistently stock buprenorphine, noting that inconsistent availability disrupted continuity of care and created uncertainty for patients attempting to fill prescriptions. As one clinician explained, there is a need for “*more proactive pharmacists*.” At the same time, pharmacy partnerships emerged as important facilitators. Several clinicians emphasized the value of “*buprenorphine availability from pharmacy*,” and highlighted how proactive pharmacists who routinely stock buprenorphine and demonstrate reduced stigma in their interactions strengthened patient access and treatment continuity.

Inner Setting

Participants identified several ECU Health System determinants that influenced buprenorphine prescribing, noting that organizational resources, workflow structures, and training capacity shaped clinicians' ability to deliver MOUD.

Resource Capacity

Clinicians were asked whether they had sufficient resources to implement and administer buprenorphine. Responses (N=50) were mixed: 12% (N=6) strongly agreed, 24% (N=12) agreed, 26% (N=13) were neutral, 20% (N=10) disagreed, and 18% (N=9) strongly disagreed. This variability may reflect uneven access to essential resources.

Participants referenced limited time and staffing as barriers, noting that these constraints hindered engagement with patients seen infrequently. One clinician noted, *"too little time to follow patients whom I see once or twice a year,"* highlighting how staffing shortages and time constraints may affect MOUD feasibility. Another clinician emphasized the need for, *"more providers/clinics and easier communication between EHR [electronic health record] so we can follow treatment plans,"* suggesting that increased staffing and improved cross-clinic communication are essential for continuity of care. Participants suggested, *"having treatment facilities not require experienced providers in MOUD, but [are] willing to hire and train,"* to expand treatment capacity. Additionally, participants highlighted the role of incentives, recommending, *"incentivize providers for identifying and treating patients with substance use issues"* to increase provider willingness to utilize MOUD.

Knowledge/Training

Limited awareness appeared in clinicians' knowledge of the X-waiver elimination. In Phase 1 (N=32), only 18.7% (N=6) reported adequate or superior knowledge, while 56.3% (N=18) described minimal or basic knowledge, and 25% (N=8) indicated no familiarity or knowledge. Phase 2 (N=18) clinicians similarly reported how the X-waiver elimination affected their management of patients, 11% (N=2) indicating minor effect, 50% (N=9) indicating no effect, and 39% (N=7) indicating no knowledge of the X-waiver elimination.

Several clinicians noted variability in how often they checked the Prescription Drug Monitoring Program (PDMP). Clinicians from Phase 1 (N=32) were asked if they check the PDMP before initiating medications for patients. While 90.6% (N=29) answered yes or most of the time, 9.4% (N=3) answered no or were unfamiliar. Similarly, clinicians from Phase 2 (N=18) were asked how they currently use the PDMP, with 72.2% (N=13) explaining they check it before prescribing a narcotic, determining a medication, or treating a patient with OUD. The remaining 27.8% (N=5) reported they never check or are unfamiliar with the system.

Participants were asked what training they had received in the last 5 years regarding managing patients on buprenorphine (N=50); 32% (N=16) reported no training, while the remaining 68% (N=34) indicated participation in one or more methods which included: addiction medicine fellowship, continuing education training, mentoring from a colleague, and the UNC ECHO program. Participants reported obtaining information from medical articles, Eat Sleep Console, MAT Training in PA/NP education, SAMHSA, and online. Several participants emphasized the need for unbiased and widespread education for primary care providers, contributing to increased knowledge and awareness.

Individual Characteristics

To assess individual level determinants, clinicians identified attributes of clinicians or patients involved in prescribing, supporting, or receiving buprenorphine treatment. Participants (N=50) noted that patient cooperation (N=27) and provider willingness (N=35) potentially influence engagement with MOUD.

Scope-of-Practice

Participants were asked whether prescribing buprenorphine to manage patients with OUD was within their scope of practice (N = 18). Just over half, 55.6% (N=10), agreed, 5.6% (N=1) were neutral, and 38.8% (N=7) disagreed. Respondents who did not prescribe buprenorphine (N=29) provided reasons such as *"no experience,"* and needed *"widespread training to all primary care physicians."* Clinicians highlighted the importance of increasing confidence and competency in outpatient settings, explaining that *"more prescribers comfortable with using it [buprenorphine] outpatient to follow up inpatient treatment"* would strengthen continuity of care.

Prescribing Rates

Participants were asked whether they had managed patients on buprenorphine for OUD between 2015 and 2022 and whether they were currently managing such patients. Overall, 42% (N=21) had previously managed patients on buprenorphine, while 58% (N=29) had not. Currently, 72% (N=36) reported they do not prescribe buprenorphine, whereas 28% (N=14) do. Several respondents emphasized the need for *"more providers willing to prescribe and manage,"* suggesting a gap in MOUD prescribing capacity in eastern NC.

Motivation

Participants identified patient-level factors, including education, motivation, and engagement, as key influences on MOUD treatment. One clinician noted *“patient cooperation and willingness to try buprenorphine.”* as a necessary improvement needed to increase patient access to MOUD. Incentive systems and organizational support were cited as strategies to encourage clinician participation, while ease of control and supportive infrastructure were highlighted as factors that enhance clinicians’ motivation to prescribe and manage buprenorphine, addressing the ongoing challenge of a *“lack of providers willing to utilize MOUD treatment.”*

Stigma

Multiple participants described stigma as a key barrier to buprenorphine implementation. Some clinicians described broader community-level needs, including improving general education and health literacy to reduce misunderstanding and stigma surrounding MOUD. While others noted healthcare provider stigma was affecting care shown by one clinician calling for *“decreased stigma and more proactive pharmacists,”* explaining that restrictive or judgmental dispensing practices reinforce community barriers to MOUD uptake. Others emphasized the need to *“remove the stigma, judgment from healthcare professionals and media,”* illustrating how regional narratives about addiction and treatment can shape acceptance of buprenorphine and hinder normalization of MOUD in routine care.

DISCUSSION

Preliminary findings show that integrating MOUD into routine care requires addressing multilevel barriers. Critical gaps in infrastructure, education, and systemic support continue to limit buprenorphine prescribing among participants in rural NC. While preliminary findings indicate a decrease in buprenorphine prescribing following the X-waiver elimination, this trend may be attributed to persistent barriers within the outer setting, inner setting, and individual CFIR domains.

Outer Setting

Our initial findings reinforce and extend evidence on financial, geographic, and structural barriers shaping MOUD access. Consistent with prior work, financial constraints and uneven insurance coverage restricted affordability, particularly for extended-release formulations that often require prior authorization.^{52,53} These results align with calls for policies that broaden reimbursement and reduce administrative hurdles.⁵⁴

Rurality limited MOUD access through geographic isolation and resource shortage.^{55,56} Geographic isolation and limited resources reinforced the critical role of PAs and NPs in rural MOUD delivery and the need for ongoing support.^{57,58} Collaborative relationships between clinics, pharmacies, and behavioral health providers remain essential, and integrating MOUD into pharmacy practice may help address gaps identified by participants.

Inner Setting

Inner setting determinants within the ECU Health System shaped buprenorphine prescribing through limited resource capacity and substantial variation in clinician knowledge. Participants reported restricted time, staffing shortages, and insufficient infrastructure, all of which reduced their ability to deliver MOUD. These findings mirror research showing that inadequate staffing and limited clinical time hinder prescribing and underscore the need for integrated workflows and follow-up systems to support sustained MOUD care.⁵⁹ Responses highlighted gaps in knowledge and training. Many clinicians reported no recent buprenorphine training, consistent with evidence that education improves confidence and intention to prescribe, and that insufficient training weakens the effects of policy changes such as the removal of the X-waiver requirement.⁶⁰ Several clinicians noted unfamiliarity of the X-waiver altogether. In Phase 1 (N=32), 25% (N=8) of clinicians reported no knowledge of the X-waiver, and in Phase 2 (N=18), 39% (N=7) reported no awareness of its elimination. Given that buprenorphine is an evidence-based treatment for OUD, this degree of unfamiliarity is alarming. Lack of knowledge about MOUD authorization reflects a critical clinical gap that may directly impede treatment access.

Differences across clinician types further highlight variability in implementation readiness. In Phase 1 (N=32), which primarily included MDs and DOs, fewer than 10% indicated they never check or were unfamiliar with the PDMP. In contrast, nearly 30% of PAs and NPs in Phase 2 (N=18) reported never checking the PDMP or being unfamiliar with the system. This discrepancy highlights a likely practice and knowledge gap between physicians and advanced practice clinicians, indicating the need for targeted PDMP and MOUD policy education. Participants identified incentive structures as a potential mechanism to normalize MOUD prescribing, aligning with evidence that incentives strengthen clinician engagement and support adoption of MOUD within health systems.⁶¹ Collectively, preliminary data point to the importance of strengthening institutional infrastructure, expanding protected time for MOUD activities, implementing targeted training and policy education, and incorporating incentive models to meaningfully enhance clinician readiness and improve MOUD implementation.

Individual Level

Contrary to our hypothesis, buprenorphine prescribing did not increase following X-waiver elimination, suggesting that policy shifts alone are insufficient. Participants described workflow challenges, limited training, and role misalignment. Literature similarly shows that clinicians benefit from targeted training, mentorship, and organizational support to integrate MOUD into routine practice.^{62,63} Participants noted that patient motivation influences treatment uptake, consistent with research showing that education, social support, and reduced stigma enhance MOUD engagement.⁶⁴⁻⁶⁶ Initial findings underscore the need for strategies addressing both clinician and patient-level determinants.

Stigma

Stigma remained a central barrier across community, provider, and system levels. Participants described misunderstanding of MOUD, limited health literacy, and negative regional narratives, aligning with literature showing that stigma reduces both prescribing and patient engagement.^{67,68} Provider-level stigma, including judgmental dispensing and negative assumptions, further limited access, reinforcing evidence that stigma within healthcare settings undermines treatment retention.⁶⁹ These findings highlight the need for stigma reduction and recovery-oriented messaging to normalize MOUD as standard, evidence-based care.

Limitations

Although the overall response rate was low (5.1%), it aligns with rates commonly reported in clinician email-based surveys.^{70,71} A 2022 study examining barriers and facilitators of clinicians prescribing buprenorphine received a higher response rate (20%), likely because clinicians were surveyed after completing a buprenorphine X-waiver training course.⁶⁹

Our study is limited by its cross-sectional design, response rate, single region setting, and reliance on self-report, which limit generalizability and introduces response bias. Given the overall low response rate, participants who responded may be particularly interested in substance use treatment or rural health initiatives, highlighting selection bias. Future work is needed and should include testing a multicomponent implementation strategy, including training, workflow integration, pharmacy partnerships, incentives, and patient-level outcomes.

CONCLUSIONS

In this regional sample of clinicians from NC, willingness and ability to prescribe buprenorphine were shaped by interlocking factors across the outer setting, inner setting, individual domains of CFIR, and stigma. Data suggests improving implementation requires a system-level, not prescriber-by-prescriber approach. Preliminary findings suggest that policy authorization alone may not be enough to ensure equitable, routine access to MOUD treatment. A coordinated, multilevel strategy may support a shift from episodic prescribing to reliable, patient-centered treatment for OUD.

REFERENCES

1. Ericson ØB, Eide D, Lobmaier P, Clausen T. (2024) Mortality risk and causes of death among people who use opioids in a take-home naloxone cohort. *Drug Alcohol Depend.* 255:111087. doi:10.1016/j.drugalcdep.2024.111087
2. Larney S, Tran LT, Leung J, Santo Jr T, Santomauro D, Hickman M, Peacock A, Stockings E, Degenhardt L. (2020) All-Cause and Cause-Specific Mortality Among People Using Extramedical Opioids: A Systematic Review and Meta-analysis. *JAMA Psychiatry* 77(5):493–502. doi:10.1001/jamapsychiatry.2019.4170
3. Lewer D, Jones NR, Hickman M, Nielsen S, Degenhardt L. (2020) Life Expectancy of People Who Are Dependent on Opioids: A Cohort Study in New South Wales, Australia. *J Psychiatr Res* 130:435–440. doi:10.1016/j.jpsychires.2020.08.013
4. Substance Abuse and Mental Health Services Administration. (2025) Key Substance Use and Mental Health Indicators in the United States: Results from the 2024 National Survey on Drug Use and Health. Center for Behavioral Health Statistics and Quality.
5. Connery HS. (2015) Medication-Assisted Treatment of Opioid Use Disorder: Review of the Evidence and Future Directions. *Harv Rev Psychiatry* 23(2):63–75. doi:10.1097/HRP.0000000000000075
6. Larochelle MR, Bernson D, Land T, Stopka TJ, Wang N, Xuan Z, Bagley SM, Liebschutz JM, Walley AY. (2018) Medication for Opioid Use Disorder After Nonfatal Opioid Overdose and Association With Mortality: A Cohort Study. *Ann Intern Med* 169(3):137–145. doi:10.7326/M17-3107
7. Dowell D. (2024) Treatment for Opioid Use Disorder: Population Estimates — United States, 2022. *MMWR Morb Mortal Wkly Rep* 2024;73. doi:10.15585/mmwr.mm7325a1
8. Bahrami K, Kuo YF, Digbeu B, Raji MA. (2023) Association of Medication-Assisted Therapy and Risk of Drug Overdose-Related Hospitalization or Emergency Room Visits in Patients With Opioid Use Disorder. *Cureus* 15(8):e44167. doi:10.7759/cureus.44167

9. Meyerson BE, Treiber D, Brady BR, Newgass K, Bondurant K, Bentele KG, Samorano S, Arredondo C, Stavros N. (2024) Dialing for doctors: Secret shopper study of Arizona methadone and buprenorphine providers, 2022. *J Subst Use Addict Treat* 160:209306. doi:10.1016/j.josat.2024.209306
10. Speight C, Caiola C, Tyndall DE, Scott ES. (2023) Barriers and facilitators to nurse practitioner buprenorphine prescribing for opioid use disorder in primary care settings. *J Am Assoc Nurse Pract*. 35(2):112–121. doi:10.1097/JXX.0000000000000811
11. LeFevre N, Louis JS, Worringer E, Younkin M, Stahl N, Sorcinelli M. (2023) The End of the X-waiver: Excitement, Apprehension, and Opportunity. *J Am Board Fam Med* 36(5):867–872. doi:10.3122/jabfm.2023.230048R1
12. Bliley T. (2000) Text – H.R.2634 – 106th Congress (1999–2000): Drug Addiction Treatment Act of 2000. July 27, 2000. <https://www.congress.gov/bill/106th-congress/house-bill/2634/text> (accessed Nov 2025).
13. Shulman M, Wai JM, Nunes EV. (2019) Buprenorphine Treatment for Opioid Use Disorder: An Overview. *CNS Drugs* 33(6):567–580. doi:10.1007/s40263-019-00637-z
14. U.S. Health Resources and Services Administration. (2023) NHSC Substance Use Disorder Workforce Loan Repayment Program | NHSC. <https://nhsc.hrsa.gov/loan-repayment/nhsc-sud-workforce-loan-repayment-program> (accessed Nov 2025)
15. Spetz J, Toretsky C, Chapman S, Phoenix B, Tierney M. (2019) Nurse Practitioner and Physician Assistant Waivers to Prescribe Buprenorphine and State Scope of Practice Restrictions. *JAMA* 321(14):1407–1410. doi:10.1001/jama.2019.0834
16. Department of Health and Human Services. (2021) Practice Guidelines for the Administration of Buprenorphine for Treating Opioid Use Disorder. *Federal Register*, April 28, 2021. <https://www.federalregister.gov/documents/2021/04/28/2021-08961/practice-guidelines-for-the-administration-of-buprenorphine-for-treating-opioid-use-disorder> (accessed Nov 2025)
17. Christine PJ, Chahine RA, Kimmel SD, Kertesz SG, McDonell MG, Jones JD, Lapham GT, Gordon AJ. (2024) Buprenorphine Prescribing Characteristics Following Relaxation of X-Waiver Training Requirements. *JAMA Netw Open* 7(8):e2425999. doi:10.1001/jamanetworkopen.2024.25999
18. Hassan MW. (2021) Text – S.445 – 117th Congress (2021–2022): Mainstreaming Addiction Treatment Act of 2021. February 25, 2021. <https://www.congress.gov/bill/117th-congress/senate-bill/445/text> (accessed Nov 2025)
19. Waiver Elimination (MAT Act). (2024) Waiver Elimination (MAT Act), November 6, 2024. <https://www.samhsa.gov/substance-use/treatment/statutes-regulations-guidelines/mat-act> (accessed Nov 2025)
20. Chua KP, Bicket MC, Bohnert ASB, Conti RM, Lagisetty PA, Nguyen TD. (2024) Buprenorphine Dispensing After Elimination of the Waiver Requirement. *N Engl J Med* 390(16):1530–1532. doi:10.1056/NEJMc2312906
21. Stone EM, Xie F, Miles J, Samples H, Olfson M, Crystal S. (2025) Buprenorphine dispensation after X-waiver elimination by clinician specialty. *Am J Prev Med* 69(5):108055. doi:10.1016/j.amepre.2025.108055
22. Guy GP, Jones CM, Rikard M, Strahan AE, Zhang K, Olsen Y. (2025) Individuals dispensed buprenorphine in the United States before and after federal policy changes aimed at increasing access. *J Addict Med* Published online February 19, 2025. doi:10.1097/ADM.0000000000001457
23. Lofaro RJ, Bohler RM, Spurgeon R, Mase WA. (2025) Rural and urban differences in treatment on demand for substance use treatment involving medications for opioid use disorder. *J Rural Health* 41(3):e70076. doi:10.1111/jrh.70076
24. US Department of Health and Human Services, Office of the Inspector General. (2020) Geographic disparities affect access to buprenorphine services for opioid use disorder. (accessed Nov 2025)
25. Andrilla CHA, Moore TE, Patterson DG, Larson EH. (2019) Geographic distribution of providers with a DEA waiver to prescribe buprenorphine for the treatment of opioid use disorder: A 5-year update. *J Rural Health* 35(1):108–112. doi:10.1111/jrh.12307
26. Lister JJ, Weaver A, Ellis JD, Himle JA, Ledgerwood DM. (2020) A systematic review of rural-specific barriers to medication treatment for opioid use disorder in the United States. *Am J Drug Alcohol Abuse* 46(3):273–288. doi:10.1080/00952990.2019.1694536
27. Franz B, Dhanani LY, Miller WC. (2021) Rural-urban differences in physician bias toward patients with opioid use disorder. *Psychiatr Serv* 72(8):874–879. doi:10.1176/appi.ps.202000529
28. Morenz AM, Nance RM, Mixson LS, et al. (2025) Barriers to accessing medications for opioid use disorder among rural individuals. *Int J Drug Policy* 140:104805. doi:10.1016/j.drugpo.2025.104805
29. Louie DL, Assefa MT, McGovern MP. (2019) Attitudes of primary care physicians toward prescribing buprenorphine: A narrative review. *BMC Fam Pract* 20(1):157. doi:10.1186/s12875-019-1047-z
30. Narayan S, Klimas J, DiMarco D, Strydom N, Maclure M, McCracken RK. (2024) Beyond opioid sparing: A qualitative study with family physicians and nurse practitioners in British Columbia. *Can J Addict* 15(4):23–31. doi:10.1097/CXA.0000000000000220
31. Reddy IA, Audet CM, Reese TJ, Peek G, Marcovitz D. (2024) Provider perceptions toward extended-release buprenorphine for treatment of opioid use disorder. *J Addict Med* 18(5):540–545. doi:10.1097/ADM.0000000000001320
32. Varley AL, Lappan S, Jackson J, et al. (2020) Understanding barriers and facilitators to the uptake of best practices for the treatment of co-occurring chronic pain and opioid use disorder. *J Dual Diagn* 16(2):239–249. doi:10.1080/15504263.2019.1675920

33. Damschroder, L. J., Aron, D. C., Keith, R. E., Kirsh, S. R., Alexander, J. A., & Lowery, J. C. (2009) Fostering implementation of health services research findings into practice: A consolidated framework for advancing implementation science. *Implementation Science*, 4(1), 50. <https://doi.org/10.1186/1748-5908-4-50>
34. Hawkins EJ, Danner AN, Malte CA, et al. (2021) Clinical leaders and providers' perspectives on delivering medications for the treatment of opioid use disorder in Veteran Affairs' facilities. *Addict Sci Clin Pract* 16(1):55. doi:10.1186/s13722-021-00263-5
35. Lott A, Danner AN, Malte CA, et al. (2025) Implementing buprenorphine for opioid use disorder in Veterans Health Administration primary care: A qualitative analysis. *Addict Sci Clin Pract* 20(1):38. doi:10.1186/s13722-025-00568-9
36. Brunet N, Moore DT, Lendvai Wischik D, Mattocks KM, Rosen MI. (2022) Increasing buprenorphine access for Veterans with opioid use disorder in rural clinics using telemedicine. *Subst Abuse* 43(1):39–46. doi:10.1080/08897077.2020.1728466
37. Bozinoff N, Grennell E, Soobiah C, et al. (2024) Facilitators of and barriers to buprenorphine initiation in the emergency department: A scoping review. *Lancet Reg Health Am* 38:100899. doi:10.1016/j.lana.2024.100899
38. NCDHHS. (2025) North Carolina Overdose Epidemic Data | Division of Public Health. <https://www.dph.ncdhhs.gov/programs/chronic-disease-and-injury/injury-and-violence-prevention-branch/north-carolina-overdose-epidemic-data> (accessed Aug 2025)
39. Carpenter D, Lambert KV, Harless JC, et al. (2022) North Carolina community pharmacists' buprenorphine dispensing practices and attitudes. *J Am Pharm Assoc* 62(5):1606–1614. doi:10.1016/j.japh.2022.04.019
40. NCDHHS. (2023) North Carolina Office of Rural Health Rural and Urban Counties. <https://www.ncdhhs.gov/ruralurban-2019/open> (accessed Aug 2025)
41. Baxley J. (2023) Disparate issues shape rural health in North Carolina. *N C Health News*, May 19, 2023. <https://www.northcarolinahhealthnews.org/2023/05/19/disparate-issues-shape-rural-health-in-nc/> (accessed Sept 2025)
42. System of Care. (ECU Health) <https://www.ecuhealth.org/about-us/system-of-care/> (accessed Sept 2025)
43. North Carolina Association of County Commissioners. County Data and Information. (accessed Nov 2025)
44. RISE29. (Rise 29) <https://rise29.ecu.edu/communities/> (accessed Oct 2025)
45. Vision Mission — ECU Health Careers. <https://careers.ecuhealth.org/pages/vision-mission> (accessed Aug 2025)
46. ECU Health Physicians. (ECU Health) <https://www.ecuhealth.org/about-us/ecu-health-physicians/> (accessed Nov 2025)
47. ECU Health. About Us. (ECU Health) <https://www.ecuhealth.org/about-us/> (accessed Nov 2025)
48. Dillman DA. (1991) The design and administration of mail surveys. *Annu Rev Sociol* 17(1):225–249. doi:10.1146/annurev.so.17.080191.001301
49. Damschroder LJ, Reardon CM, Widerquist MAO, Lowery J. (2022) The updated Consolidated Framework for Implementation Research based on user feedback. *Implement Sci* 17(1):75. doi:10.1186/s13012-022-01245-0
50. CFIR Research Team. (2025) Consolidated Framework for Implementation Research (CFIR). <https://cfirguide.org/> (accessed Aug 2025)
51. Fetters MD, Curry LA, Creswell JW. (2013) Achieving integration in mixed methods designs—Principles and practices. *Health Serv Res* 48(6 Pt 2):2134–2156. doi:10.1111/1475-6773.12117
52. Andraka-Christou B, Simon KI, Bradford WD, Nguyen T. (2023) Buprenorphine treatment for opioid use disorder: Comparison of insurance restrictions, 2017–21. *Health Aff (Millwood)* 42(5):658–664. doi:10.1377/blthaff.2022.01513
53. Anyanwu P, Olateju OA, Tata V, et al. (2024) Understanding the financial barriers to treatment among individuals with opioid use disorder: A focus group study. *Harm Reduct J* 21(1):220. doi:10.1186/s12954-024-01133-4
54. Bowser, D., Bohler, R., Davis, M. T., Hodgkin, D., & Horgan, C. (2024) Payment-related barriers to medications for opioid use disorder: A critical review of the literature and real-world application. *Journal of Substance Use and Addiction Treatment*, 165, 209441. <https://doi.org/10.1016/j.josat.2024.209441>
55. Graves JM, Abshire DA, Alejandro AG. (2022) System- and individual-level barriers to accessing medical care services across the rural-urban spectrum, Washington State. *Health Serv Insights* 15:11786329221104667. doi:10.1177/11786329221104667
56. Sharareh N, Zheutlin AR, Qato DM, Guadamuz J, Bress A, Vos RO. (2024) Access to community pharmacies based on drive time and by rurality across the contiguous United States. *J Am Pharm Assoc* 64(2):476–482. doi:10.1016/j.japh.2024.01.004
57. Nelson SC, Hooker RS. (2016) Physician assistants and nurse practitioners in rural Washington emergency departments. *J Physician Assist Educ* 27(2):56–62. doi:10.1097/JPA.0000000000000074
58. Xue Y, Smith JA, Spetz J. (2019) Primary care nurse practitioners and physicians in low-income and rural areas, 2010–2016. *JAMA* 321(1):102–105. doi:10.1001/jama.2018.17944
59. Oros SM, Christon LM, Barth KS, Berini CR, Padgett BL, Diaz VA. (2021) Facilitators and barriers to utilization of medications for opioid use disorder in primary care in South Carolina. *Int J Psychiatry Med* 56(1):14–39. doi:10.1177/0091217420946240
60. Franz B, Dhanani LY, Hall OT, Brook DL, Simon JE, Miller WC. (2023) Differences in buprenorphine prescribing readiness among primary care professionals with and without X-waiver training in the US. *Harm Reduct J* 20(1):180. doi:10.1186/s12954-023-00918-3

61. Solomon KT, O'Connor J, Gibbons JB, et al. (2023) Association between hospital adoption of an emergency department treatment pathway for opioid use disorder and patient initiation of buprenorphine after discharge. *JAMA Health Forum* 4(3):e230245. doi:10.1001/jamahealthforum.2023.0245
62. Foster SD, Lee K, Edwards C, et al. (2020) Providing incentive for emergency physician X-waiver training: An evaluation of program success and postintervention buprenorphine prescribing. *Ann Emerg Med* 76(2):206–214. doi:10.1016/j.annemergmed.2020.02.020
63. Lanham HJ, Papac J, Olmos DI, et al. (2022) Survey of barriers and facilitators to prescribing buprenorphine and clinician perceptions on the Drug Addiction Treatment Act of 2000 waiver. *JAMA Netw Open* 5(5):e2212419. doi:10.1001/jamanetworkopen.2022.12419
64. Bagley SM, Schoenberger SF, dellaBitta V, et al. (2023) Ambivalence and stigma beliefs about medication treatment among young adults with opioid use disorder: A qualitative exploration of young adults' perspectives. *J Adolesc Health* 72(1):105–110. doi:10.1016/j.jadohealth.2022.08.026
65. Irani E, Macleod C, Slat S, et al. (2024) The effect of a pilot brief educational intervention on preferences regarding treatments for opioid use disorder. *Drug Alcohol Depend Rep* 11:100235. doi:10.1016/j.dadr.2024.100235
66. Kumar N, Oles W, Howell BA, et al. (2021) The role of social network support in treatment outcomes for medication for opioid use disorder: A systematic review. *J Subst Abuse Treat* 127:108367. doi:10.1016/j.jsat.2021.108367
67. Burgess A, Bauer E, Gallagher S, et al. (2021) Experiences of stigma among individuals in recovery from opioid use disorder in a rural setting: A qualitative analysis. *J Subst Use Addict Treat* 130:108488. doi:10.1016/j.jsat.2021.108488
68. Franz B, Dhanani LY, Bogart S, et al. (2025) Different forms of stigma and rural primary care professionals' willingness to prescribe buprenorphine. *J Subst Use Addict Treat* 171:209633. doi:10.1016/j.jsat.2025.209633
69. Lefebvre RC, Chandler RK, Helme DW, et al. (2020) Health communication campaigns to drive demand for evidence-based practices and reduce stigma in the HEALing Communities Study. *Drug Alcohol Depend* 217:108338. doi:10.1016/j.drugalcdep.2020.108338
70. Andraka-Christou B, Page C, Schoebel V, Buche J, Haffajee RL. (2022) Perceptions of buprenorphine barriers and efficacy among nurse practitioners and physician assistants. *Addict Sci Clin Pract* 17(1):43. doi:10.1186/s13722-022-00321-6
71. St-Pierre F, Petrosyan R, Gupta A, et al. (2023) Impact of the COVID-19 pandemic on internal medicine training in the United States: Results from a national survey. *BMC Health Serv Res* 23(1):1285. doi:10.1186/s12913-023-10237-9

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Madison Wood is a graduate of East Carolina University, where she earned a B.S. in Public Health in May 2025. During her time at ECU, she developed a strong interest in implementation science, contributing to projects focused on buprenorphine prescribing practices and overdose prevention in U.S. pharmacies. She currently works as a Research Assistant at East Carolina University, supporting projects that examine access to harm reduction services and medication-assisted treatment in rural communities. She also serves as an Assistant Project Manager in the Department of Implementation Science at an R1 research institution, contributing to initiatives that evaluate harm reduction strategies, access, and policy. Collectively, these experiences have strengthened her commitment to advancing equitable access to care and improving the well-being of underserved populations.

PRESS SUMMARY

Expanding access to buprenorphine, a medication that helps treat opioid use disorder, is critical to reducing overdose deaths. In 2023, the Mainstreaming Addiction Treatment Act removed a major barrier that had previously limited which clinicians could prescribe this medication. This study examined whether that policy change increased prescribing in a rural North Carolina health system. Despite the removal of this restriction, prescribing did not increase and, in some cases, declined. Clinicians reported that their ability to prescribe buprenorphine was influenced not only by policy, but also by workplace support, available resources, and community-level challenges. These findings highlight that policy change alone is not enough. Targeted support at multiple levels is needed to expand access to this life-saving treatment and better address the opioid crisis.

Demographic Influences on Cooperation in One-Shot, Anonymous Prisoner's Dilemma Games

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ABSTRACT

The Prisoner's Dilemma examines decision-making in situations in which there is discord between individual incentives and cooperation. Theory predicts that rational individuals, working to maximize their own individual payoff, will act non-cooperatively in their own self-interest. However, prior research proposes that cooperation may vary across demographic groups. A total of 184 individuals were surveyed using Google Forms to collect demographic information and were presented with a modern adaptation of the Prisoner's Dilemma. Associations between age, race, gender, religiosity, and likelihood of cooperation were explored. Results indicated that female participants demonstrate significantly higher rates of cooperation than their male counterparts. Additionally, younger individuals (18-34) were also significantly more likely to defect than older individuals (35+). Unexpectedly, there were no significant associations found between race, religion, and cooperation despite expectations. The findings suggest that gender and age may have some influence over variation in cooperative decision-making while other demographics such as race and religiosity have limited influence. Theory provides a guideline for what to expect, but human behavior is not fully predictable. This research provides insight into the nuances of cooperation and how individual characteristics and their corresponding life experiences can cause deviation from theoretical expectation.

KEYWORDS

Cooperation; Prisoner's Dilemma; Game Theory; Demographics; Decision-Making; Behavioral Economics; Chi-Square; Experimental Economics; Economic Psychology; R Programming

INTRODUCTION

The Prisoner's Dilemma and its Social Implications

The Prisoner's Dilemma game models a situation in which two individuals are in a conflict where they have the choices to either cooperate with their opponent or defect with various payoffs correlating to the decisions made.¹ An individual who cooperates is benefiting the opponent while they themselves pay a cost.² On the other hand, an individual who defects would be working to benefit themselves. Within the canonical Prisoner's Dilemma, the best outcome is the one in which there is no other payoff in which both players would do better. This payoff lies where both players cooperate with one another. However, should a player choose to defect while the other cooperates, the defector receives the highest payoff. If both players choose to defect, however, they are both worse off and thus experience the worst outcome.¹ While standard game theory predicts that rational individuals will act in their own self-interest, researchers have explored how cooperative behavior changes when Prisoner's Dilemma scenarios are adapted to reflect modern social contexts.

Dorrough and Glöckner³ establish that cooperation is considered an inherently friendly act while defecting is inherently selfish and unfriendly. There is a societal expectation that individuals act in a particularly socially acceptable way. Individuals are often motivated to be perceived as kind and altruistic. People look down on those who act selfishly while praising those who always put others first. However, Brañas-Garza and Morales-Siles⁴ suggest that in these anonymous Prisoner's Dilemma games only about 20% of people tend to choose the altruistic approach. There is a conflict of interest between working in self-interest and succumbing to societal norms. Defection will ensure the best payoff for the individual each time; however, cooperation is often viewed as the more socially desirable option. This raises the question as to who would choose to defect or cooperate and why. Gender, age, race, religiousness, and other demographics may play a part in this phenomenon.

Gender in Cooperation

The world has long assumed that women are more cooperative and docile than men. The expectation of women to be less competitive and magnanimous is, at the end of the day, based in common stereotype rather than fact.⁵ Even though stereotypes

like these can be harmful, they may not always be untrue as Capraro⁶ found that women are statistically more likely to cooperate than men. On the other hand, Dorrough and Glöckner³ found that, conversely, men were more likely to cooperate. However, regardless of whether or not cooperation is involved, when presented with choices, women are more likely to pick the “socially respectable” choice than men are.⁵ When looked at concurrently, the variety in these studies implies that gender differences are not only shaped by behavior, but another variable as well.

Beyond the observed behavior, there is a phenomenon that makes itself evident. People, regardless of gender, are more likely to cooperate with a woman over a man as they expect women to provide reciprocity for their cooperation.⁵ This exposes an interesting paradox as despite being more likely to be cooperated with, women expect to be cooperated with less than men do.³ It can be theorized that this is due to the different life experiences and stereotypes placed upon each gender. Traditional gender-role stereotypes often characterize men as the providers while portraying women as the caretakers or dependents. These differing life experiences and perceived societal expectations may help to explain why these trends emerge. These findings suggest that not only gender itself that influences cooperation, but the experiences individuals face because of their gender.

Age in Cooperation

Rebellious youth is a common stereotype that suggests younger individuals are more likely to challenge authority than their older counterparts. Despite the common perception that older adults are cooperative and obedient, it is natural to wonder if older adults really are simply more restrained and cooperative than their youthful counterparts. Romano et al.⁷ found that there is no significant difference in the levels of cooperation between young and old adults. This is consistent with the study by Mienaltowski and Wichman⁸ which came to the same conclusion. Despite being equally likely to cooperate, older adults are more likely to express generosity than younger generations.⁷ The imbalance of these two points implies that while generosity may be definitively age-dependent, there may be other factors that influence cooperation.⁷

Levels of one-shot cooperation are equal between older adults and younger adults but, when you keep the game going, a stark fact makes itself clear. Older adults are more forgiving and trustful while younger adults tend to be more vengeful. This nature may put these older adults at risk of being taken advantage of, but it also opens the opportunity for reconciliation which strengthens relationships.⁸ This may help to explain why individuals tend to believe that older adults are more likely to cooperate than younger adults. Due to their forgiving nature, older adults showed willingness to cooperate with younger adults despite believing that the younger adults would defect.⁷ While older adults are no more likely to initially cooperate with others than their younger counterparts, they do show a surprising level of compassion that leads them to make more cooperative decisions later down the line. This aligns itself with the “positivity effect” seen in older adults. Older adults unconsciously choose to spend their cognitive resources on positive over negative stimuli.⁹ With a natural inclination towards positivity, this may aid in explaining why older adults tend to display more forgiving and generous behavior.

Race and Religiousness in Cooperation

Race is more than just the color of your skin, but also a community you are a part of. There are daily obstacles and challenges each race of people must experience on a day-to-day basis that alter their view on cooperation. Romano¹⁰ established that black individuals have higher rates of cooperation than their white counterparts. Additionally, black individuals were also shown to have more trust and higher expectations in their opponent than did white individuals.¹⁰ Despite this, participants of all races felt more cooperative with those of their own race rather than those not.²

Religiosity is a big part of the culture of a lot of races and can also play a part in cooperation. In religion, the mantra of “love thy neighbor” and, in general, doing good to all is often emphasized as a moral duty. This idea correlates to the idea of cooperation, in that cooperation is the kind and just thing to do and as such would be the religious thing to do. Romano¹⁰ identified that black individuals are considerably more religious than white individuals. He also stated that religious individuals were more likely to believe their opponent would cooperate just how black individuals expressed the same feelings. Religiousness and race seem to go hand in hand when it comes to cooperation. The cultural experience one obtains with their racial identity seems to shape how people work with and trust other individuals.

Research Gap

Despite extensive research on cooperation, previous research has reported inconsistent findings regarding the influence of demographic characteristics in one-shot, anonymous Prisoner’s Dilemma settings. This study addresses this gap by examining how age, gender, race, and religiosity influence cooperation in a controlled survey-based modern workplace adaptation of the Prisoner’s Dilemma.

METHODS AND PROCEDURES

This study examined how demographic characteristics influence cooperation in anonymous, one-shot Prisoner's Dilemma games. The analysis focuses on identifying patterns of cooperative behavior across the demographic variables of age, race, gender, and religiosity.

Data were collected through an online Google Forms survey which garnered 184 participants. Participants were recruited through a combination of online platforms and personal outreach. The survey was distributed via SurveyCircle, online forums such as Reddit, and through outreach to university faculty who shared the survey with their students. Additionally, participants were recruited through personal networks, including friends, family members, and colleagues, who further distributed the survey within their own networks. This approach resulted in a convenience sample drawn from a range of backgrounds rather than a single institutional population. The first section of the survey collected participant demographic information including biological gender, gender identity, age, race, and level of religiousness. In this study, 'gender' refers specifically to biological sex, male or female, as self-reported by each participant. All demographic questions were optional, and as a result, response counts varied across variables.

Following the demographic section, participants were presented with a modern adaptation of an anonymous, one-shot Prisoner's Dilemma in which they were faced with a situation involving a job promotion. This adaptation of the canonical Prisoner's Dilemma was designed to maintain the central conflict between cooperation and self-interest while altering the traditional payoff structure to increase the realism of the decision-making context through a workplace promotion scenario. Mutual cooperation does not guarantee both participants an identical payoff but rather ensures a fair chance at promotion solely based on merit. The situation was presented as follows:

You along with another co-worker are up for a promotion. You both have dirt on one another that could compromise the others chances of getting promoted.

During the interview process you as well as your co-worker have the opportunity to either spill the dirt on the other or stay quiet.

If one spills the dirt and the other doesn't, the one who spills the dirt guarantees the promotion. If both spill the dirt neither candidate gets the promotion. If neither candidate spills any dirt, the promotion goes to whichever candidate is more qualified.

Would you spill the dirt or stay quiet?

NOTE: You have no way of communicating with your co-worker nor do you know what they have chosen.

The participants chose whether or not they would "spill the dirt" (not cooperate) or "stay quiet" (cooperate). The question emphasized the anonymity aspect of the situation, ensuring participants knew that there was no known demographic information on the competitor, nor could any discussion happen with the competitor.

The data were compiled in Microsoft Excel and exported as a .csv file. This data was then imported into RStudio as a dataframe for statistical analysis using the tidyverse package. The data were cleaned to remove any incomplete responses. The data were subsequently sorted into separate dataframes corresponding to each demographic variable and associated decision. Data were analyzed using both original and aggregated groupings (white vs non-white and 18-34 vs 35+) to satisfy the expected cell count assumptions required for chi-square analyses.

To evaluate the relationship between cooperation and each demographic variable, chi-squared tests of independence were conducted. This method was selected due to the categorical nature of both the dependent and independent variables. Expected values were calculated using the table function, chisq.test function, and \$expected output in R. For each analysis, chi-square statistics and the corresponding p-values were computed and compared to a significance level of 0.05.

This methodology allowed for the clear identification of trends between cooperation and demographic data. Using an anonymous, one-shot format allowed for the study of biological and innate instincts rather than individual strategy based on outside variables. The survey data allowed for the collection of a broad range of demographic data efficiently while chi-squared testing permitted objective pattern recognition ideal for this study.

There were limitations to this study that are important to mention. While the use of a survey made collection of a large amount of demographic data convenient, self-reported responses may not reflect fully real-world behavior. Knowledge of response

collection and analysis may make participants more inclined to make the decision they see as more socially acceptable rather than truthfully reporting how they feel. Furthermore, since participants were responding to a hypothetical situation rather than one with real consequences, cooperation observed within this study may vary from behavior displayed in real-world, incentive driven situations. Additionally, the survey involved a small sample size and utilized convenience sampling. This resulted in small sample sizes for certain demographic groups necessitating the modification of data groupings as, in their original state, they were not an adequate representation of the broader population, which could lead to skewed results. Although biological gender and gender identity were collected from each participant, there was an insufficient number of responses from gender-diverse individuals. As a result, findings related to gender are limited to biological sex and may not generalize to broader gender identities. Despite these limitations, this methodology allowed for the measurement of observable differences in cooperation between demographic groups and provided a clear guideline for analysis.

RESULTS

A total of 184 participants completed the survey. Demographic information was collected on biological gender, age, race, and religiosity. Because demographic questions were optional, the number of responses varied slightly across demographic variables. Participant demographic characteristics are summarized in Table 1.

Characteristic	Spill the Dirt <i>n</i> = 22	Stay Quiet <i>n</i> = 161	$\chi^2(df)$	<i>p</i>
Biological Gender				
Female	9 (8.2%)	101 (91.8%)	$\chi^2(1) = 3.84$	.0499
Male	13 (17.8%)	60 (82.2%)		
Age				
18–34	16 (16.7%)	80 (83.3%)	$\chi^2(1) = 4.12$	.0420
35+	6 (6.9%)	81 (93.1%)		
Race				
White	11 (10.2%)	97 (89.8%)	$\chi^2(1) = 0.84$	.360
Non-White	11 (14.7%)	64 (85.3%)		
Religiosity				
Religious	9 (9.6%)	85 (90.4%)	$\chi^2(1) = 1.09$	.300
Non-religious	13 (14.6%)	76 (85.4%)		
<i>Note.</i> Values are presented as <i>n</i> (%). Percentages are calculated within each demographic category.				

Table 1. Participant characteristics according to participants' Prisoner's Dilemma decision.

Of the 184 participants, 87.4%, or 160 participants, chose to stay quiet while the remaining 12.6%, or 24 participants, chose to spill the dirt. Overall, participants were substantially more likely to cooperate than to defect in the workplace Prisoner's Dilemma scenario. To determine the association between specific demographic characteristics and cooperation, chi-squared tests of independence were conducted for each variable. Female participants were more likely to cooperate than male participants. A chi-squared test of independence indicated a significant association between gender and cooperation ($\chi^2_1 = 3.84$, $p = 0.0499$, Cramér's $V = .12$). An initial chi-squared test of independence indicated no significant association between age and cooperation ($\chi^2_5 = 8.25$, $p = 0.083$). Because several age categories produced expected cell counts below five, participants were regrouped into two age categories (18–34 and 35+) and the analysis was repeated. The second chi-squared test indicated a significant association between age and cooperation ($\chi^2_1 = 4.12$, $p = 0.042$, Cramér's $V = .13$). Older participants were more likely to choose to stay quiet than participants aged 18–34. An initial chi-squared test of independence found no significant association between race and cooperation ($\chi^2_3 = 4.04$, $p = 0.26$). Because several racial categories produced expected cell counts below five, participants were regrouped as White and non-White and the analysis was repeated. The second chi-squared test also indicated no significant association between race and cooperation ($\chi^2_1 = 0.84$, $p = 0.36$, Cramér's $V = .00$). A chi-squared test of independence indicated no significant association between religiosity and cooperation ($\chi^2_1 = 1.09$, $p = 0.30$, Cramér's $V = .02$).

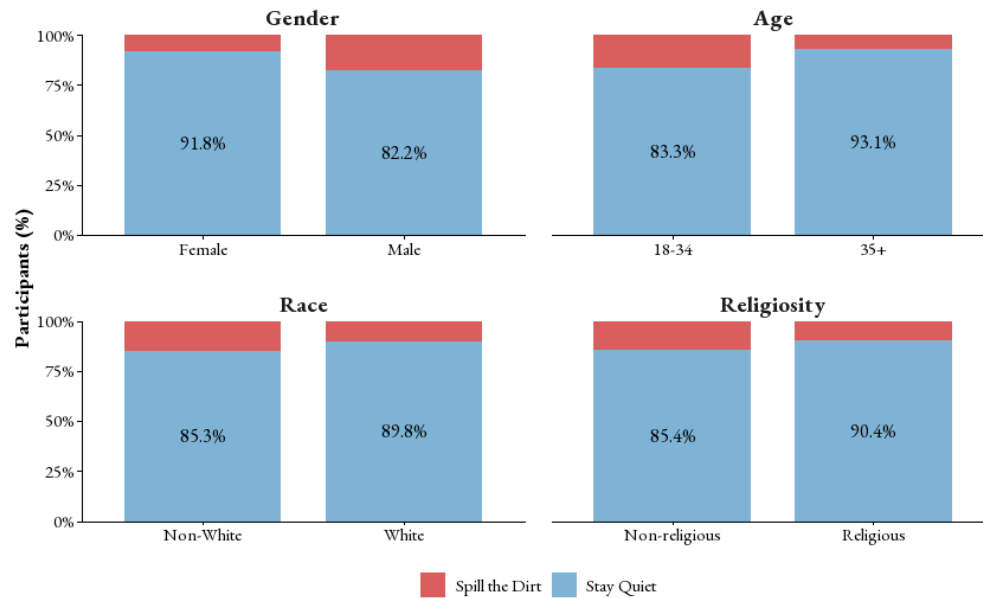


Figure 1. Proportion of participants choosing to stay quiet (cooperate) or spill the dirt (defect) across demographic groups.

To determine whether the observed demographic associations remained after simultaneously accounting for the other demographic variables, a multivariable logistic regression model was fitted with biological gender, age group, race, and religiosity as predictors of cooperation. After adjustment, none of the demographic variables remained statistically significant at the 0.05 level. However, the direction of the associations was consistent with the chi-square analyses, with male participants exhibiting lower odds of cooperation (OR = 0.41, 95% CI [0.16, 1.02], $p = .059$) and participants aged 35 years and older exhibiting higher odds of cooperation (OR = 2.60, 95% CI [0.99, 7.67], $p = .063$). Race and religiosity were not significantly associated with cooperation after adjustment.

DISCUSSION

This study indicates that demographic factors do not uniformly influence cooperative behavior. While gender and age were associated with significant differences in cooperation, race and religiosity were not associated with significant differences in cooperation. These findings highlight the importance of behavioral variation across specific demographic groups and suggest that cooperation cannot be fully explained by uniform theoretical assumptions.

Although the multivariable logistic regression provided weaker statistical evidence for the associations between gender and cooperation and between age and cooperation, the direction of these effects remained consistent with the primary chi-squared analyses, suggesting that gender and age may continue to play a role in cooperative decision-making. Because this study focused on a small number of pre-planned demographic hypotheses rather than exploring a large number of possible relationships, a multiple comparison correction was not applied. The consistency between the multivariable logistic regression and the primary analyses provides additional support for the robustness of these findings.

One of the most notable findings of this study is the exceptionally high rate of cooperation, with approximately 87% of participants choosing to cooperate despite theoretical predictions favoring defection. This substantial deviation indicates that factors such as lower stakes in the modern Prisoner's Dilemma in which the consequence involves not receiving a promotion rather than incarceration, the hypothetical nature of the situation, the perception of being judged when filling out a research survey, or the anonymous nature of the study influenced decision-making. An additional consideration is that the modified payoff structure of the modern workplace adaptation of the Prisoner's Dilemma may also have had an effect on cooperation rates. This scenario may have encouraged cooperation by preserving a fair opportunity for promotion when both individuals cooperate, reducing the tension between self-interest and cooperation. While these are all plausible explanations, further research would be necessary to determine the relative contribution of each individual factor.

Cooperation extends beyond theoretical models and plays a critical role in real-world social, economic, and organizational interactions. The present findings suggest that these behaviors cannot be fully explained by assumptions of rational self-interest alone. This study examined how demographic characteristics such as gender, age, race, and religiosity may lead to variations in cooperation and identified patterns of group behavior rather than focusing solely on the individual.

These findings are significant in a broader context, indicating that cooperation is not only driven by rational self-interest but by behavioral tendencies and group-level patterns. This contributes to a more nuanced understanding of cooperation and how, in the real world, it varies from theory. Collectively, these findings contribute to a more nuanced understanding of how to predict behavior in decision-making environments.

CONCLUSIONS

This study highlights the importance of understanding how demographics affect cooperative behavior when it comes to decision-making. Game theory predicts that rational individuals will choose to be uncooperative in one-shot Prisoner's Dilemma situations. However, this research demonstrates that human behavior does not always align with theoretical predictions. Instead, it suggests that cooperation in decision-making is influenced by behavioral tendencies as reflected in the patterns this study identified in cooperation across specific demographic groupings.

The most significant insight found from this study is the variation in cooperation presented in the age and gender groupings. The results indicated that women are more likely to cooperate than their male counterparts. Additionally, older individuals (35+) were more likely to cooperate than younger individuals (18-34). These results imply that there are certain groups that are more inclined towards cooperation in anonymous, one-shot Prisoner's Dilemma settings than others. This trend is not true for all demographic groupings however, as there was no statistically significant evidence to suggest that race or level of religiousness has any influence over likelihood to cooperate in those same settings. This reinforces that not all demographics have an equal level of influence over cooperation.

The importance of this study reaches beyond the Prisoner's Dilemma. Understanding the variation in cooperation across different demographic groupings can have a significant effect on social, workplace, and economic interactions. Cooperation is a fundamental component of many systems that have been established in the real world. By identifying these patterns, a better understanding of decision-making in cooperative situations across many demographic groups and how that affects risk-taking and trust can be developed. Focusing on group-level tendencies, rather than the individual, improves the ability to predict behavior across larger samples.

For those in business settings and client-facing roles, it is important to consider human behavior when it comes to variation in cooperation rather than assuming uniform, theoretical decision-making. Negotiation and collaboration are a major part of how society works, especially in the workplace. Understanding demographic variation in these situations may allow for the use of more effective strategies.

Cooperation, in the theoretical Prisoner's Dilemma, is measured by the assumption that every individual is working in their own self-interest. However, human behavior is more complicated than that. Traditional models do not fully account for behavioral tendencies and group-level behavioral habits that inform decision-making beyond selfish reasoning. Continuing to observe these trends will allow for a better understanding and improved predictions involving cooperative behavior in real-world and theoretical settings.

While this study provides valuable insight into the influence that demographic factors have on cooperation, there are several areas in which research on this topic can be explored. An important consideration is pursuing research on this topic with a larger sample size. A sample of 184 respondents was collected which limited the diversity of the results and lacked responses from smaller subgroups. A larger sample would provide a more representative study that would allow for results with more generalizability.

Future research could also consider larger and more in-depth demographic variables. While biological gender was studied, it would also be of interest to study gender identity as well. Additionally, for this study individuals had to self-identify as religious or non-religious but, it could be of interest to break that down into smaller more specific categories such as devoutly religious and slightly religious with clearly defined definitions of each. Other variables could include socioeconomic status and level of education as well. Cultural background is also an important factor that could be studied, and a comparison within racial groups of different cultural backgrounds and their likelihood of cooperation may lead to different results.

This study focused on anonymous, one-shot Prisoner's Dilemma games. Future research could use different variations of the Prisoner's Dilemma which would allow the study of repeated interaction and grudges as well as bias and assumptions of knowing who you are competing against. This could pave the way for analysis on how social factors affect cooperation rather than just biological or "in-group" factors.

While this study focused on adult participants, it may be interesting to expand the age range to include younger participants. With the ideals of sharing and teamwork being frequently thrust upon younger individuals, a cyclical trend might be seen in which around young adulthood, uncooperative behavior peaks while the beginnings and ends of life is where cooperation is maximized.

With this study being a survey, individuals provided self-reported responses while knowing that their choices would be collected and analyzed. This may cause people to choose what they see as the “best” or socially correct option rather than what they really would choose if they were faced with that situation. This opens the door to continue this study as a non-experimental, observational study in which data is collected on subjects in their natural environment purely by observation with no interference. This ensures that participants aren’t altering their behavior to make themselves look better.

This study serves as a solid foundation for further analysis of the effects that demographic characteristics have on cooperation. Future studies will aid in refining our understanding of human behavior and enhance the ability to predict outcomes in decision-making situations.

ACKNOWLEDGMENTS

The author thanks Rosemela Bastian for her involvement in the Women in STEM mentorship research program and for her contributions to the presentation of this research.

REFERENCES

1. Brede, M. (2013) Short Versus Long Term Benefits and the Evolution of Cooperation in the Prisoner's Dilemma Game. *PLoS ONE*, 8(2), e56016. <https://doi.org/10.1371/journal.pone.0056016>
2. Kumar, M. M., Tsoi, L., Lee, M. S., Cone, J., & McAuliffe, K. (2021) Nationality dominates gender in decision-making in the dictator and prisoner's dilemma games. *PLoS One*, 16(1), e0244568. <https://doi.org/10.1371/journal.pone.0244568>
3. Dorrough, A. R., & Glöckner, A. (2018) A cross-national analysis of sex differences in prisoner's dilemma games. *British Journal of Social Psychology*, 58(1), 225-240. <https://doi.org/10.1111/bjso.12287>
4. Brañas-Garza, P., & Morales-Siles, A. J. (2003) Gender differences in Prisoners' Dilemma. Fundación Centro de Estudios Andaluces, Documento de Trabajo E2003/19.
5. Bennett, C. (2023) Gender identity within the prisoner's dilemma. *Journal of Student Research*, 12(3). <https://doi.org/10.47611/jsrhs.v12i3.4969>
6. Capraro, V. (2018) Women are slightly more cooperative than men (in one-shot prisoners dilemma games played online). *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.3182429>
7. Romano, A., Bortolotti, S., Hofmann, W., Praxmarer, M., & Sutter, M. (2021) Generosity and cooperation across the life span: A lab-in-the-field study. *Psychology and Aging*, 36(1), 108-118. <https://doi.org/10.1037/pag0000457>
8. Mienaltowski, A., & Wichman, A. L. (2019) Older and younger adults' interactions with friends and strangers in an iterated prisoner's dilemma. *Aging, Neuropsychology, and Cognition*, 27(2), 153-172. <https://doi.org/10.1080/13825585.2019.1598537>
9. Hicks-Patrick, J., Hayslip, B., & Hollis-Sawyer, L. A. (2021) *Adult Development and Aging: Growth, Longevity and Challenges*. SAGE Publications.
10. Romano, V. E. (2007) *Race, Gender, and the Prisoner's Dilemma: A Study in Social Dilemma Cooperation* [Doctoral dissertation, University of Florida]. University of Florida Digital Collections. https://ufdcimages.uflib.ufl.edu/UF/E0/01/89/61/00001/romano_v.pdf

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PRESS SUMMARY

This study examines how demographic factors such as gender, age, race, and religiosity influence cooperation in decision-making situations using a modern variation of the Prisoner’s Dilemma. Traditional game theory suggests that rational individuals will choose to act selfishly; however, results show that real human behavior is more complex. Gender and age were associated with differences in cooperation while race and religiosity did not. These findings highlight how demographics influence cooperation beyond pure rationality. These patterns help explain decision-making in the real world and provide insight into how people behave in social and economic situations.

Mathematical Models for Coupling Rocket Trajectory with Passive Stability

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ABSTRACT

This article develops a unified hierarchy of mathematical models for rocket trajectory and stability. While modern rocket simulators utilize full six degree-of-freedom (6DOF) formulations, these models can be very computationally expensive. They also obscure the true mathematical structure governing the coupling of trajectory and stability. Conversely, simplified rocket models often neglect aerodynamic restoring and damping effects, leading to inaccurate predictions. In this paper a sequence of progressively higher-order dynamical systems is constructed from two to four degrees of freedom. These models are each derived from basic physical principles, verified against the real-world validated rocket simulator RASAeroII. This framework uncovers the minimal set of physical mechanisms required to capture important stability characteristics, including oscillatory modes, damping behavior, and the influence of roll coupling. By tracking the mathematics, the proposed models provide both computational efficiency and a unique physical insight to rocket dynamics. The resulting hierarchy establishes a clear connection between simplified trajectory models and full 6DOF simulations. This offers a practical and understandable foundation for passive stability analysis and rocket simulation.

KEYWORDS

Degrees of Freedom; Trajectory; Apogee; Passive Stability; Caliber; Sounding Rocket; Axisymmetric; Harmonic Oscillator; Force Averaging

INTRODUCTION

Since 1959, NASA's Sounding Rocket Program has provided massive contributions to the national space effort. Designed for sub-orbital missions and surveillance, sounding rockets are a staple in analyzing the physics of rockets within Earth's atmosphere. Sounding rockets, or slender-body rockets, are a class of rockets with axisymmetric, simple bodies¹ - they consist of a nose cone, cylindrical body tube, fins, and commonly a boat tail. Sounding rockets come in a variety of shapes, sizes, and stages, which all largely determine a rocket's stability. If no dynamic control systems are required to achieve a certain caliber, or measure, of stability throughout flight, a rocket is considered to be passively stable. The result of passive stability is of great interest to this article, and directly correlates to the success and versatility in sub-orbital experiments and missions.

Rigid body dynamics in three-dimensional space is completely described by six degree of freedom (6DOF) models, and are applicable to rockets. Such models produced by private space corporations and government agencies each utilize a unique algorithmic model - these models contain many separate nonlinear ODE systems, coupled through code logic.¹ A handful of explicit 6DOF models exist,^{2,3} however these models can be frighteningly complicated, cannot be utilized without proper computing power and time, and thus are outside the scope of this article.

Simplified trajectory models can be found in many places, notably GitHub. However, these models tend to make gross assumptions about tunable aspects such as drag and air density. Clearly, uncoupling trajectory from stability causes inaccuracies that cannot be compensated without data from full simulations. Trajectory and stability in any rigid body must be modeled together. This begs the question - what exactly is the minimal state space required to describe the coupled relationships between trajectory and stability? More specifically, how many degrees of freedom are required to describe the path of a rocket?

In this article, the gap is bridged by determining if higher levels of fidelity yield more meaningful results. First, this article mathematically proves the minimal state-space requirement, a 2DOF model. While this model successfully couples vertical trajectory with pitch attitude, this method lacks agreement with publicly available simulators and stability considerations. Next, a 3DOF model is introduced, which captures true trajectory and stability in the two-dimensional sense. By considering static and dynamic stability, pitch dynamics can be further represented as a second-order harmonic oscillator. Finally, a 4DOF model is constructed, incorporating roll dynamics through Euler's Equations of Motion. This allows the unique point-of-view of the direct results roll has on rocket trajectory and stability. After each system is derived, simulation results follow, thus verifying agreement with proven models. A discussion about this article's findings between the three models follows, ending with conclusions and references.

BACKGROUND

The Black Brant V (five) sounding rocket was developed by Magellan Aerospace in Winnipeg, Canada.¹ It has proven itself as a reliable staple in many sounding rocket programs around the world, including NASA's. Their Sounding Rocket Program Handbook outlines the data and uses for many of their common sounding rockets, including measurements and characteristics of the Black Brant V. Having only one stage, the 'C' variant of this rocket contains four fins and a slightly more powerful motor, when compared to the 'B' variant with three fins. The Black Brant VC's more powerful engine makes it ideal for missions with an apogee, or maximum altitude, from 80 to 260km, carrying payloads from 500 to 1200lbs. This rocket is stackable and comes in many variants, notably the Black Brant IX and XIa, which stack boosters underneath. This allows the aforementioned rockets to achieve much higher altitudes and payload capacities, where usage depends on the mission outline.

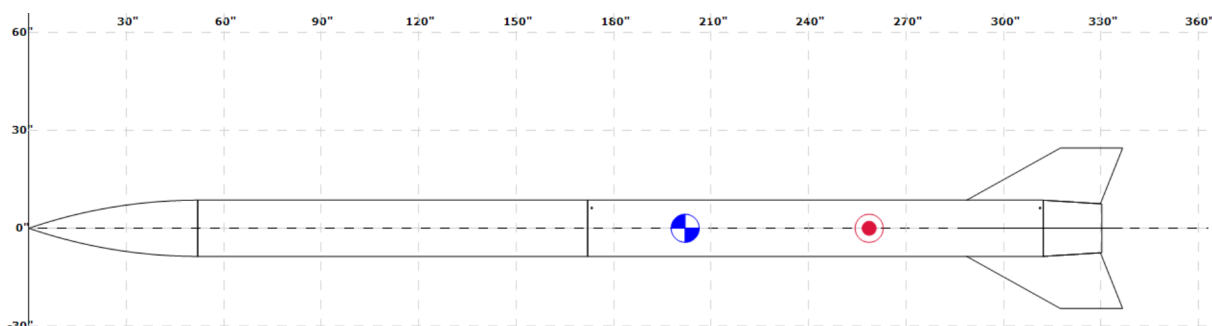


Figure 1. The Black Brant VC Sounding Rocket, modeled inside RASAeroII.

Using RASAeroII, which is a 3DOF rocket simulator,⁴ the Black Brant VC was modeled in **Figure 1**. RASAeroII boasts an average accuracy within 3.47% of real world results for apogees under 300000 feet, and a general average real world accuracy of five percent for apogees above 300000 ft.⁴ Verification of the models produced in this article will be completed based on the agreement between RASAeroII, as gathering real world data from sounding rockets is outside the scope and ability of this article.

When discussing rocket stability, the most important measure comes down to the *stability margin*, defined as the relative distance between the centers of gravity and pressure. Center of pressure should live near the fins of a stable rocket, where the average surface area resides, and moves with mach speed. Under subsonic conditions, when mach speed is less than 0.8, the center of pressure barely moves. During the transonic region between mach 0.8

and 1.2, center of pressure spikes aft mostly due to wave drag. Finally, at supersonic speeds above mach 1.2, the center of pressure moves forwards. On the other hand, center of gravity lives at the balance point of a rocket, and moves forwards depending on how quickly fuel mass depletes.⁵ Once fuel mass depletes, it can be expected that the center of gravity does not change for the duration of flight.

Definition 1. Let x_{CG} and x_{CP} be the positions of center of gravity and pressure, respectively. Additionally, let D be the diameter of the rocket's body tube. Then stability margin SM is calculated by:⁶

$$SM = \frac{x_{CP} - x_{CG}}{D}, \quad \text{Equation 1.}$$

where a stable rocket has a **positive** stability margin. The larger this value, the more a rocket will counter perturbing forces with restoring moments.

The rate of change of restoring moments produced by a rocket, about pitch, is C_{m_α} . This static stability term is the derivative of the moment coefficient C_m w.r.t. the angle of attack α .

Definition 2. Let C_{N_α} represent the rate of change of normal forces experienced by the rocket in the pitch direction, calculated using the Rogers Modified Barrowman Method.⁴ Then the term C_{m_α} is best estimated using the stability margin SM :²

$$C_{m_\alpha} = -SM C_{N_\alpha}. \quad \text{Equation 2.}$$

The rate of change of damping about pitch arises from aerodynamic forces induced with rotational motion.⁵ This term represents the rate at which a rocket will increase or decrease oscillations to reach a steady state. C_{m_α} is referred to as the **pitch stability derivative**, and C_{m_q} as the **pitch damping derivative**.

Definition 3. Let C_{m_q} be the rate at which oscillations are damped due to restoring moments. Then the best estimation of C_{m_q} can be calculated as:²

$$C_{m_q} = -2C_{N_\alpha} SM, \quad \text{Equation 3.}$$

which assumes aerodynamic forces are concentrated around center of pressure x_{CP} .

For rocket stability, both derivatives C_{m_α} and C_{m_q} must be **negative** for stable flight to occur. Else, the rocket tumbles.⁵ Air density within Earth's atmosphere ρ decreases exponentially with altitude x , described below using the exponential density profile of Earth's atmosphere:⁵

$$\rho = \rho_0 e^{-\frac{x}{H}}. \quad \text{Equation 4.}$$

Using atmospheric ceiling height $H = 850000$ meters, a plot is presented over altitude x , and air density with altitude can be viewed in **Figure 2** as a logarithmic plot to better show the exponential nature of **Equation 4**. Gravitational acceleration experienced by an object in Earth's atmosphere is determined by²

$$g = g_0 \left(\frac{r_e}{r_e + x} \right)^2, \quad \text{Equation 5.}$$

where g_0 is gravity at sea level and r_e is the radius of Earth, in meters. Viewing the plot in **Figure 3**, it's clear to see how gravitational acceleration decreases almost linearly when leaving Earth's surface.⁵ Additionally, the total mass of a rocket is calculated by the sum of constant dry mass m_{dry} and current liquid fuel mass m_f ,

$$m = m_{dry} + m_f. \quad \text{Equation 6.}$$

The thrust curve T describes thrust force, in Newtons, produced over time. This is where maximum thrust and action time are described. The thrust interpolant for the Black Brant VC sustainer is plotted below in **Figure 4**, derived from data found in NASA's Sounding Rocket Program Handbook,¹ and used similarly in both RASAeroII and MATLAB simulations to enforce the verification of model agreement.

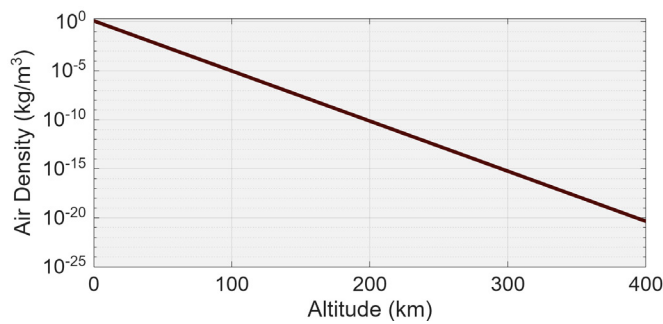


Figure 2. Air density over altitude, in kilometers (logarithmic scale).

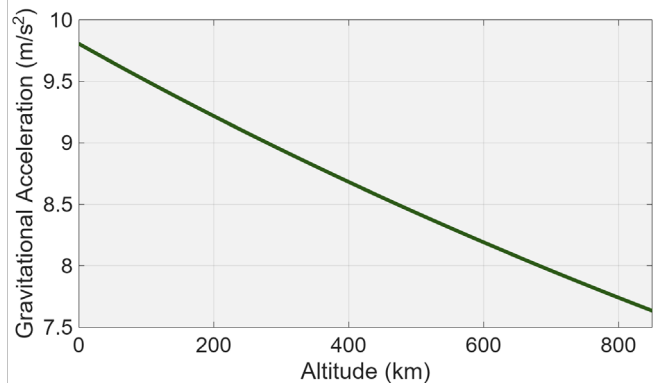


Figure 3. Gravity over altitude, in kilometers.

The temperature model T_a describes the change in temperature, in Kelvin, as altitude increases through the layers of Earth's atmosphere.⁷ Due to the scope of this article's models, the piecewise temperature model below accounts for the first $H = 400$ kilometers of Earth's atmosphere from sea level to the edge of the thermosphere, constructed using measurements of temperatures throughout the layers of Earth's atmosphere from the National Oceanic and Atmospheric Administration (NOAA):

$$T_a = \begin{cases} \frac{26.65 - T_0}{11000}x + T_0 & \text{if } 0 \leq x < 11000 \\ 216.65 & \text{if } 11000 \leq x < 20000 \\ \frac{53.35}{30000}x + 181.05 & \text{if } 20000 \leq x < 50000 \\ 270.13 & \text{if } 50000 \leq x < 53000 \\ -\frac{97}{36000}x + 404.1 & \text{if } 53000 \leq x < 86000 \\ 173 + 827(1 - \exp^{-\frac{x-86000}{198500}}) & \text{if } x \geq 86000 \end{cases}, \quad \text{Equation 7.}$$

where x is in meters, and T_0 represents temperature at sea level in Kelvin, varying based on season and location. Plotting the temperature model in **Figure 5** helps to understand how temperature is proportional to density until solar absorption occurs, increasing temperatures above 86 kilometers rapidly from sea level.

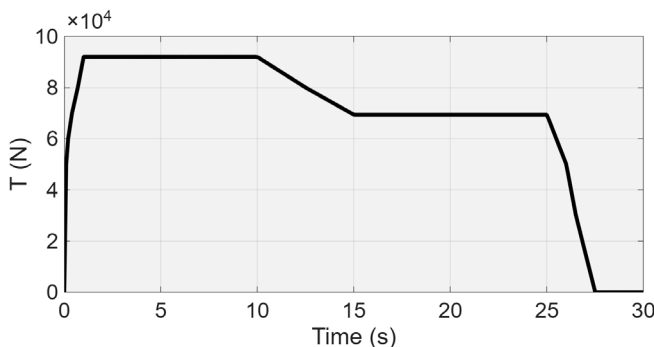


Figure 4. Thrust profile of the Black Brant VC sustainer, in Newtons.

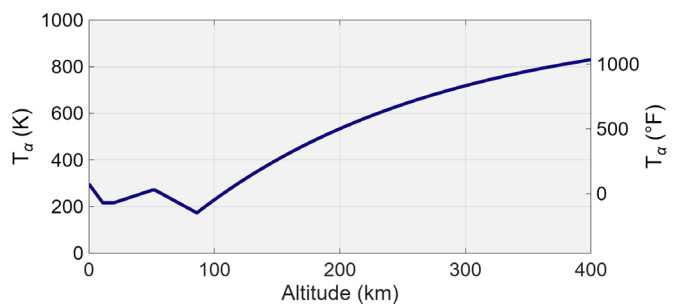


Figure 5. Temperature over altitude, in kilometers.

To find mach speed of a rocket traveling through the layers of Earth's atmosphere, the speed of sound a is first calculated by the equation below as¹

$$a = \sqrt{\gamma_a R T_a}, \quad \text{Equation 8.}$$

where $\gamma_a = 1.4$ is the ratio of specific heats, and $R = 287 \text{ J kg}^{-1} \text{ K}^{-1}$ is the specific gas constant. Thus, the speed of sound only fluctuates with temperature T_a , determined by altitude x as seen from **Equation 7**. Mach number v_m

can now be defined by dividing positive velocity by the speed of sound:¹

$$v_m = \frac{|v|}{a}. \quad \text{Equation 9.}$$

Pitch inertia I_y , which depends on current fuel mass m_f , is best estimated for sounding rockets like the Black Brant VC by adding the inertial contributions of the body and liquid fuel. Inertia represents an object's resistance to rotation about an axis. The equation below estimates the inertia for a thin-walled cylinder:⁸

$$I_y = \frac{1}{12}m(3R^2 + L_t^2) + m_f(x_{aft} - x_{CG})^2, \quad \text{Equation 10.}$$

where R is the body radius, L_t is total length of the rocket, and x_{aft} is the distance between the nosecone and center of the fuel cell, all in meters. The rate of change of fuel mass m_f (kilograms), known as fuel burn rate m'_f ($\frac{kg}{s}$), is given by¹

$$m'_f = -\frac{T}{g_0 I_{sp}}, \quad \text{Equation 11.}$$

where I_{sp} is the specific impulse of the rocket motor. When I_{sp} is multiplied by sea level gravity g_0 , muzzle velocity is produced.⁸ The specific impulse of a motor is the measure of seconds in which one unit of thrust can be produced from one unit of fuel. This reflects the efficiency in which fuel is converted to thrust for a motor, with a larger specific impulse implying a greater fuel efficiency.

TWO DEGREES OF FREEDOM - METHODS AND PROCEDURES

In theory, the simplest way to couple rocket trajectory and stability would be a 2DOF model, where only one axis each describing each are considered. The three axes of a rocket, in reference to its body, can be viewed in **Figure 6**. Each axis can describe translation along with rotation, and thus objects in the 3D sense have six degrees of freedom. Vertical translation, or traveling along axis x^B , can produce results like altitude and apogee, whereas rotation about axis y^B describes pitch attitude for stability.

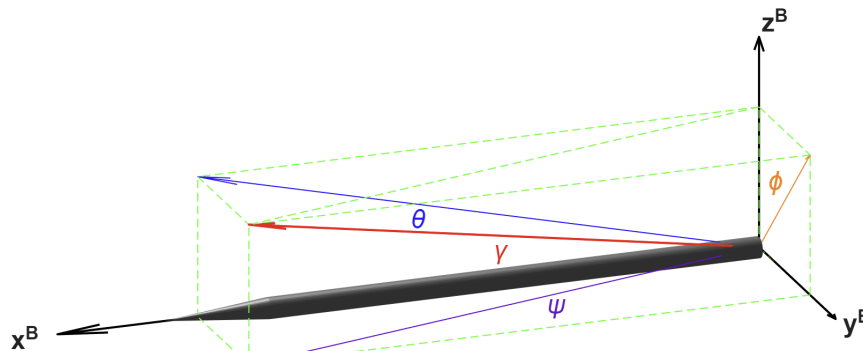


Figure 6. Rocket body reference axes.

From **Figure 6**, attitudes ϕ , θ , and ψ represent roll, pitch, and yaw, describing radians of rotation about axes x^B , y^B , and z^B , respectively. Flight path angle γ represents the inverse tangent of the ratio of velocities in the vertical / horizontal plane, expanded upon in the 3DOF section. This vector is the resulting direction of where the rocket is moving, not necessarily where the nose is pointing. Finally, when the rocket is rotated 90° clockwise about axis y^B , translation along x^B becomes altitude, y^B is distance, and z^B as sidewalk.

TRAJECTORY - 2DOF

Consider translation along the x^B axis - when pitch attitude $\theta = \frac{\pi}{2}$, x^B is vertical, and so is the rocket. From Newton's 2nd Law of Motion, the sum of accelerative rates⁸ can be calculated to define the acceleration a rocket experiences. Taking the time derivative of displacement x gives velocity v , and once again yields acceleration v' .

These values must be simultaneously ‘vertical’ and ‘overall’ due to the limitation of this model, which has only one translational axis:

$$\begin{aligned} x' &= v, \\ v' &= \frac{T}{m} - g - \frac{F_D}{m}. \end{aligned} \quad \text{Equation 12.}$$

From **Equation 12**, F_D is the force experienced by the rocket due to drag.⁵ Drag force F_D is calculated below as

$$F_D = \bar{q} S C_D, \quad \text{Equation 13.}$$

where dynamic pressure $\bar{q} = \frac{1}{2} \rho v^2$, reference area $S = \pi r^2$, and drag coefficient C_D are considered. The drag coefficient changes with mach speed v_m and angle of attack α , requiring an extensive model of its own for realistic calculations. The types of drag considered include base, wave, pressure, skin friction, and drag due to angle of attack, with slight differences between engine on and off conditions.

STABILITY - 2DOF

Now, consider rotation about axis y^B - in the strictly vertical model, it becomes clear that the directions in which pitch attitude (θ) and flight path angle (γ) vectors follow must live along axis x^B . This leads to an intuitive but important result.

Lemma 1. *If a rigid body model is limited to one axis each of translation and rotation, then attitude must remain constant.*

Proof. Consider a 2DOF rocket model, tracking vertical translation and transverse rotation. Angle of attack is defined as

$$\alpha = \theta - \gamma, \quad \text{Equation 14.}$$

where θ is pitch attitude and γ is flight path angle, in radians. Because only vertical travel is considered, no deviation from this axis can be tracked. Intuitively, $\alpha = 0$ always - it follows this limitation holds for the other translational directions, such as distance or sidewalk with yaw attitude. Therefore, every rigid body model with only one axis each of translation and rotation must have attitude remaining constant. $\square$

Within the 2DOF vertical flight model, $\theta = \gamma$ and thus $\alpha = 0$. This result alone suggests the need for an additional translational degree of freedom. Nonetheless, this article acknowledges the mathematical possibility of analysis, and assigns the rest of the state variables needed to see what results can be obtained.

Pitch angular acceleration q' is calculated by dividing the aerodynamic pitching moment M by pitch inertia I_y .⁵, consisting of both static and dynamic terms, derived from Euler’s Equations of Motion:⁸

$$M = \bar{q} S \ell (C_{m_\alpha} \alpha + C_{m_q} \frac{\ell}{2v} q). \quad \text{Equation 15.}$$

Reference length ℓ is the distance, in meters, from center of gravity to center of pressure - when $C_{m_\alpha} < 0$, aerodynamic moment *opposes* angle of attack. This stabilizes the rocket along flight path γ . Additionally, when $C_{m_q} < 0$, the rocket experiences a resistance to angular acceleration, defining the rates at which aerodynamic moments dampen oscillations caused by these restoring moments.

It’s imperative to understand that the sign of SM , from **Equation 1**, will subsequently determine the signs of both C_{m_α} and C_{m_q} in this model. When the stability margin is *positive*, the rocket will experience correct perturbing forces with an ever-increasing amount of torque, causing instability and tumbling. Additionally, if these rates are negative, but too small, the rocket will fail to restore stability about pitch quickly enough for reliable flight.

The stability subsystem is now:

$$\begin{aligned}\theta' &= q, \\ q' &= \frac{M}{I_y},\end{aligned}\tag{Equation 16.}$$

and by **Lemma 1**, $\alpha = 0$, thus only damping effects remain, removing stiffness from **Equation 16** entirely. All together, a model is constructed describing the coupling between vertical trajectory and pitch damping in two degrees of freedom.

$$\begin{aligned}x' &= v, \\ v' &= \frac{T}{m} - g - \frac{F_D}{m}, \\ \theta' &= q, \\ q' &= \frac{\bar{q}S\ell^2}{4vI_y}C_{m_q}q.\end{aligned}\tag{Equation 17.}$$

Equation 17 mathematically couples trajectory into stability, however no freedom exists for pitch attitude θ , flight path angle γ , or angle of attack α . Still, results agreeable with RASAeroII can be shown.

RESULTS - 2DOF

Utilizing RASAeroII, results of the Black Brant VC were obtained under purely vertical flight, equivalent to the fidelity of a 2DOF model. Most sounding rockets employ yo-yo despin, parachute, and drogue phases, however these consideration have been removed for the simplicity of testing the mathematical models' agreement with RASAeroII. It is the scope of this article to verify the mathematical agreement between the two models, as opposed to measuring accuracy to real world data which is unobtainable for this rocket specifically.

Simulation results of the Black Brant VC from **Equation 17** is now shown below, overlaid by the data obtained from the RASAeroII simulation. The MATLAB 2DOF model underestimates apogee by 0.9%, mostly due to a lack of stiffness in stability, while maximum and minimum speeds are within 0.3%. Although the considerations of the 2DOF model are too low to be physically reliable, they still agree with RASAeroII's estimations within 1%.

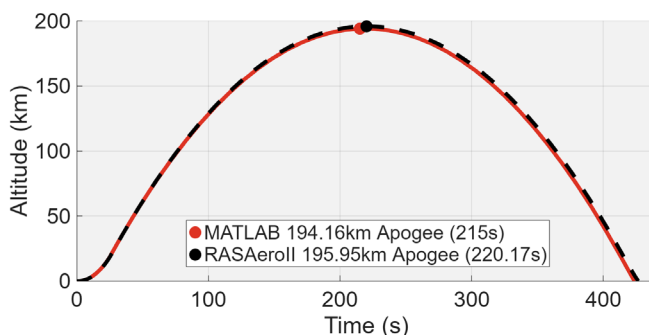


Figure 7. Altitude over time of the Black Brant VC compared between RASAeroII (dashed black line) and the MATLAB 2DOF simulator (solid red line).

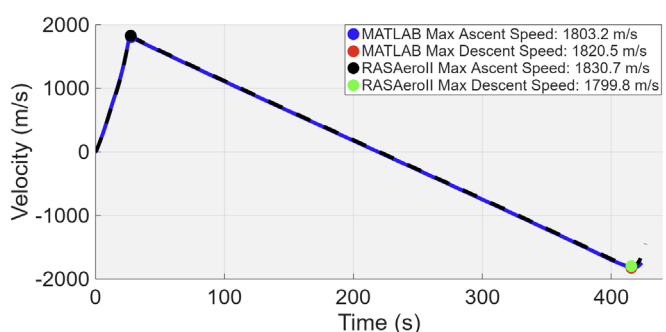


Figure 8. Vertical velocity over time of the Black Brant VC compared between RASAeroII (dashed black line) and the MATLAB 2DOF simulator (solid blue line).

THREE DEGREES OF FREEDOM - METHODS AND PROCEDURES

In order to properly capture stability, it's clear from **Lemma 1** that α must be nonzero. More specifically, pitch attitude θ and flight path angle γ must be independent of each other,⁸ and free to change during flight. It is here this article takes a moment to clarify the assumption of an axisymmetric rocket - when viewed from the nosecone along axis x^B , the rocket may not be perfectly symmetric in design, and geometric centers remain along x^B always.¹ Based on **Equation 14** from **Lemma 1**, a third degree of freedom is necessary to describe α this way.⁸ By

choosing to model travel along axis y^B , flight path angle γ can be defined as the $\arctan()$ of the ratio of velocities

$$\gamma = \arctan\left(\frac{v_x}{v_y}\right), \quad -\pi \leq \gamma \leq \pi \quad \text{Equation 18.}$$

where v_x is velocity in the vertical sense along x^B , and v_y horizontally along y^B . The ratio of these velocities yields drift in a two-dimensional plane, allowing for γ to reflect resulting flight path angle.⁵ Taking advantage of this, the rates of change of velocity can be constructed by finding the magnitude of vertical and horizontal velocity vectors.⁵ The system below describes vertical translation now,

$$\begin{aligned} x' &= v_x, \\ v_x' &= \frac{T \sin \theta}{m} - g - \frac{v_x F_D}{vm}. \end{aligned} \quad \text{Equation 19.}$$

and horizontal translation can be modeled similarly:

$$\begin{aligned} y' &= v_y, \\ v_y' &= \frac{T \cos \theta}{m} - \frac{v_y F_D}{vm}. \end{aligned} \quad \text{Equation 20.}$$

Overall velocity v is now⁵

$$v = \sqrt{v_x^2 + v_y^2}, \quad \text{Equation 21.}$$

and the pitch stability subsystem remains the same as **Equation 16** with no additional considerations. The 3DOF model becomes:

$$\begin{aligned} x' &= v_x, \\ v_x' &= \frac{T \sin \theta}{m} - g - \frac{v_x F_D}{vm}, \\ y' &= v_y, \\ v_y' &= \frac{T \cos \theta}{m} - \frac{v_y F_D}{vm}, \\ \theta' &= q, \\ q' &= \frac{M}{I_y}. \end{aligned} \quad \text{Equation 22.}$$

THREE DEGREES OF FREEDOM - RESULTS

A 3DOF rocket simulator can now be implemented in MATLAB. This time, the versatility of **Equation 22** is highlighted by introducing *initial launch angles*. The Black Brant VC is evaluated in the figures below when launched at zero, five, ten, and fifteen degrees from vertical, displaying how choosing such a condition effects trajectory results. RASAeroII continues to be the comparative benchmark for this fidelity.

Under vertical launch, the MATLAB simulator estimates apogee with five orders of agreement to RASAeroII's estimation. As launch angle perturbs from zero, the MATLAB simulator retains at least two orders of agreement for apogee, distance, and speed estimations, highlighted in **Figures 9 to 12**.

With these results, a theorem is introduced clarifying the distinction between two and three DOF stability subsystems, and the difference this makes for analyzing passive stability of rockets.

Theorem 2. *A rocket dynamics model exhibits a genuine coupling between trajectory and stability in the 2D sense iff a minimum of three degrees of freedom are considered.*

Proof. A proof by contrapositive follows, first showing $\neg B \Rightarrow \neg A$, then concludes by showing $B \Rightarrow A$:

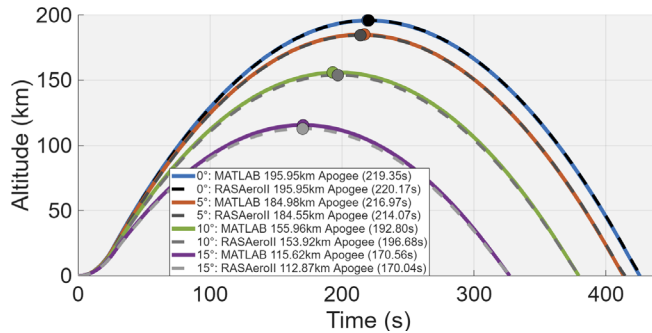


Figure 9. Altitudes over times of the Black Brant VC compared between RASAeroII (dashed grayscale lines) and the MATLAB 3DOF simulator (solid color lines).

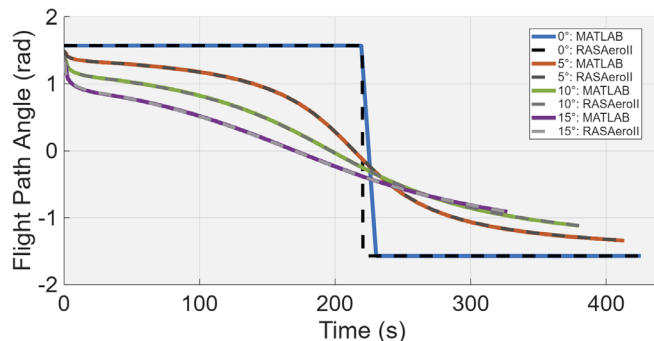


Figure 11. Flight path angles over times of the Black Brant VC compared between RASAeroII (dashed grayscale lines) and the MATLAB 3DOF simulator (solid color lines).

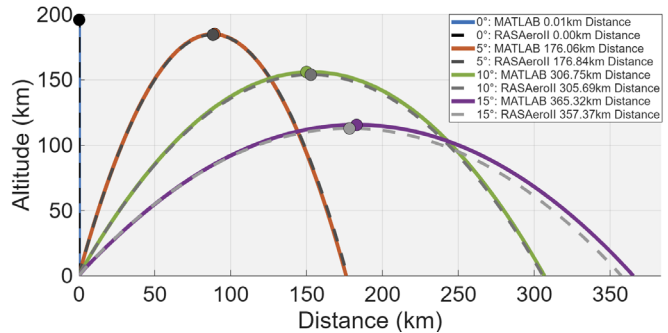


Figure 10. Altitudes over distances of the Black Brant VC compared between RASAeroII (dashed grayscale lines) and the MATLAB 3DOF simulator (solid color lines).

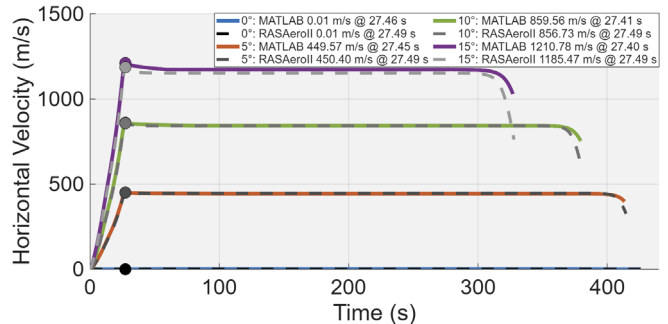


Figure 12. Horizontal velocities over times of the Black Brant VC compared between RASAeroII (dashed grayscale lines) and the MATLAB 3DOF simulator (solid color lines).

Let a rocket dynamics model exhibit a true coupling between trajectory and stability. This means the position of the rocket in a 2D plane is free to move in two different directions, and the attitude in this plane can both affect and be affected by the trajectory of the rocket.

Assume, to the contrary, this rocket dynamics model has fewer than three degrees of freedom. Then two cases follow:

Case 1: One translational and one rotational degree of freedom are considered. By **Lemma 1**, the attitude must remain constant.

Case 2: Two translational degrees of freedom are considered. Then the model is purely translational, with no stability coupling.

In both cases, a contradiction is reached - neither of these cases properly couple trajectory and stability. Thus a rocket dynamics model with fewer than three degrees of freedom cannot exhibit a genuine coupling of the two.

Conversely, assume a model has three degrees of freedom in the two-dimensional sense, consisting of two translational and one rotational. Then attitude affects the trajectory in this plane by determining the direction of acceleration. Additionally, trajectory affects the aerodynamic moments governing rotational acceleration. This is exactly what produces a genuine coupling between trajectory and stability in the 2D sense, so a rocket dynamics model must contain at least three degrees of freedom to describe this coupling.

Therefore, a rocket dynamics model exhibits a genuine coupling between trajectory and stability in the 2D sense if and only if a minimum of three degrees of freedom are considered. $\square$

Expanding upon **Theorem 2**, consider the 3DOF stability subsystem, from **Equation 16**:

$$\begin{aligned}\theta' &= q, \\ q' &= \frac{\rho v^2 S \ell}{2I_y} C_{m_\alpha} (\theta - \gamma) + \frac{\rho v S \ell^2}{4I_y} C_{m_q} q,\end{aligned}\tag{Equation 23.}$$

and define terms

$$k = -\frac{\rho v^2 S \ell}{2I_y} C_{m_\alpha},\tag{Equation 24.}$$

$$c = -\frac{\rho v S \ell^2}{4I_y} C_{m_q},\tag{Equation 25.}$$

where k is denoted stiffness and c as damping⁸. Then **Equation 23** gives the second-order harmonic oscillator⁸

$$\theta'' + c\theta' + k(\theta - \gamma) = 0.\tag{Equation 26.}$$

Natural frequency ω_n and damping ratio ζ can now be derived from the oscillator. The damped frequency ω_d represents the decay of oscillation frequencies experienced by the rocket:

$$\omega_n = \sqrt{k}, \quad \zeta = \frac{c}{2\omega_n}, \quad \omega_d = \omega_n \sqrt{1 - \zeta^2}.$$

Taking the partials of **Equation 23**, the Jacobian is evaluated as:

$$J = \begin{pmatrix} 0 & 1 \\ -k & -c \end{pmatrix},\tag{Equation 27.}$$

with eigenvalues

$$\begin{aligned}\lambda_{1,2} &= -\frac{c \pm \sqrt{c^2 - 4k}}{2}, \\ &\equiv -\zeta\omega_n \pm i\omega_d.\end{aligned}\tag{Equation 28.}$$

The real part of the eigenvalues from **Equation 28** is:

$$\text{Re}(\lambda_{1,2}) = -\frac{c}{2} = -\zeta\omega_n,\tag{Equation 29.}$$

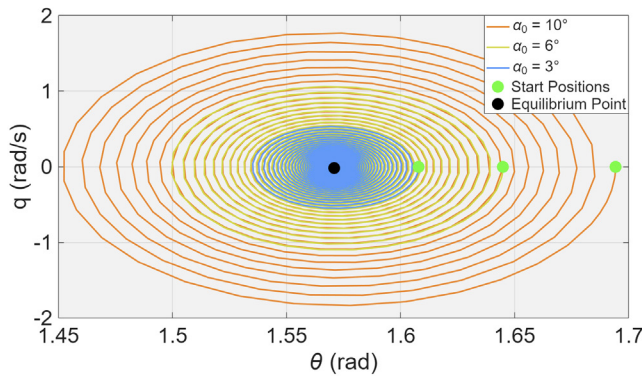
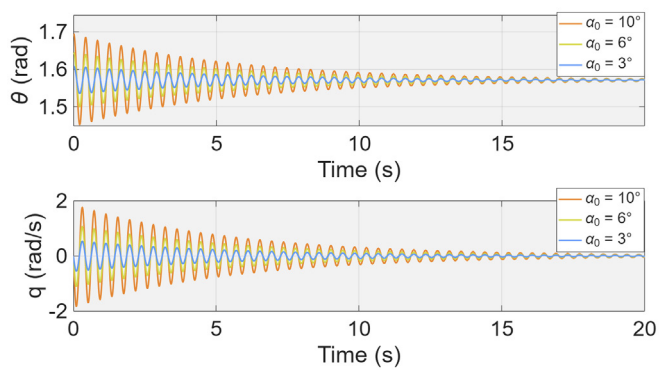
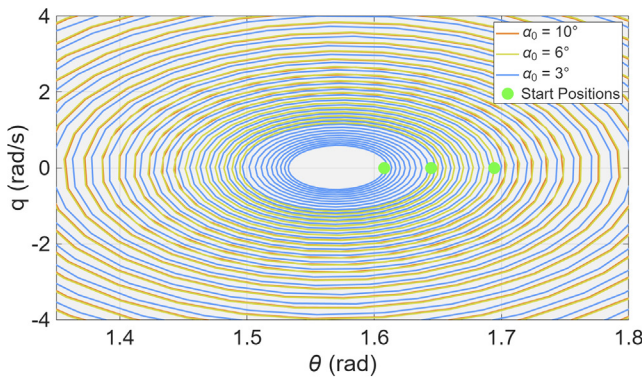
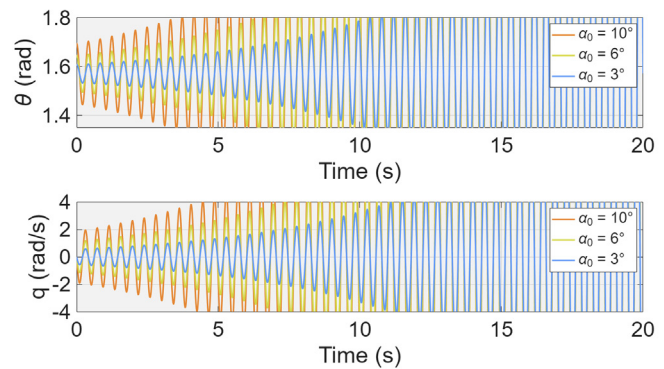
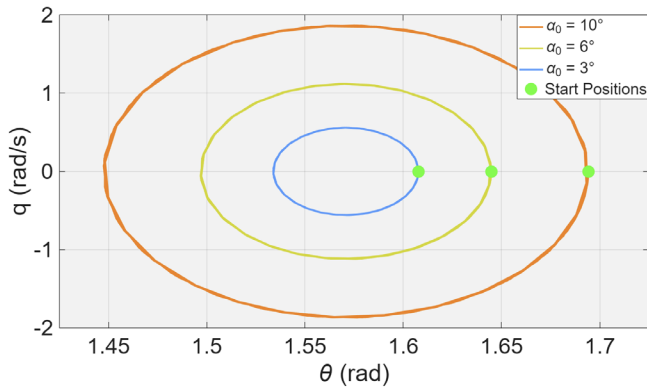
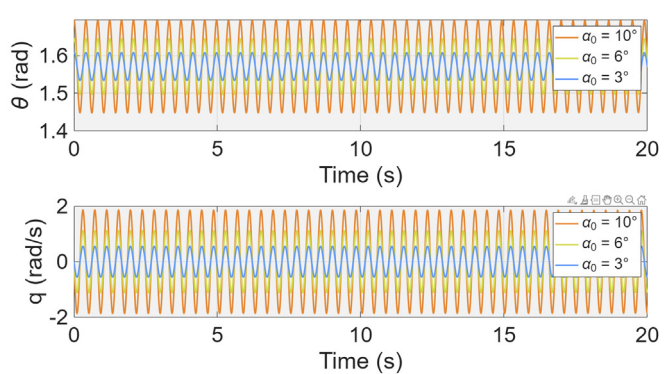
and because of the expansion of damping term c from **Equation 25**, the eigenvalues have a negative real part only if pitch damping derivative $C_{m_q} < 0$, giving both $c > 0$ and $\zeta > 0$. Because of the velocity term being squared in the numerator of k but not in c , the discriminant of the eigenvalues is guaranteed to always be negative. Thus, when $c > 0$, a *stable* spiral sink is formed. If pitch damping derivative $c = 0$, oscillations are simply undamped and form a limit cycle. Finally, when $c < 0$, *unstable* flight occurs in the shape of a spiral source. A very simple corollary follows:

Corollary 3. *Rocket stability is determined by the stability margin.*

Proof. When the stability margin is positive, the damping derivative is negative, and damping term c is positive. When $c > 0$, the eigenvalues from **Equation 28** are negative, and the rocket is stable. It follows that when the stability margin is negative, the rocket is unstable due to the eigenvalues being positive. Thus the stability of a rocket is determined by the stability margin. $\square$

Using values at $t = 15$ seconds from the 3DOF MATLAB simulation, phase portraits can be constructed at different perturbations of angle of attack as seen below. These figures represent the pitch stabilization of the Black Brant VC over a local timespan. Because fifteen seconds into launch is near the moment of largest dynamic pressure, these plots represent the moment of greatest instability for this rocket specifically. The solution timeplots for $\theta(t)$ and $q(t)$ are shown comparatively, considering these angles of attacks in **Figures 13 to 18**.

To demonstrate the importance of damping term c in determining the sign of the real part of the eigenvalues, the phase portraits and timeplots below display how pitch stability changes when $c < 0$ and $c = 0$, creating unstable

Figure 13. Phase portraits when $c > 0$.Figure 14. Timeplots when $c > 0$.Figure 15. Phase portraits when $c < 0$.Figure 16. Timeplots when $c < 0$.Figure 17. Phase portraits when $c = 0$.Figure 18. Timeplots when $c = 0$.

FOUR DEGREES OF FREEDOM - METHODS AND PROCEDURES

Moving into new territory, a second rotational degree of freedom about either roll (axis x^B) or yaw (axis z^B) can be added, resulting in a 4DOF model. First, Euler's Equations of Motion for rigid bodies must be considered,⁸ one of the many ODE systems involved in modern 6DOF rocket simulators. Euler's Equations of Motion are defined about axes x^B , y^B , and z^B as follows:

$$\begin{aligned} L &= I_x p' + (I_z - I_y)qr, \\ M &= I_y q' + (I_x - I_z)pr, \\ N &= I_z r' + (I_y - I_x)pq. \end{aligned} \quad \text{Equation 30.}$$

Here, angular accelerations p' , q' , and r' are referenced about roll, pitch, and yaw, respectively. Angular rates p , q , and r are referenced in the same manner, along with aerodynamic moments about roll L , pitch M , and yaw N .⁸

Principal inertial tensors I_x , I_y , and I_z all correspond to their respective axes (roll, pitch, and yaw), and one can see the derivation for aerodynamic pitching moment M and pitch inertia I_y from **Equations 15 and 10** in the previous models. Recall the assumption made earlier about axisymmetric rockets - a theorem is provided below about the unique reduction of Euler's Equations of Motion.⁸

Theorem 4. *Let B be a rigid rocket body whose mass distribution is axisymmetric about its longitudinal axis x^B . Then the following properties hold simultaneously:*

- Roll angular acceleration is dynamically uncoupled from both pitch and yaw angular accelerations.
- Roll rate is the sole angular rate coupling term between pitch and yaw dynamics.

Proof. Let a rocket's body B be axisymmetric about axis x^B , so $I_y = I_z$. Then **Equation 30** can be reduced and rewritten as a system of angular acceleration about roll, pitch and yaw:

$$\begin{aligned} p' &= \frac{L}{I_x}, \\ q' &= \frac{M + (I_y - I_x)pr}{I_y}, \\ r' &= \frac{N - (I_y - I_x)pq}{I_y}, \end{aligned} \quad \text{Equation 31.}$$

where roll angular acceleration p' is no longer influenced by pitch or yaw dynamics, and roll rate p is the sole angular rate coupling pitch and yaw dynamics.⁸ □

Because of this result, the model can be extended to four degrees of freedom in the following unique manner:

$$\begin{aligned} x' &= v_x, \\ v'_x &= \frac{T \sin \theta}{m} - g - \frac{v_x F_D}{vm}, \\ y' &= v_y, \\ v'_y &= \frac{T \cos \theta}{m} - \frac{v_y F_D}{vm}, \\ \theta' &= q, \\ q' &= \frac{M + (I_y - I_x)pr}{I_y}, \\ \psi' &= r, \\ r' &= \frac{N - (I_y - I_x)pq}{I_y}, \end{aligned} \quad \text{Equation 32.}$$

where ψ is yaw attitude, r is yaw rate, and r' is yaw angular acceleration from Euler's Equations of Motion. This way, nose coning motion can be considered between attitudes θ (pitch) and ψ (yaw), and roll rate p becomes a tunable parameter, directly influencing the transfer of energy between these angular systems.

When it comes to passive stabilization in the real world, maintaining a roll rate p is essential to capitalizing on stability by influencing natural frequency ω_n and damping ratio ζ . Events like shooting a bullet and throwing a football are great examples of axisymmetric objects that require spin stabilization for desired flight. This gyroscopic stiffness effect is what allows smaller flying bodies that are too marginally stable on their own to be artificially stabilized with roll.

In order to maintain stability in a variety of conditions, the Black Brant VC has an average prescribed roll rate of 3.5 cycles per second,¹ which is perfect for ideal force averaging⁸ without the risk of structural damage due

to over damping. First, this article considers the new, four equation stability subsystem from **Equation 32** with hopes of seeing what effects roll has on passive stability through phase plane analysis. Expanded, the following subsystem is obtained:

$$\begin{aligned}\theta' &= q, \\ q' &= \frac{\bar{q}S\ell}{I_y}C_{m_\alpha}\alpha + \frac{\bar{q}S\ell^2}{2vI_y}C_{m_q}q + \frac{(I_y - I_x)p}{I_y}r, \\ \psi' &= r, \\ r' &= \frac{\bar{q}S\ell}{I_y}C_{n_\beta}\psi + \frac{\bar{q}S\ell^2}{2vI_y}C_{n_r}r - \frac{(I_y - I_x)p}{I_y}q,\end{aligned}\tag{Equation 33.}$$

and only because of the axisymmetric assumption, it may be assumed that stability derivatives $C_{m_\alpha} \equiv C_{n_\beta}$, where C_{n_β} is the rate of change of restoring moments about yaw axis z^B (from N). Similarly, damping derivatives $C_{m_q} \equiv C_{n_r}$, where C_{n_r} is the rate of change of damping about the yaw axis z^B (from N).⁵ Thus the claim that $M \equiv N$ for this axisymmetric rocket holds. Recall the previous stiffness and damping terms⁸ k and c from **Equations 24 and 25**:

$$\begin{aligned}\theta'' + c\theta' + k(\theta - \gamma) - \Omega\psi' &= 0, \\ \psi'' + c\psi' + k\psi + \Omega\theta' &= 0.\end{aligned}\tag{Equation 34.}$$

Define complex variable $z = (\theta - \gamma) + i\psi$, so $z' = q + ir$ and $z'' = q' + ir'$. Solving for z'' produces a single, second-order complex harmonic oscillator, representing the coupling between pitch and yaw from **Equation 34**.

$$z'' + (c + i\Omega)z' + kz = 0\tag{Equation 35.}$$

Here, Ω in **Equation 35** is the term $\frac{(I_y - I_x)p}{I_y}$, responsible for coupling pitch and yaw. When roll rate $p = 0$, $\Omega = 0$, and the pitch and yaw stability subsystems become uncoupled and independent. It becomes clear now exactly how energy is transferred between pitch and yaw - in addition to coupling these rotational axes, roll rate coupling term Ω provides a deeper result for natural frequency ω_n and damping ratio ζ .

$$\omega_n = \sqrt{k}, \quad \zeta = \frac{c + i\Omega}{2\omega_n}, \quad \omega_d = \omega_n \sqrt{1 - \zeta^2}.$$

Interestingly enough, roll rate does not effect a rocket's static stiffness, as this is a geometric property primarily governed by stability margin SM from **Equation 1**. Rather, roll is responsible for coupling pitch and yaw dynamics, modifying dynamic stability instead. What must be understood about roll is that this coupling can alter the natural frequency ω_n and damping ratio ζ , but not necessarily in a strictly 'increasing' or 'decreasing' manner.

Roll is best understood as a mechanism for averaging the aerodynamic and structural asymmetries of a rocket, and thus when a rocket is ideally axisymmetric, like the Black Brant VC, this effect is minimal. However, in practical, real world systems where small imperfections always exist, roll can reduce the influence these asymmetries contribute to instability. As a result, a rocket that rolls has the unique ability to reduce localized stresses on the rocket body frame by distributing these aerodynamic loads more evenly about the two axes during flight, preventing events like bending frames and breaking fins.

In some cases, introducing roll can help mitigate unwanted dynamic effects, such as those encountered near maximum dynamic pressure or during transonic flight. By preventing these 'directional biases' in pitch and yaw, roll promotes a more balanced response to perturbations, though it does not guarantee increased damping nor overall stability. The amount of perturbing forces can neither be increased nor decreased, only redistributed.

FOUR DEGREES OF FREEDOM - RESULTS

Equation 32 was coded in MATLAB with the goal of viewing the real world effects spin has on the Black Brant VC specifically. With a launch angle of five degrees from vertical, the following plots compare results obtained

with and without roll, implemented in the simplest fashion by using a linear interpolant to increase roll from zero to $p = 3.5$ cycles per second by fuel burnout, then maintained for the duration of flight. It's important to note this is not realistic, but rather the simplest way to view the effects rolling the Black Brant VC has on previously calculated results.

Additionally, it follows from **Theorem 4** that when roll rate $p = 0$, the pitch angular acceleration equation simplifies to $q' = \frac{M}{I_y}$, and thus the 4DOF model simplifies to the 3DOF model covered in the previous section. For this reason, the plots below are not compared with data from the RASAeroII simulator due to redundancy in results, and the fact that RASAeroII does not support such rolling conditions as a 3DOF simulator.

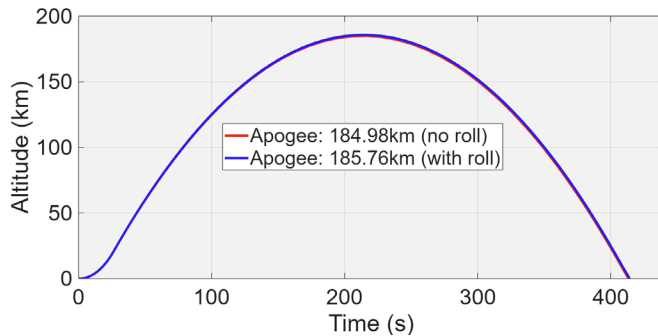


Figure 19. MATLAB 4DOF Simulator - altitude over time, comparing rolling and non-rolling conditions.

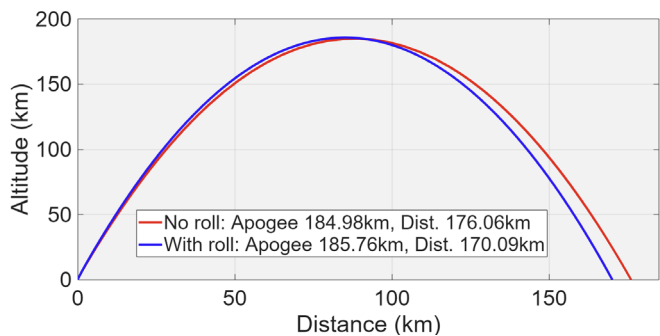


Figure 20. MATLAB 4DOF Simulator - altitude over distance, comparing rolling and non-rolling conditions.

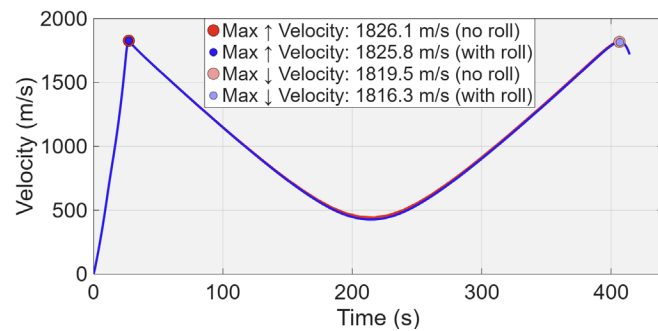


Figure 21. MATLAB 4DOF Simulator - velocity over time, comparing rolling and non-rolling conditions.

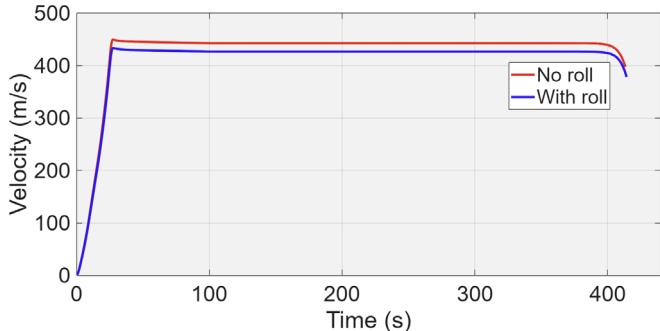


Figure 22. MATLAB 4DOF Simulator - horizontal velocity over time, comparing rolling and non-rolling conditions.

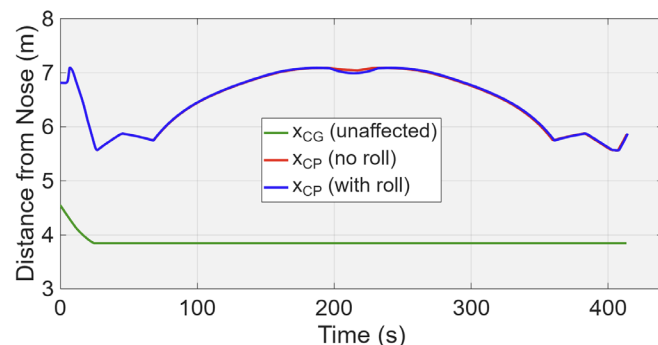


Figure 23. MATLAB 4DOF Simulator - centers of gravity and pressure over time, comparing rolling and non-rolling conditions.

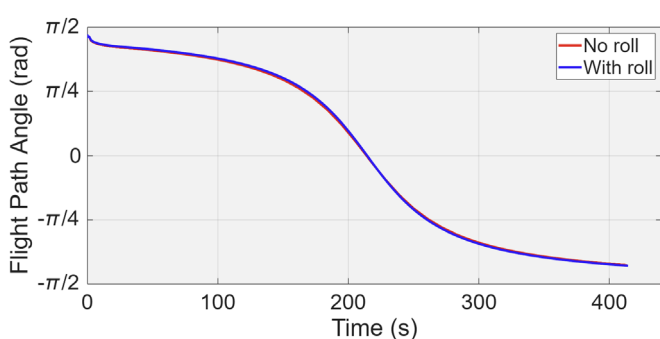


Figure 24. MATLAB 4DOF Simulator - flight path angle over time, comparing rolling and non-rolling conditions.

Results suggest that the Black Brant VC experiences a *greater* apogee, with the sacrifice of *smaller* distance under these rolling conditions. Roll rate will also *decrease* velocity due to energy being consumed during spin, however this energy helps to redistribute the already small differences in perturbing forces experienced about pitch and yaw

in a more even manner.

The direct effect roll rate has on passive stability of the Black Brant VC can be viewed with the figures below. A local simulation was run at time $t = 15$ in the same manner as the 3DOF stability subsystem, yielding many additional results considering yaw. Coning motion and coning decay are direct results of the 4DOF subsystem's complex oscillator, displaying the tradeoff of taking longer to reach a steady state with less stress on the body frame.

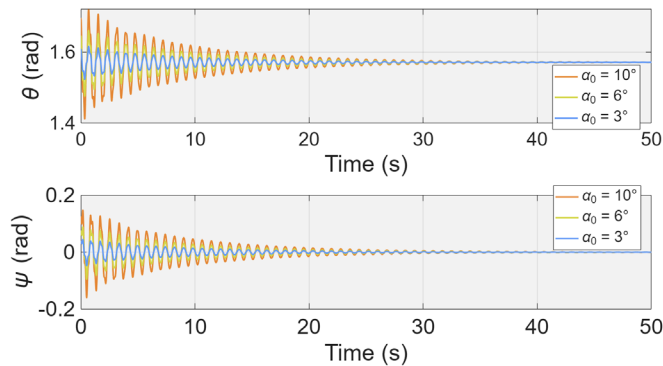


Figure 25. MATLAB 4DOF simulator - attitude timeplots.

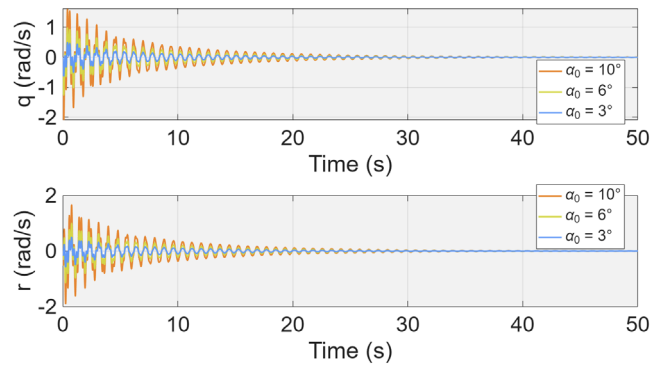


Figure 26. MATLAB 4DOF simulator - angular rate timeplots.

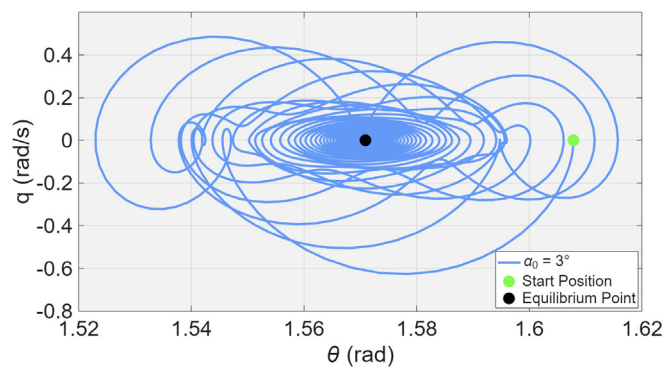


Figure 27. Pitch stability phase portrait, $\alpha_0 = 3^\circ$.

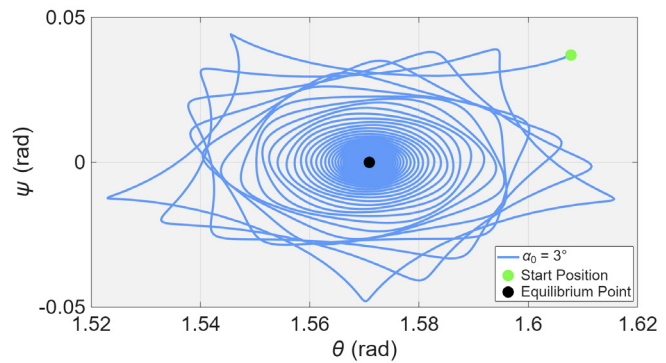


Figure 28. Coning motion phase portrait, $\alpha_0 = 3^\circ$.

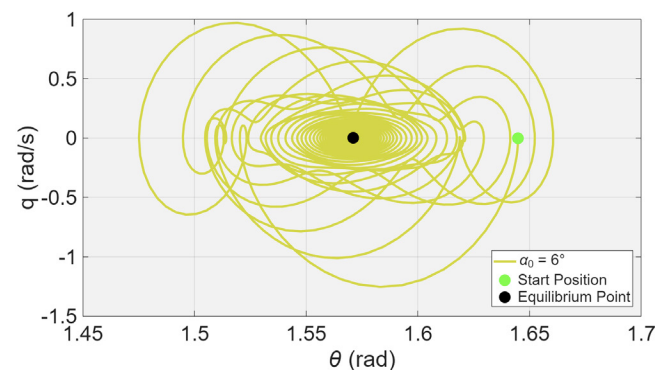


Figure 29. Pitch stability phase portrait, $\alpha_0 = 6^\circ$.

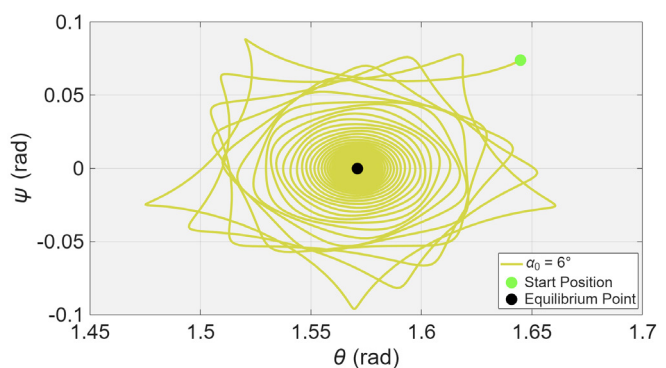


Figure 30. Coning motion phase portrait, $\alpha_0 = 6^\circ$.

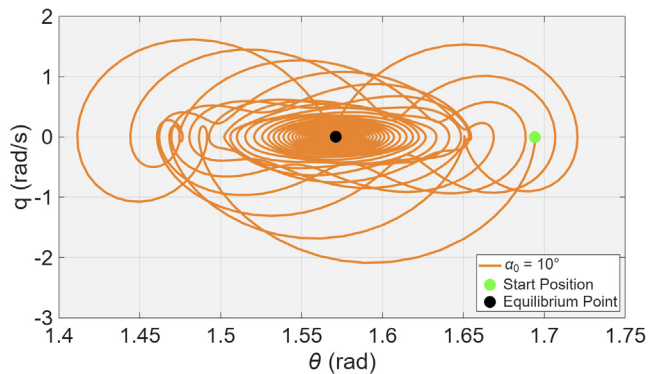


Figure 31. Pitch stability phase portrait, $\alpha_0 = 10^\circ$.

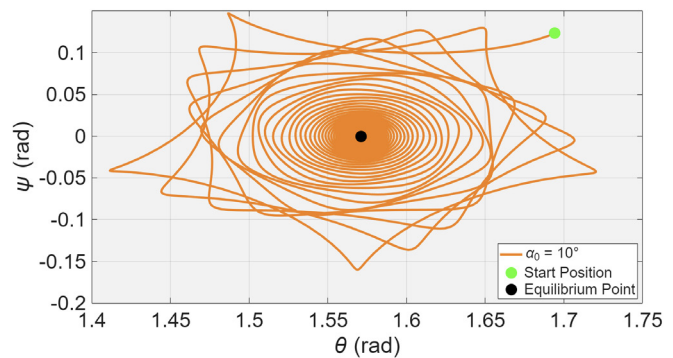


Figure 32. Coning motion phase portrait, $\alpha_0 = 10^\circ$.

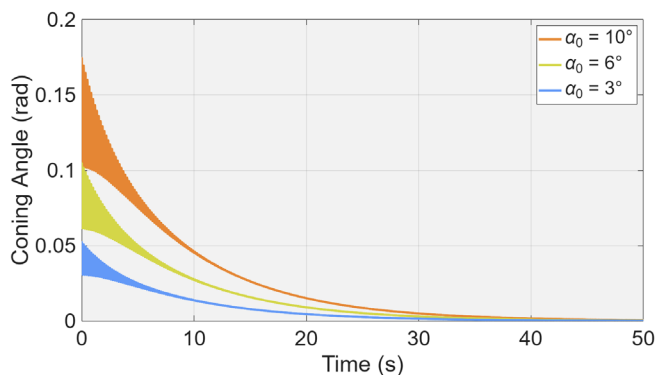


Figure 33. Exponential decay of coning motion.

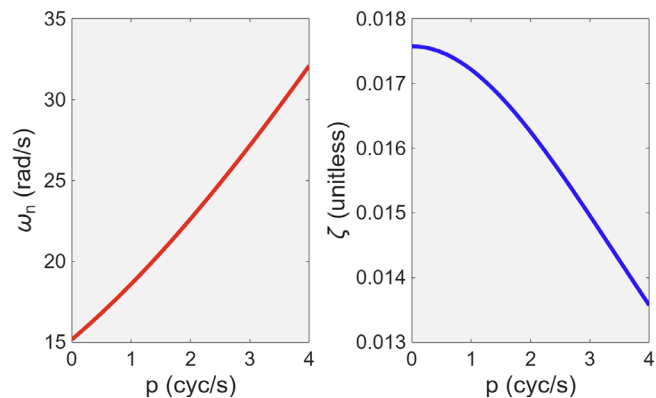


Figure 34. Natural frequency and damping ratio ζ calculations.

DISCUSSION

With the 2DOF model, rocket trajectory and stability can be mathematically coupled, as shown in **Equation 17**, but not without large physical constraints. Both simulators report a flight duration of approximately six minutes and fifty-two seconds, and while MATLAB trajectory attributes agree with estimations produced by RASAeroII up to two orders, pitch attitude θ remains constant at $\frac{\pi}{2}$ radians. Subsequently, its derivative, pitching rate, remains zero. This is why angle of attack is always zero, proved in **Lemma 1**. This results in an infinitely damped rocket - no amount of perturbing forces can effect stability of the rocket in this model, thus **Equation 17** is insufficient for passive stability analysis.

Adding a third degree of freedom results in a complete picture of both rocket trajectory and stability about pitch - RASAeroII reports an apogee of **682879ft** under vertical launch, and the 3DOF model reports apogee at **682883ft**, a difference of only *four feet*, resulting in much higher agreement with RASAeroII. Angle of attack α is no longer forced to be zero, thus **Equation 22** allows for deviation from flight path angle γ , and stability is properly analyzed about pitch axis y^B . This is the minimal mathematical model that bidirectionally couples trajectory with stability, as was proved in **Theorem 2**, and passive stability of a rocket can be determined by viewing the solution timeplot of $\theta(t)$ and $q(t)$ from **Figure 14**, showing damped oscillations over time.

To further this article's research into new territory, a fourth degree of freedom was added to the model. By the result obtained in **Theorem 4**, roll is uncoupled from pitch and yaw in an truly axisymmetric rocket, and thus can be treated as a parameter in **Equation 32**. The 4DOF stability subsystem from **Equation 33** contains four equations, and the complex oscillator from **Equation 35** describes many results such as nose coning motion, pitch stability, and yaw stability, with and without roll. From **Figure 34**, it's clear that an increase in roll rate results in an increase of natural frequency for the Black Brant VC specifically, and decreases its damping ratio. Too much

roll rate for this rocket can inflate natural frequency until damping becomes too small, resulting in a stable limit cycle, as opposed to reaching an equilibrium point. This is much more stressful on the rocket's mainframe, and therefore every rocket will have some ideal roll rate, including zero, in which force averaging provides the best positive effect on passive stability and stress on the rocket's mainframe.

A rocket with excessive damping or a low natural frequency cannot always be directly corrected through roll, however inducing roll can alter the coupled dynamics of the pitch / yaw stability subsystem, which can modify the damping ratio and natural frequency through energy exchange between these two axes. This is because perturbing forces cannot be increased or decreased without structurally changing the shape and size of a rocket, but can be redistributed more evenly between the pitch / roll plane and the yaw / roll plane, causing a phenomenon known as force averaging. The best representation of how roll affects stability is shown below for the Black Brant VC, comparing 3DOF to 4DOF pitch stability phase portraits.

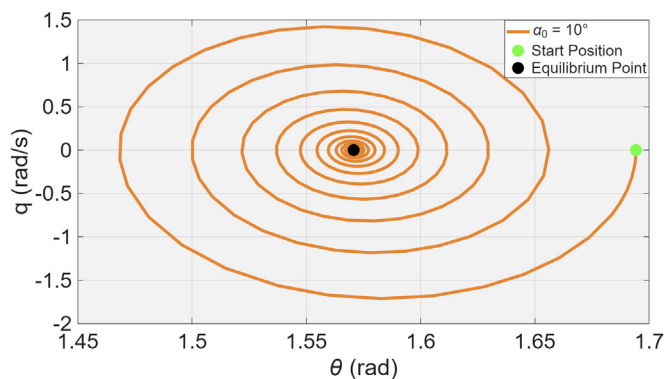


Figure 35. Pitch stability, 3DOF, no roll (inflated C_{m_q}).

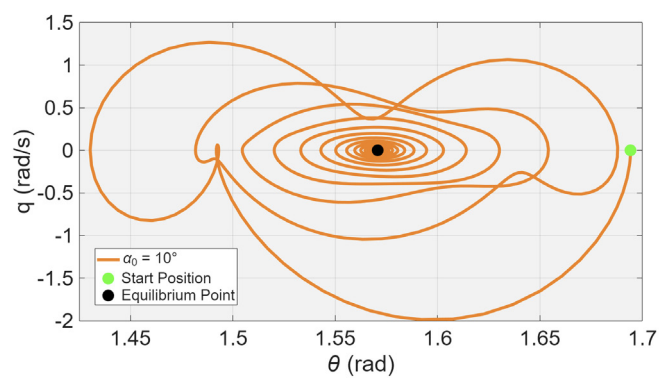


Figure 36. Pitch stability, 4DOF, with roll (inflated C_{m_q}).

By inflating the damping derivative fivefold, it's clear how force averaging in **Equation 34** eventually evens the pitch stability phase portrait in **Figure 36** to a spiral sink - the same spiral sink as the center of the 3DOF oscillator from **Equation 26**, as seen in **Figure 35**. By redistributing energy between these axes of rotation, roll seems to lessen the time spent at larger pitch attitude and pitching rate values, with the sacrifice of a slightly larger range in both respects.

Finally, the figures below highlight coning with pitching rate, and rates with pitch attitude - the yaw counterparts are similar in shape and size with different values. This unique and new insight into passive stability with roll allows this article to present exactly how a rocket is behaving within the pitch and yaw axes in local timespans.

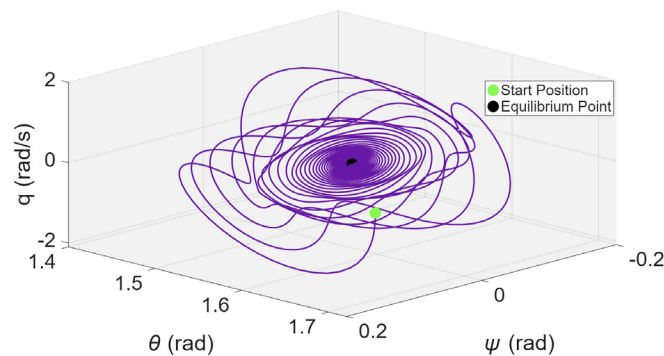


Figure 37. Coning motion with pitching rate.

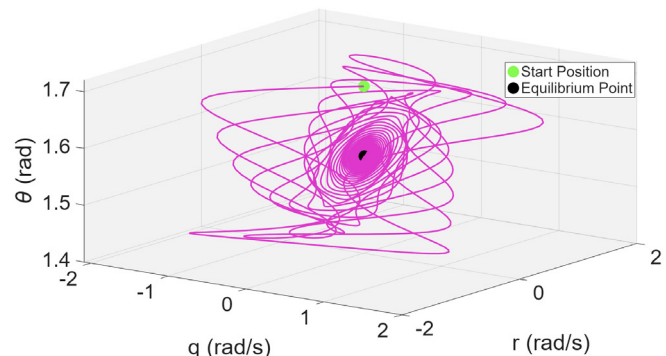


Figure 38. Angular rates with pitch attitude.

By considering the varying degrees of freedom covered in this article, **Table 1** is constructed, which highlights the level of passive stability considered by the oscillator produced by each model's stability subsystem.

Degrees of Freedom	Stability Oscillator	Results
2	$\theta'' + c\theta' = 0$	Damping only
3	$\theta'' + c\theta' + k(\theta - \gamma) = 0$	Stiffness and damping
4	$z'' + (c + i\Omega)z' + kz = 0$	Force averaging and coning

Table 1. Each oscillator derived and results of each model's stability subsystem.

CONCLUSIONS

The three degree of freedom model is necessary and sufficient for bidirectionally coupling rocket trajectory with stability. This model requires a minimum of six ordinary differential equations, and calculates copious amounts of data about a single rocket launch. Application of this model in MATLAB results in an accurate rocket simulator, justifying the massive leap in simplicity with physics and hand-solved solutions. The ability to track such results is expected of a 3DOF simulator, however the ability to view phase portraits of pitch stability at any snapshot in the rocket's travel is a special point of view unique to this article.

The four degree of freedom model has the potential to surpass rocket simulators currently available to the public in terms of simplicity and ease of understanding. Utilizing Euler's Equations of Motion to couple rotation about pitch with yaw is both novel and unique for this application - roll rate can not only be parameterized in such a model, but solved for as well. The important result of **Theorem 4** means rockets that may have had force biases in perturbation in other simulators, can be experimented with force averaging by adjusting roll rate in this article's 4DOF model.

Four degree of freedom rigid body models are most commonly used in vehicles with limited degrees of freedom, such as cars and boats. Applied to rockets, the axisymmetric condition removes the need to track two degrees of freedom each of horizontal translation and rotation, common for missiles and projectiles. A 5DOF model has since been implemented and coded in MATLAB by including translation along z^B , resulting in a three-dimensional picture of trajectory. Removing the axisymmetric assumption allows for a full rigid-body 6DOF model, which was completed in June of 2026, and a second research article has been written and submitted for publication consideration all about 6DOF considerations. Applications of these models can easily be applied to ballistics and other similarly-shaped flying bodies for smaller modeling examples.

ACKNOWLEDGEMENTS

The UNF Mathematics Department has been a massive resource in writing this article, in addition to both the UNF Physics and Engineering Departments. My capstone mentor, Dr. Mohammad Mahbubur Rahman, has provided invaluable insight into the world of mathematical modeling, harmonic oscillators, and dynamical systems - I thank him greatly for his time and devotion to my research project. Finally, I thank my beautiful fiancée Sophie, who has supported me fully throughout this research.

REFERENCES

1. Sounding Rockets User Handbook, NASA Goddard Space Flight Center & Wallops Flight Facility, <https://sites.wff.nasa.gov/code810/files/SRHB.pdf> (accessed Jan 2026)
2. Aliyu, Bhar Kisabo; Aliyu, Funmilayo Adebimpe; Odooh, Clement Okwo; Sholiyi, Olusegun Samuel (2019) A State-Space Modeling of a Rocket for Optimal Control System Design, *Journal of Aircraft Space and Technology* Volume 3 No. 1, 2019, 128-137, <https://doi.org/10.3844/jastsp.2019.128.137>
3. F. Mingireanu, L. Georegescu, G. Murariu, and I. Mocanu (2013) Trajectory Modeling of Grad Rocket with Low-Cost Terminal Guidance Upgrade Coupled to Range Increase Through Step-Like Thrust-Curves, *Rom. Journ. Phys.*, Vol. 59, Nos. 3-4, P. 369-381, Bucharest, 2014, https://rjp.nipne.ro/2014_59_3-4/RomJPhys.59.p369.pdf

4. RASAeroII, Rocket Aerodynamic Analysis and Flight Simulation Software, Version 1.0.2.0, <https://rasaero.com/> (accessed Jan 2026)
5. J. D. Anderson and O. Biblarz (1989) Standard Atmosphere, Air Foils, Wings, and Other Dynamic Shapes, and Principles of Stability and Control, in *Introduction to Flight* 3rd ed., 69–82, 178–255, 357–408, McGraw Hill.
6. Cadamuro, R., Cazzola, M.T., Lontani, N., Riboldi, C.E.D. (2024) A Static Stability Analysis Method for Passively Stabilized Sounding Rockets, *MDPI* 11, 242. <https://doi.org/10.3390/aerospace11030242>
7. G. P. Sutton and O. Biblarz (2001), Definitions and Fundamentals, in *Rocket Propulsion Elements* 7th ed., 27–44, John Wiley & Sons.
8. D. J. Inman (2014), Introduction to Vibration and the Free Response, and Multiple Degree of Freedom Systems, in *Engineering Vibrations* 4th ed., 1–116, 303–433, Pearson.
9. Bartik, J. A. (2026, 2-21) *A Mathematical Model for Coupling Rocket Trajectory with Passive Stability*. 59th Annual Joint Florida MAA / FTYCMA Conference, SCF Brandenton, FL.
10. Bartik, J. A. (2026, 4-18) *Redefining Rocket Science, Part 1: Mathematical Models for the Minimal Coupling of Trajectory and Stability*. 4th Annual UNF Osprey Mathematics Conference, Jacksonville, FL.
11. Bartik, J. A. (2026, 4-18) *Redefining Rocket Science, Part 2: Roll-Induced Averaging and the Emergence of High-Fidelity Dynamics*. 4th Annual UNF Osprey Mathematics Conference, Jacksonville, FL.

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PRESS SUMMARY

What's the simplest way to understand how a rocket stays stable as it blasts off into space? In the world of aerospace engineering, state-of-the-art simulators use expensive math models to track every aspect of rocket motion. They're powerful, but cost time and power, and they're impossible to understand without high-end equipment and proper security clearance. This article starts with the simplest model possible, building layer by layer until the essential physics behind rocket stability reveal themselves. Finally, just enough detail is added to capture oscillations and include spin. Something incredible comes of this: a rocket's "wobble" can be understood as a beautifully structured spiral motion - a harmonic oscillator governed by aerodynamics and spin. This article proves you don't need a massive computer to simulate rocket stability. With the *right* minimal model, the physics behind rocket dynamics becomes clear, intuitive, and beautiful!

A Comparative Study of MBTI- and Learning Style–Based Grouping for Enhancing Group Effectiveness and Balance in Problem-Based Learning

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<https://doi.org/10.33697/ajur.2026.183>

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ABSTRACT

Problem-Based Learning (PBL) depends on effective collaboration, yet the optimal strategy for forming student groups remains unclear. This study compared two group formation approaches: heterogeneous groups based on the Myers–Briggs Type Indicator (MBTI) and homogeneous groups based on the Active Experimentation–Reflective Observation dimension of Kolb's Learning Style Inventory (LSI). Undergraduate students enrolled in Cell Biology and Introduction to Biology Laboratory courses were assigned to one of the two grouping strategies. Group functioning and role performance were evaluated using end-of-course surveys, and outcomes were compared using independent-samples *t*-tests and Pearson correlation analyses. Students in LSI-based groups reported significantly higher listening, productivity, psychological safety, belonging, satisfaction, and leader and communicator role performance than those in MBTI-based groups, whereas contribution and organizer performance did not differ significantly. Correlation analyses showed that satisfaction was most strongly associated with productivity in MBTI-based groups but with psychological safety in LSI-based groups. These findings suggest that grouping students according to learning style may better promote effective collaboration and positive group experiences than personality-based grouping in undergraduate PBL settings.

KEYWORDS

Myers-Briggs Type Indicator; Kolb's Learning Style Inventory; Group Dynamics; Problem-Based Learning; Group Productivity; Group Satisfaction; Classroom Learning; Group Roles; Educational Outcome

INTRODUCTION

Over the past five decades, the aims of higher education have shifted from a traditional emphasis on knowledge for its own sake to a more pragmatic focus on career readiness and the development of transferable skills.¹As universities expand curricula to span disciplines and align with workforce needs, they increasingly prioritize competencies such as communication, critical thinking, collaboration and adaptability.²This evolution reflects broader societal changes such as economic pressures, technological advances, and rising expectations that higher education should contribute directly to employability. Consequently, universities are reimagining their role as launchpads for professional success, alongside their core mission of learning.^{1,4}

In today's educational settings, group-based learning has gained prominence, particularly through approaches such as Problem-Based Learning (PBL). A persistent challenge, however, is forming balanced and effective groups that leverage individual members' strengths. A balanced and effective group is one in which the composition and interaction of the group members allow for the achievement of the group goals, frequently oriented towards problem solving. Personality types (e.g., Myers-Briggs Type Indicator- MBTI) and learning styles (e.g., Kolb's learning styles) are two widely studied frameworks that offer insight into how individuals interact, process information, and contribute to group work.^{5,6}

PBL is an instructional approach in which students work in small groups to investigate and solve open-ended, real-world problems, developing content knowledge alongside skills in critical thinking, collaboration and self-directed learning. Originally developed for medical education, PBL has since been adopted broadly across the sciences and health professions because it mirrors the collaborative, problem-solving demands of professional practice.⁷Because PBL depends on sustained small-group work rather than individual study, the way groups are composed is not incidental to the method. Instead, it is one of the central design decisions an instructor makes, and it shapes whether the group ultimately functions as a cohesive team or as a collection of individuals working in parallel.⁸

MBTI- based grouping in collaborative and PBL settings

The MBTI, developed by Isabel Briggs Myers and Katharine Cook Briggs, sorts respondents into one of 16 types based on four dichotomous preferences: Extraversion/Introversion, Sensing/Intuition, Thinking/Feeling, and Judging/Perceiving. In educational contexts, MBTI has been used to anticipate group dynamics. For example, ‘extraverted’ types are described as more comfortable in discussion-heavy settings, ‘thinking’ types as oriented toward logic-driven problem-solving, and ‘judging’ types as preferring structured, deadline-driven work.⁹

A smaller number of studies have directly tested whether MBTI-informed group composition improves outcomes in problem- or project-based settings. Related work, however, has approached this question observationally rather than through deliberate group assignment. For instance, a 2017 study by Ihm, An, and Seo examined 263 first-year dental students at Seoul National University who were randomly assigned into 11 small groups of up to eight students plus a facilitator, with MBTI types collected before PBL began and performance measured across four assessment components. The sample skewed toward extraverts (58.9%), sensors (66.5%), thinkers (74.5%), and judgers (63.9%), and females outperformed males on total PBL scores. Rather than manipulating group composition, the researchers used the Shannon diversity index to measure the MBTI heterogeneity that emerged naturally within each randomly formed group, and found that more diverse groups tended to perform better overall and specifically on facilitator evaluations (reflecting problem-solving ability), with the highest-performing groups clustered around ENTJ, ISTJ, and ESTJ profiles.¹⁰ This study offers useful groundwork by suggesting a link between personality diversity and PBL performance, but because groups were randomly assigned rather than deliberately composed by MBTI, it stops short of testing MBTI-informed grouping as an intervention. This gap is representative of the broader literature: most studies have evaluated MBTI-based diversity in isolation, whether through observation or intervention, rather than benchmarking it against an alternative composition framework, leaving open the question of whether MBTI's apparent benefits are specific to personality-based grouping or would appear with any structured, non-random composition strategy.

LSI- based grouping in collaborative and PBL settings

In 1984, several years after MBTI was created, David A. Kolb introduced his Experiential Learning Theory (ELT), inspired by the work of the gestalt psychologist Kurt Lewin, as well as John Dewey and Jean Piaget. ELT articulates a four-stage learning cycle (Concrete Experience, Reflective Observation, Abstract Conceptualization, Active Experimentation) and four corresponding learning styles. ELT emphasizes that individuals favor different modalities of learning and that teaching approaches should accommodate these variations to enhance engagement and learning outcomes. Within this model, the Active Experimentation–Reflective Observation (AE–RO) dimension speaks most directly to how a student behaves in a group: AE-oriented students tend to learn by doing and engaging immediately, while RO-oriented students tend to hold back to observe and process before contributing.¹¹

Prior work on learning-style-based grouping has generally examined *homogeneous* composition, which is grouping students by shared style, but without directly testing it against a mixed-style alternative. For instance, a 2012 study by Alghasham examined 75 first-year medical students at Qassim College of Medicine, identifying each student's learning style using Active-Reflective inventory (40% active, 60% reflective) and sorting them into nine PBL tutorial groups segregated by style (four active-only, five reflective-only) rather than mixed. Blinded tutors rated student behavior over five weekly PBL sessions across four domains: independent study, teamwork, reasoning/problem-solving, and active participation. Active learners were more collaborative, participative, and skilled at hypothesis generation, while reflective learners relied more on independent study, careful listening, and prior knowledge. However, these behavioral differences did not carry over to formative quiz scores, which showed no consistent advantage for either group. Notably, although the study design was homogeneous, the author concluded (without direct empirical comparison) that PBL groups should instead be intentionally mixed by learning style to balance these complementary strengths, a recommendation that itself remains untested against an actual mixed-group condition.¹²

Differentiating the Two Frameworks and Limitations of MBTI

Although MBTI and Kolb's ELT are often discussed together as personality/learning-style tools for group design, they are conceptually distinct in ways that matter for interpreting grouping outcomes. MBTI is a typological model: it sorts individuals into discrete categories along four independent preference dichotomies and is primarily descriptive of general behavioral and interpersonal tendencies. Kolb's model, by contrast, is dimensional and situates learners along two continuous axes (CE–AC and AE–RO) that describe how information is processed and acted upon, making it more directly tied to how a student engages with a specific task or activity rather than personality broadly.

This distinction matters because MBTI has been the subject of longstanding methodological criticism as a research and measurement instrument. Concerns raised in the psychometric literature include low test-retest reliability, with a substantial proportion of respondents receiving a different type classification on retesting weeks later; the forced dichotomization of what are more plausibly continuous traits into binary categories, which discards meaningful variance; and weak evidence for the

instrument's predictive validity relative to dimensional models such as the Five-Factor Model (Big Five), which is more consistently supported in personality research.^{13,14} Because MBTI's dichotomous types can obscure meaningful within-group variability, an MBTI-based classification such as the Keirsey temperament framework used in the present study necessarily treats individuals near a dichotomy's midpoint the same as individuals with a strong preference, a limitation worth bearing in mind when interpreting group-level outcomes tied to temperament category.¹⁵ Kolb's Learning Style Inventory (LSI) has also drawn validity criticism, though generally less severe, including questions about the stability of style classification across contexts and the extent to which self-reported style predicts actual behavior in group settings.¹⁶

METHODS AND PROCEDURES

Participants

Participants of this study were undergraduate students at the University of Wisconsin- Superior enrolled in Cell Biology (Fall 2022, Fall 2023) and Introduction to Biology Laboratory (Fall 2023, Section 001 and 002). Students were invited to participate in this study of the first day of each course. The invitation informed the students that (a) the course would involve substantial small group work regardless of study participation, (b) participation in the research study (completion of assessment and evaluation survey) was voluntary, and (c) participation, or the specific group/role a student was assigned to, would not affect course grades. Each course was assigned, in its entirety, to one grouping condition (MBTI- based or LSI- based); no course section contained a mixture of both conditions. Condition assignments by course section, semester, and enrollment size is reported in the Results Section (Demographics of Participants), see **Table 4**. It is also important to note that both the Fall 2022 and Fall 2023 Cell Biology course was instructed by the same instructor and followed the same learning curriculum and assignments to maintain consistency between these two sections.

Assessments

All participating students completed a Student Information Survey and either of the two validated self- report assessments prior to group formation. The Student Information Survey asked students to report their goals for the course, self- perceived strength and weaknesses relevant to group coursework, prior experience working in small groups, and a preferred group role (Leader, Communicator, or Organizer). Students then completed the assigned self- assessment for their said course, either the online MBTI assessment, or the LSI.

Group Formation and Role Determination: MBTI Based Groups

MBTI-based groups were formed using the Keirsey Temperament Sorter, a framework that organizes the 16 MBTI types into four broader temperaments, see **Table 1**.

Temperament	Defining Dichotomies	MBTI Types Included
Guardian	Sensing + Judging (SJ)	ISTJ, ISFJ, ESTJ, ESFJ
Artisan	Sensing + Perceiving (SP)	ISTP, ISFP, ESTP, ESFP
Idealist	Intuitive + Feeling (NF)	INFJ, INFP, ENFJ, ENFP
Rational	Intuitive + Thinking (NT)	INTJ, INTP, ENTJ, ENTP

Table 1: Full mapping of the 16 MBTI types to the four Keirsey temperaments used for group stratification.¹⁵

Keirsey’s framework splits Sensing (S) types by their Judging/Perceiving preference (Guardian vs. Artisan) because, within Sensing types, this dichotomy most strongly differentiates preference for structure versus spontaneity. It splits Intuitive (N) types by their Feeling/Thinking preference (Idealist vs. Rational) because, within Intuitive types, this dichotomy most strongly differentiates value-driven versus logic-driven orientation. This is why the four temperaments are defined by different letter pairs (SJ/SP for Sensing types, NF/NT for Intuitive types) rather than a single consistent dichotomy across all four groups.

Each student was first classified into one of the four temperaments using **Table 1**. Groups were then formed using a stratified-composition strategy intended to maximize temperament diversity within each group. Groups were typically three members: for a three-member group, any three of the four temperaments (Guardian, Artisan, Idealist, Rational) could be represented, giving flexibility in which three temperaments were combined depending on section composition. A smaller number of groups had four members; in these cases, all four temperaments were represented once each, except when a section's temperament distribution made this impossible, in which case the most abundant temperament in that section was doubled up. No group contained more than one representative of the same temperament except under this doubling rule.

Within each temperament-stratified group, students were assigned one of three functional roles (Leader, Communicator, Organizer) based on their specific MBTI type, following the mapping in **Table 2** (below), such that each group had exactly one Leader, one Communicators, and one or two Organizers.

GROUP ROLE	MBTI TYPES	RATIONALE
Leaders	ENTJ, ESTJ, ENFJ, ESTP, ENTP	These types are natural at setting direction and structure, motivating others, and ensuring progress by keeping the group accountable to timelines and goals
Communicators	ENFP, ESFP, ESFJ, INFP, INFJ	These types excel at connecting with others, expressing group ideas clearly, and serving as bridges between the team and external stakeholders
Organizers	INTJ, INTP, ISTJ, ISFJ, ISTP, ISFP	These types thrive in analyzing details, refining outputs, and ensuring the final product is both accurate and high-quality, keeping the project grounded and complete.

Table 2. MBTI-to-role mapping used for functional role assignment within MBTI-based groups.

Because a temperament-stratified group could contain more than one student whose MBTI type mapped to the same functional role (most commonly among Organizer-eligible types, since six of the sixteen types map to that role), the role-preference item from the Student Information Survey was used as a tiebreaker: when two eligible students in the same group mapped to the same role, the student who had indicated that role as a preference was assigned to it, and the other was assigned the next-best-fitting available role. Following group formation and role determination, each student was emailed to notify them of the role they were assigned, a detailed explanation as to how their personality assessment contributed to the role assigned, and the expectation of their role in their group (**Table 3**).

GROUP ROLE	EXPECTATIONS
Leaders	Establish a clear timeline and plan for all the group activities, responsible for establishing deadline for the final project (human bio course only), Ensuring the work is evenly distributed and everyone in the group is participating in and contributing to the group activity, Ensures the group stays on task and the assignment is being completed in a timely manner.
Communicators	Serves as a group spokesperson checking in with the instructor when clarification is needed, submitting group assignments and participating on behalf of the group on class discussion boards.
Organizers	Quality control and finalization, overseeing the finalization of the infographic (human bio only), reviewing the content, design and overall quality of all the assignments the group is submitting. Contribute new ideas and perspectives to the group.

Table 3. Group roles and expectations in a PBL setting: Leaders (planning, deadlines, and accountability), Communicators (spokesperson and assignment submission), and Organizers (quality control, finalization, and idea contribution).

Group Formation and Role Determination: LSI Based Groups

For the purposes of this study, LSI group formation used only the Active Experimentation (AE)–Reflective Observation (RO) dimension of Kolb's Learning Style Inventory. Students scoring higher on Active Experimentation were classified as active learners, whereas those scoring higher on Reflective Observation were classified as reflective learners. Every participant received a score on this dimension and was therefore classified into one of these two categories. Although the Concrete Experience (CE)–Abstract Conceptualization (AC) dimension was also measured, it was not used for group formation. The AE–RO dimension was selected because it most directly reflects how students engage in collaborative learning tasks, including their preferred level of participation, discussion style, and approach to problem solving within a group. In contrast, the CE–AC dimension primarily describes how learners perceive and process information internally rather than how they interact with peers during collaborative activities. Because the primary outcomes of this study focused on group dynamics, communication, productivity, and role fulfillment, the AE–RO dimension was considered the most relevant dimension for forming groups.¹⁷

LSI based groups were formed homogeneously with respect to the AE/RO classification described above: students classified as active learners were grouped only with other active learners, and students classified as reflective learners were grouped only with other reflective learners. No group contained a mixture of active and reflective learners. Group size was matched to the MBTI condition (three to four students per group) wherever enrollment allowed.

Roles within LSI based groups were assigned directly from the role-preference item on the Student Information Survey: students were grouped with same-style peers whose stated role preferences (Leader, Communicator, Organizer) were non-overlapping, so that each group again contained one Leader, one Communicator, and one to two Organizers.

Rationale for the Composition Strategy and a Note on Design Symmetry

The two grouping conditions in this study were composed using different strategies: MBTI-based groups were formed heterogeneously (stratified across temperaments), while LSI-based groups were formed homogeneously (matched on learning style). This asymmetry was a deliberate feature of the original study design, not an oversight, and is described here explicitly so that it can be evaluated on its merits.

The heterogeneous, one-member-per-temperament structure used for MBTI groups follows a composition convention commonly recommended in Keirsey/MBTI-based team-building guidance, which favors temperament diversity within a team to ensure coverage of different behavioral and functional strengths. We want to be precise about what this citation does and does not support: it describes a widely used team-formation heuristic, not a controlled study demonstrating that heterogeneous Keirsey-based grouping produces superior PBL performance outcomes relative to homogeneous grouping.¹⁸ We are not aware of a published study that makes that specific comparison, and we have not represented the heterogeneous approach as empirically validated for that purpose.

The homogeneous structure used for LSI based groups was informed by prior, unpublished classroom observations by the research team, which suggested that groups mixing students with markedly different learning paces or engagement styles experienced more friction and lower performance than groups of students with similar learning approaches. Because this observation had not been formally tested, one aim of the present study was to evaluate it empirically by contrasting a heterogeneous, personality-based composition strategy against a homogeneous, learning-style-based one.

We note explicitly that this design choice confounds framework (MBTI vs. Kolb learning style) with composition strategy (heterogeneous vs. homogeneous): differences observed between the MBTI and LSI conditions in this study cannot be attributed solely to the underlying psychological framework, since they may instead (or additionally) reflect the composition strategy paired with each framework. This limitation, and the factorial design (Homogeneous MBTI, Heterogeneous MBTI, Homogeneous LSI, Heterogeneous LSI) that would be required to separate these two variables, is discussed further in the Discussion and Limitations sections.

Group Evaluation

Across the course, students engaged in collaborative activities including online discussions and PBL assignments. Students in Cell Biology completed exam wrappers at the end of each structured course unit; each wrapper included 10 Likert-scale items (1 = Strongly Disagree, 5 = Strongly Agree) assessing group functioning (e.g., “I believe the group worked well together to accomplish the project”). All students in all courses additionally completed a course wrapper at the end of the semester, which included the same 10 Likert-scale group-functioning items plus three additional Likert-scale items assessing performance in each students’ assigned role (Leader, Communicator, or Organizer). These wrapper responses were the source of all group performance, satisfaction, and role-performance data reported in the Results.

Data Analysis

SPSS and Microsoft Excel were used for all analyses. Independent-samples t-tests were used to compare mean scores between MBTI-based and LSI-based groups on each group-performance metric (listening, productivity, sense of safety, belonging, satisfaction, contribution) and on each role-performance rating (Leader, Communicator, Organizer). Pearson correlation coefficients were computed to assess relationships among group-level variables (e.g., satisfaction, productivity, psychological safety) separately within each grouping condition, using data from the two Cell Biology cohorts (fall 2022 LSI based, fall 2023 MBTI based). Statistical significance was set at $\alpha = 0.05$ for all tests.

IRB Permissions’ number

All study procedures involving human participants were reviewed and approved by the University of Wisconsin–Superior Institutional Review Board (IRB approval number E159).

RESULTS

Demographic of Participants.

Table 4 summarizes enrollment, grouping condition, and Keirsey temperament distribution by course section.

Course / Semester	N	Condition	Guardian	Artisan	Idealist	Rational
Cell Biology, Fall 2022	15	LSI (homogeneous)	—	—	—	—
Cell Biology, Fall 2023	21	MBTI (heterogeneous)	9	0	6	6
Biology Lab, Sec. 1, Fall 2023	18	MBTI (heterogeneous)	5	3	7	3
Biology Lab, Sec. 2, Fall 2023	16	LSI (homogeneous)	—	—	—	—

Table 4. Enrollment and Keirsey temperament distribution by course section and grouping condition. Dashes indicate sections assigned to the LSI based condition, for which temperament was not used for grouping.

Group Performance Metrics

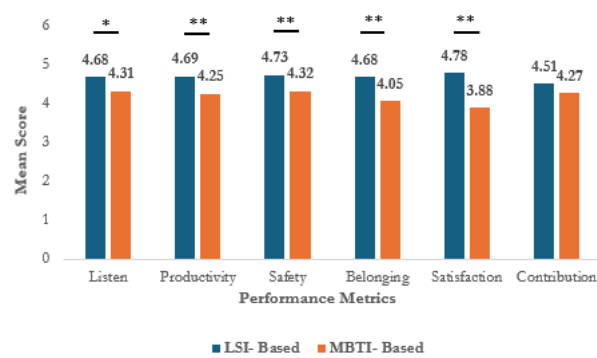


Figure 1. Comparison of Mean performance metrics between MBTI- based and LSI- based grouping strategies. The bar chart shows the mean scores for listening, productivity, sense of safety, belonging, satisfaction and contribution for students in Cell Biology 2023 (MBTI- based groups) and Cell Biology 2022 (LSI- based groups). Asterisk indicates statistically significant differences between group strategies (* $p < 0.05$). All metrics showed significant decreases in the MBTI-based cohort except for contribution.

Figure 1 compares mean scores for listening, productivity, sense of safety, belonging, satisfaction, and contribution between the MBTI-based cohort (Cell Biology, fall 2023) and the LSI-based cohort (Cell Biology, fall 2022). Mean scores were lower in the MBTI-based cohort on every metric, reaching statistical significance for all metrics except contribution. The largest differences were observed for belonging (MBTI: 4.68 vs. LSI: 4.05, t -test $p = 0.0003$) and satisfaction (MBTI: 4.78 vs. LSI: 3.88, $p < 0.0001$). Contribution did not differ significantly between cohorts (MBTI: 4.51 vs. LSI: 4.27, $p = 0.13$), despite a numerically lower mean in the MBTI-based group.

Role Fulfillment and Performance by Group Type

Role-performance ratings (self- and peer-assessed, 0–3 scale, where 0 = “never participated” and 3 = “exceeds expectations”) were compared between conditions for each functional role using independent-samples t -tests. Students in LSB groups scored significantly higher than students in MBTI groups in the Leader role ($t = 4.21$, $p < 0.001$) and the Communicator role ($t = 3.87$, $p = 0.002$). No significant difference between conditions was observed for the Organizer role ($t = 0.45$, $p = 0.66$).

Correlations Between Group Variables

Using data from the two Cell Biology cohorts (LSI, fall 2022, $N = 15$; MBTI, fall 2023, $N = 21$), Pearson correlations were computed separately within each condition among group satisfaction, productivity, and psychological safety (“safe-to-share”). Within MBTI-based groups, satisfaction was most strongly correlated with perceived productivity. Within LSI-based groups, satisfaction was most strongly correlated with psychological safety (safe-to-share) rather than productivity. Full correlation coefficients are reported in **Table 5**.

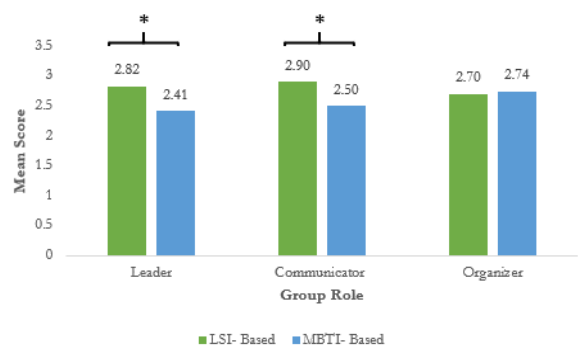


Figure 2. Role performance ratings by group type. Students in Biology Lab course, rated themselves and their group members on a 0–3 scale. Mean scores were compared between MBTI-based and LSB groups using independent, pairwise t-tests for each role. LSB groups scored significantly higher in the Leader ($t = 4.21$, $p < 0.001$) and Communicator ($t = 3.87$, $p = 0.002$) roles. No significant difference was observed for the Organizer role ($t = 0.45$, $p = 0.66$). Asterisks on the figure indicate statistically significant differences between group types.

Variable	Contribution	Listen	Productivity	Safe to Share	Belonging	Satisfaction
LSI- Based						
Satisfaction	0.576*	0.732**	0.648**	0.750**	0.756**	---
Productivity	0.606*	0.906**	---	0.933**	0.843**	0.648**
Safe to Share	0.512	0.911**	0.933**	---	0.954*	0.750**
MBTI- Based						
Satisfaction	0.387	0.644**	0.568**	0.523**	0.739**	---
Productivity	0.362	0.593**	---	0.560**	0.510**	0.568**
Safe to Share	0.511*	0.678**	0.560**	---	0.708**	0.523**

Table

5. Correlation among group variables for LSI- based and MBTI-based groups. Shown are Pearson correlation coefficients between group satisfaction, productivity, and perceived safety to share opinions (Safe-to-Share) and the variables contribution, listening, productivity, safety, belonging, and satisfaction for two group types: Learning Style–Based (LSB) groups ($N = 15$; Fall 2022) and MBTI-Based groups ($N = 21$; Fall 2023) from a Cell Biology course. Correlation analyses were conducted using SPSS. Diagonal entries (---) indicate self-correlations. Asterisks denote statistical significance of the correlations ($*p < 0.05$; $**p < 0.01$)

DISCUSSION AND LIMITATIONS

The primary aim of this study was to compare MBTI-based and LSI-based grouping frameworks to determine which more effectively enhanced performance metrics and role fulfillment in PBL environments. Across two course contexts: Cell Biology and Introduction to Biology Laboratory; LSI -based grouping consistently outperformed MBTI-based grouping on key performance metrics. In particular, **Figure 1** demonstrates that students in MBTI-based groups (Cell Biology 2023) reported lower scores across nearly all performance metrics of group functioning compared to students in LSB groups (Cell Biology 2022), including listening, productivity, sense of safety, belonging, and overall satisfaction. Contribution was the only metric that did not differ significantly between grouping strategies, suggesting a selective rather than uniform impact of grouping approach on student experiences.

LSI-based groups demonstrated significantly higher productivity scores in both Cell Biology and Biology Lab courses, reinforcing the idea that grouping students according to shared learning processes (e.g., active vs. reflective) may reduce friction in task execution and pacing. The additional findings related to listening and sense of safety further support this interpretation. Groups formed based on learning style alignment may facilitate more predictable communication patterns and mutual responsiveness, enabling students to feel heard and comfortable sharing ideas. In contrast, MBTI-based grouping, which intentionally promotes personality heterogeneity, may introduce variability in communication preferences and decision-making styles that complicate coordination, particularly in time-limited or task-intensive PBL settings.

Group satisfaction and belonging exhibited the largest and most robust differences between grouping strategies, with MBTI-based groups reporting markedly lower scores in both domains. These findings suggest that beyond task efficiency, learning-style homogeneity may play a critical role in fostering social cohesion and inclusion within small-group learning environments. Importantly, the absence of a significant difference in contribution indicates that students in MBTI-based groups did not perceive themselves as contributing less, despite experiencing lower satisfaction and weaker group climate.

Role performance analyses further clarify how grouping strategies shape group processes. As seen in **Figure 2**, Students in LSI-based groups scored significantly higher in Leader and Communicator roles, while no significant differences were observed for the Organizer role. Leadership and communication are inherently interactive and depend on shared expectations, pacing, and responsiveness. Learning-style similarity may facilitate smoother leadership emergence and clearer communication norms, whereas heterogeneous personality groupings may require greater negotiation and adaptation. The stability of the Organizer role across grouping conditions suggests that detail-oriented or task-structuring responsibilities may be less sensitive to group composition and more dependent on individual traits or clearly defined task demands.

Correlation analyses provide additional insight into the mechanisms underlying these differences. As seen in **Table 5**, In MBTI-based groups, satisfaction was strongly correlated with perceived productivity, suggesting that these groups may be particularly sensitive to affective dynamics: when interpersonal functioning declines, productivity may be disproportionately affected. In contrast, LSI-based groups exhibited stronger associations between satisfaction and psychological safety, indicating that learning-style alignment may foster environments in which students feel comfortable expressing ideas, asking questions, and engaging in constructive disagreement. Sense of safety has been widely identified as a key predictor of effective teamwork and learning, particularly in collaborative educational contexts.

While MBTI-based grouping offers a structured framework for role differentiation and exposure to interpersonal diversity, the present findings suggest that learning style alignment may be a more robust predictor of effective group functioning in PBL settings. LSI-based grouping more directly supports productivity, satisfaction, and positive group climate. Importantly, these results do not imply that MBTI is pedagogically ineffective, but rather that its strengths may not align optimally with performance-driven PBL outcomes.

This study has several limitations. Sample sizes were modest and drawn from a single institution, limiting generalizability. The Cell Biology grouping conditions were implemented across different semesters rather than within the same cohort, introducing potential cohort effects. Additionally, outcome measures relied on self-reported Likert-scale instruments, which may be subject to response bias. Future studies should incorporate larger, multi-institutional samples, randomized within-cohort designs, and objective performance measures to further clarify how grouping strategies influence learning outcomes.

CONCLUSIONS

This study demonstrated that LSI-based grouping, grounded in Kolb's ELT, is more effective than MBTI-based grouping in promoting group productivity, satisfaction, and role fulfillment in undergraduate PBL settings. While MBTI-based groups showed meaningful internal correlations between satisfaction and productivity, they consistently underperformed relative to LSI-based groups on primary outcome measures. These findings suggest that how students learn may be more consequential for group effectiveness than how they interact personality-wise. For instructors designing collaborative learning environments, particularly in science courses that rely heavily on teamwork, grouping students by learning style may offer a practical and evidence-based strategy for enhancing both performance and student experience.

ACKNOWLEDGEMENTS

We thank all the students who participated in the surveys for their time and contributions to this study. We also acknowledge the Undergraduate Research Student-Centered Activities (URSCA) program at the University of Wisconsin–Superior for funding this research. Additionally, we appreciate the support of course instructors and teaching staff who facilitated participant access and assisted with logistical aspects of data collection.

REFERENCES

1. Teichler, U. (1999) Higher education policy and the world of work: changing conditions and challenges, *High. Educ. Policy* 12, 285–312. [https://doi.org/10.1016/S0952-8733\(99\)00019-7](https://doi.org/10.1016/S0952-8733(99)00019-7)
2. Pandya, B., Ruhi, U., and Patterson, L. (2023) Preparing the future workforce for 2030: the role of higher education institutions, *Front. Educ.* 8, 1295249. <https://doi.org/10.3389/feduc.2023.1295249>
3. Suleman, F. (2021) Revisiting the concept of employability through economic theories: Contributions, limitations and policy implications. *Higher Education Quarterly*, 75(4), 548–561. <https://doi.org/10.1111/bequ.12320>

4. Hooley, T.J., Bennett, D. & Knight, E.B. Rationalities that underpin employability provision in higher education across eight countries. *High Educ* 86, 1003–1023 (2023) <https://doi.org/10.1007/s10734-022-00957-y>
5. Rodríguez Montequín, V., Mesa Fernández, J.M., Balsera, J.V. *et al.* Using MBTI for the success assessment of engineering teams in project-based learning. *Int J Technol Des Educ* 23, 1127–1146 (2013) <https://doi.org/10.1007/s10798-012-9229-1>
6. Kyprianidou, M., Demetriadis, S., Tsiatsos, T. *et al.* Group formation based on learning styles: can it improve students' teamwork?. *Education Tech Research Dev* 60, 83–110 (2012) <https://doi.org/10.1007/s11423-011-9215-4>
7. Khoo, H.E. (2003), Implementation of problem-based learning in Asian medical schools and students' perceptions of their experience. *Medical Education*, 37: 401–409. <https://doi.org/10.1046/j.1365-2923.2003.01489.x>
8. Schmidt, H.G., Rotgans, J.I. and Yew, E.H. (2011), The process of problem-based learning: what works and why. *Medical Education*, 45: 792–806. <https://doi.org/10.1111/j.1365-2923.2011.04035.x>
9. Myers, I. B. (1962) *The myers-briggs type indicator* (Vol. 34). Palo Alto, CA: Consulting Psychologists Press.
10. Ihm, J., An, S. and Seo, D. (2017), Do Dental Students' Personality Types and Group Dynamics Affect Their Performance in Problem-Based Learning?. *Journal of Dental Education*, 81: 744–751. <https://doi.org/10.21815/JDE.017.015>
11. Kolb, D. A. (2007) *The Kolb learning style inventory*. Boston, MA: Hay Resources Direct.
12. Alghasham, A. A. (2012) Effect of students' learning styles on classroom performance in problem-based learning. *Medical teacher*, 34(sup1), S14–S19. <https://doi.org/10.3109/0142159X.2012.656744>
13. Boyle, G.J. (1995), Myers-Briggs Type Indicator (MBTI): Some Psychometric Limitations. *Australian Psychologist*, 30: 71–74. <https://doi.org/10.1111/j.1742-9544.1995.tb01750.x>
14. McCrae, R. R. (2009) The five-factor model of personality traits: Consensus and controversy. *The Cambridge handbook of personality psychology*, 148–161.
15. Keirsey, D. (1998) Please understand me II: Temperament, character, intelligence. (*No Title*).
16. Koob, J. J., & Funk, J. (2002) Kolb's learning style inventory: Issues of reliability and validity. *Research on social work practice*, 12(2), 293–308. <https://doi.org/10.1177/104973150201200206>
17. Kolb, A. Y., & Kolb, D. A. (2009) Experiential learning theory: A dynamic, holistic approach to management learning, education and development. *The SAGE handbook of management learning, education and development*, 7(2), 42–68.
18. Mazni, O., Syed-Abdullah, S. L., & Hussin, N. M. (2010, December) Analyzing personality types to predict team performance. In *2010 International Conference on Science and Social Research (CSSR 2010)* (pp. 624–628). IEEE. <https://doi.org/10.1109/CSSR.2010.5773856>

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PRESS SUMMARY

Group work is a cornerstone of many college science courses, yet how students are assigned to teams is often overlooked. In this study, we found that forming groups based on students' learning styles led to higher productivity, stronger leadership and communication, and greater overall satisfaction compared to grouping students by personality type using the Myers-Briggs Type Indicator (MBTI). Students in learning style-based groups reported feeling more comfortable sharing ideas and worked more efficiently together, while personality-based groups showed lower satisfaction and performance overall. These findings suggest that aligning how students learn may be more important than mixing personality types when designing effective collaborative learning experiences in higher education.

