School Science and Mathematics Association
Founded in 1901

Proceedings of the 124th Annual Convention of the School Science and Mathematics Association

Science for All: Fostering Inclusion, Innovation, & Unity in STEM Classrooms

Fort Worth, Texas
November 13–15, 2025

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PRESIDENT'S FORWARD

It is my great honor to welcome you to the 124th Annual Convention of the School Science and Mathematics Association (SSMA). Since its founding in 1901, SSMA has stood as a vibrant professional community committed to the integration of science and mathematics education through research, practice, and service. For more than a century, our members have championed excellence in teaching and learning, cultivated meaningful collaborations, and advanced scholarship that continues to shape classrooms, schools, and communities across the nation and beyond.

As we gather for this year's convention, we celebrate not only SSMA's strong history but also its continued evolution in response to the ever-changing landscape of STEM education. The challenges and opportunities of the 21st century call for educators who are prepared to engage students in authentic inquiry, foster connections between disciplines, and cultivate the habits of mind that support problem solving, reasoning, and creativity. SSMA members have long been at the forefront of this work—bridging theory and practice to create learning experiences that are rigorous, relevant, and responsive to the needs of all learners.

The presentations and papers in these proceedings reflect the depth and diversity of our community. They showcase innovative research, exemplary teaching, and emerging partnerships that embody SSMA's mission to promote research-based improvements in science and mathematics education. They also represent our ongoing commitment to inclusivity, collaboration, and professional growth—values that continue to sustain SSMA as a leading voice in the broader STEM education landscape.

As we meet in Fort Worth, Texas, we look ahead to our 125th anniversary with gratitude and anticipation. The legacy we inherit is one of perseverance, collegiality, and shared purpose. The future we build depends on our continued willingness to learn from one another, to question and refine our practices, and to imagine new possibilities for the next generation of teachers, learners, and researchers.

Thank you for contributing to this enduring community and for your continued support of SSMA's mission. May the ideas, insights, and relationships sparked during this convention renew your passion for teaching, deepen your scholarship, and inspire you to carry forward the work that has defined our organization for more than a century.

With appreciation,

Sandi Cooper
SSMA President (2024–2026)

PREFACE

These proceedings are a written record of some of the research and instructional innovations presented at the 124th Annual Convention of the School Science and Mathematics Association held November 13–15, in Fort Worth, TX. The blinded, peer-reviewed proceedings include nineteen papers regarding instructional innovations and research. The acceptance rate for the proceedings was 95%. We are pleased to present these Proceedings as an important resource for the mathematics, science, and STEM education community.

Katie Anderson-Pence & Amy Ray
Editors

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SECTION I: SCIENCE

STEM TEACHERS AS CURRICULUM DEVELOPERS: HOW TO INCLUDE THE CLASSROOM IN COMMUNITY SCIENCE

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Abstract

Community Science (CS) has the potential to be a transformative classroom practice that allows students to experience real-world scientific research while also improving their scientific literacy. However, CS curriculum typically is limited to students engaging in science research primarily as data collectors, leading to students not participating in activities such as data analysis and forming research questions. We aim to expand the one-day data collection event for the Dragonfly Mercury Project to improve the connection between the collaborating scientists and students as well as supporting teachers who are interested in incorporating CS into their curriculum.

Introduction

This program started when a professor from the science department in conjunction with the United States Geological Survey (USGS) asked us to help create a curriculum for the Dragonfly Mercury Project (DMP). DMP is a research project that aims to improve the scientific understanding of mercury (Hg) pollution risk through the combined efforts of scientists, National Park Services (NPS), and community members as data collectors. By collecting larval dragonflies, scientists can measure the Hg concentrations across various watersheds. Currently, the DMP is a one-day collection event that allows students, teachers, NPS, and bench scientists to collaborate in the field. To improve upon this one-day experience, we aim to create a curriculum that supports students' science identities, deepen their knowledge of the Nature of Science (NOS), and improve knowledge mobilization partnerships (KMP). By creating this curriculum, we hope to support teachers who are interested in ways of incorporating community science (CS) into their classrooms and making science careers a reality for their students.

CS engagement allows students to authentically participate in real-world scientific research, but the ability for teachers to incorporate CS experiences into their curriculum can be challenging for different reasons. Often, CS opportunities are initiated by scientists or outside organizations and offer little for participating teachers to contribute with how the curriculum is planned and developed (Atias et al., 2022; Solé et al., 2024). Teachers might also struggle with aligning scientists' goals for research with learning outcomes within the students' curriculum (Bopardikar et al., 2023). Our goal is to create a flexible curriculum that supports teachers' content and pedagogical knowledge needs in order to increase the likelihood of teachers participating in the DMP as part of their own curriculum. The curriculum, Dragonfly Mercury Project Elevated by Education (DMP+E^2), is geared towards middle school and uses the Next Generation Science Standards (NGSS). In these proceedings we elaborate on the decisions that were made while in the process of creating our curriculum.

Objectives and Purpose

Initially, the DMP+E^2 was meant to be written in conjunction with a proposed National Science Foundation grant wherein the participating teachers would contribute curriculum and implement it in their own classrooms. The grant would allow us to create professional development to support teachers' learning about CS curriculum and how it could support science content instruction and scientific literacy. Once teachers received professional development, they would create, then pilot the curriculum and document their modifications to the curriculum. However, feedback from the rejected grant proposed that having a premade curriculum for teachers to iterate on would be more beneficial to our intended goal: encouraging teachers to take ownership of their classroom and modify CS curriculum to fit their own classroom context. With this in mind, we set out to create lessons that would be taught either before or after the students experienced the one-day collection event.

Although the CS curriculum could apply to any age group, we wanted to narrow our focus to fit a middle school context for the first iteration of the DMP+E^2. When reading through the NGSS, the majority of standards that relate to the DMP could be found in the middle school age band. We felt that middle school teachers would be more likely to use the curriculum when compared to elementary teachers (fewer related standards) and high school teachers (siloed subjects having to be individually catered to). The use of the NGSS as the basis for curriculum standards allows us to make the curriculum accessible to a larger population of teachers rather than just focusing on standards we personally use (e.g., Texas Essential Knowledge and Skills). The curriculum itself would focus on connecting real world research experiences to scientific content, future careers paths that relate to the DMP, and building scientific literacy by explicitly connecting their real-world experiences to the Nature of Science (NOS).

Instructional Framework and Related Literature

CS, also known as citizen science, is a way to produce scientific knowledge while also incorporating the contribution of community members who are typically outside of the scientific community. For participating students, the development of scientific concepts (Roche et al., 2020) and the enactment of scientific practices such as inquiry and argumentation (Osborne, 2014) has the benefit of improving scientific literacy and critical thinking (Shah & Martinez, 2016). These higher order outcomes for science curriculum can be difficult to enact, particularly imparting the NOS. While the CS curriculum can be an excellent way to bring authentic scientific research experiences to students, there are some common issues with previous CS projects that include the classroom. Solé et al. (2024) conducted a literature review of schools participating in CS and found that many CS projects limited student engagement to just data collection. For CS projects to claim the community aspect of the research, community members need to have more agency "in as many stages in the scientific enterprise as possible" (Solé et al., 2024, p. 394). However, the establishment and maintenance of DMP can be challenging. For the DMP, the initial research question, establishment of research methods, and lab analysis are already set by the participating scientific community. The issue, as curriculum writers, was to authentically engage students beyond the one-day data collection event. Hadjichambis et al. (2023) recommend "more emphasis on active and social learning mechanisms… (e.g., interacting with others, using project documentation, creating and sharing personal artifacts)" (p. 82) when improving student CS experiences that rely on data collection as engagement.

The DMP+E^2 utilizes a phenomena-based approach that guided our creation of lesson plans to support the DMP's one-day data collection event. Symeonidis and Schwarz (2016) describe authentic phenomena to be "real-world themes" that are inherently multidisciplinary (p. 35). The authenticity of the phenomena is derived from selecting means of investigating and learning about the phenomena in similar ways that would happen in the real world (i.e., learning about pollution and watersheds through the collection of larval dragonflies rather than lecture). A deeper understanding of the phenomena and the science behind it "can be directly applied across borders between subjects and outside the classroom in situations where the information and skills are used (natural transfer)" (Silander, 2015, p. 17). This natural transfer, a real-world application of knowledge rather than just rote memorization, being an essential learning outcome when applying the NGSS. Additionally, the phenomena that drives the curriculum does not need to just be the one-day collection event. Rather, the event will act as an "anchoring phenomenon" that will be bolstered by related, everyday phenomena that support students' wonderings about mercury pollution, its impact on the environment, and how scientists can better understand how it is deposited across different watersheds (Achieve et al., 2017, p. 2).

Our goal with this CS curriculum is to increase the likelihood of teachers engaging with and supporting the DMP. A way to support teachers in implementing CS is to provide premade school materials and lesson plans that can be integrated into the school curricula (Kloetzer et al., 2021). Solé et al. (2024) noted that when establishing learning and scientific objectives for CS initiatives, potential learning objectives of inquiry, content knowledge, NOS, or improving students' attitudes towards STEM are often overshadowed by raising awareness regarding the research topic. While awareness of water pollution and conservation efforts are important, we seek to expand on students' experience of science in the classroom through authentic science research and learning experiences that are meaningful to the students. By connecting the experience of data collection to the overall scientific process (i.e., developing research questions and data analysis) (Scheuch et al., 2018), we aim to explicitly articulate the NOS and how science and science careers can influence communities. Using a phenomena-based instructional framework, the goal of the DMP+E^2 is to create a curriculum that not only supports the DMP but also aligns with NGSS's science and engineering practices and crosscutting concepts to explain real life phenomena. By integrating students' experiences of the DMP and providing opportunities to reflect and inquire about related phenomena, we seek to provide new contexts for students to apply their new scientific concepts and practices (Penuel et al., 2019).

Practice and Innovation

We started by looking at the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) and deciding what age group would benefit most from the DMP. After sifting through NGSS and the DMP concepts, we decided that there are more middle school concepts that could be addressed by this project.

Lesson Plan Template

After solidifying Middle School as our target audience, we needed to create a lesson plan template. Creating this template would ensure that all lessons are uniform in layout, content, resources, and accessibility. The lesson plan template that we used as a model was recycled from another project. We chose this as a model because it had most of the things we felt we needed (e.g., objective, teacher considerations, materials, and interdisciplinary standards) but also space for us to add more content as we saw fit. The template we used had the 5E model already set up. After some discussion we decided that this template was the model we wanted to use in our lesson plan. Along with the 5E we kept categories in the template that addressed the lesson topic, a lesson description, standards, the science and engineering practices, cross cutting concepts, objectives, materials needed, teacher knowledge required, vocabulary, career options, and a space for each of the 5E's. The parts that we felt needed to be added were cross-curricular connections and possible misconceptions.

Instructional Framework

After researching different instructional frameworks, we decided to create a phenomenon-based curriculum. The first decision that needed to be made in this step was how many lessons we needed to create and what the content of those lessons should entail. Once we decided what phenomenon we would use per lesson, we then narrowed down the lessons from thirteen to ten with each lesson having the potential to have a phenomena-based activity.

Classroom Examples

We have not had an opportunity to pilot any of the lessons. However, we do have a lesson that we will be piloting with middle school students in a Texas school. The lesson is a Lake Erie ecosystem Jenga game. The lesson was adapted from Biffi et al. (2016). This lesson will be done after the students have some understanding of ecosystems and will set the foundation for the interconnectedness within an ecosystem. The students will have a brief introduction to the ecosystem in Lake Erie and some of the biotic factors. There are cards that the students will then pull, and the card will give them a scenario and the consequences for the ecosystem. For example they might have to take a species of fish out due to a consequence of the scenario Following the game logic of Jenga, the removal of species as blocks will eventually lead to the destabilization of the ecosystem. They will then see how important all of the pieces are as a whole. This shows that the ecosystem may become less stable as outside variables, such as mercury, are introduced. This lesson and others build toward the CS experience of collecting nymphs to be sent for analysis of mercury as a way to provide valuable data to scientists.

All lessons have all of the pieces that the teacher needs to successfully implement the lesson in their classroom. The teacher just needs to print the materials for their class. Part of the piloting will help make sure that the lessons flow the way they are intended but also to make sure that there are no missing components for the teachers. Since we are both teachers, we have plenty of opportunities for our colleagues to pilot these lessons in a space where we are available to answer questions and get feedback quickly.

Implications

CS initiatives are a growing part of scientific research that can actively include students. While most CS initiatives engage community members primarily through data collection (Solé et al., 2024), there can still be valuable experiences when also implementing supporting curriculum that allows for collaborative means of learning (Hadjichambis et al., 2023) to utilize students' unique meaning making. However, to make CS more approachable to teachers who may be less familiar with CS projects like DMP, we want our curriculum to fit their pedagogical and content knowledge needs. By participating in authentic scientific inquiry as teachers and integrating science content standards into learning units, teachers can better support their students' own integration of science practices and knowledge (Kite et al., 2020).

CS allows opportunities for teachers, students, and scientists to work together in real world scenarios. The goal of our curriculum is to help teachers find a way to get started. Once they get started with CS, it is our hope that our curriculum will help support the endeavor of encouraging students to see the world of science as more than just a subject in a classroom.

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"I'M NOT GOING TO BE USING THAT": SCIENCE TEACHER VIEWS ON TECHNOLOGY PROFESSIONAL DEVELOPMENT

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Abstract

Teachers need to be knowledgeable about technology tools and be familiar with technologies in STEM careers in order to effectively teach students. What are science teachers' views on technology professional development (PD)? A case study of seven high school science teachers revealed district-sponsored technology PD was disliked, but the reasons for disliking the PD varied. Teachers are described as "technology enthusiasts" or "technology tolerators;" and their concerns with technology PD centered on differentiation, application, and repetition. The research includes implications and suggestions for improving for science teacher technology PD and areas for future research.

Introduction

Teachers need to be knowledgeable about technology tools in order to effectively teach students and be familiar with technologies in STEM careers. Classroom technology integration is often a popular topic for teacher professional development (PD). Unfortunately, exposure to technology PD (TPD) does not ensure science teachers will implement new technologies into their instruction or change their teaching practices (Fernandes et al., 2020), thus understanding teacher perspectives on TPD is valuable for science teacher educators, PD providers, and science teachers. Furthermore, understanding science teacher perspectives on TPD may lead to more effective models of professional learning and a deeper understanding of science teaching and learning.

The purpose of this research is to explore high school science teacher experiences with TPD and ways teachers describe their priorities for teaching and learning in relation to their PD needs. This target group is significant because high school science teachers are a unique subset of teachers with distinctive PD needs in content, pedagogy, and technology, yet there is little research about TPD with science teachers (Fernandes et al., 2020; Zimmer & Matthews, 2022). This case study focuses specifically on seven science teachers' descriptions and views on technology and PD.

Literature Review

Science teachers need to learn a variety of new concepts and skills to stay current in the field of science teaching, and any learning opportunities for teachers should be targeted and strategic to meet their individual needs (Luft et al., 2022). PD can support teachers' use of technology to enhance science instruction (Fernandes et al., 2020). Integrating technology into science education may provide the opportunity for students to investigate scientific phenomena, although effective technology integration by teachers is complex (Higgins & Spitulnik, 2008). Technology should be infused in teaching and learning (Bos, 2011), and highly effective teachers are able to weave together content, pedagogy, and technology (Koehler & Mishra, 2009).

Theoretical Framework and Methodology

This research used a constructivist research framework that places science teachers as social actors to explore and interpret individual teacher understandings from PD. Grounded theory (Glaser & Strauss, 1967) methods were used to explore teachers' experiences with TPD and provided flexibility for the data to determine the direction of the research (Charmaz, 2006). The following research question framed the research in time and space: How do teachers from the same high school science department describe their experiences with TPD?

Concentrating the research on high school science teachers from a single school district ensured the teachers have shared in some of the same TPD experiences and allowed the teachers to explain nuances in their perceptions of the same PD events. The teachers had a wide variety of teaching backgrounds and years of teaching experience. A total of seven teachers completed pre- and post-interviews, were observed during back-to-school PD week and participated in a focus group at the end of the week. The participants' teaching experience ranged from 7 to 37 years, and experience teaching at the campus ranged from 0 to 21 years. All of the participants were certified in science one teacher was also certified in Mathematics and Physical Education.

Data Collection

A variety of qualitative data was collected during the week prior to the beginning of the school year, referred to as "back-to-school or in-service PD week" and after school started. Open-ended questions during interviews and focus groups provided teachers with multiple opportunities to describe their experiences and perceptions about TPD. During the initial interview, teachers described their careers in education and were asked to consider three open-ended questions to prompt their thinking about their best, worst, and ideal PD experience(s).

These interview questions focused on general PD experiences, without a time frame relating to their first year of teaching or back-to-school PD week. Broad questions gave teachers space to describe a variety of PD experiences that occur at different times of the school year, over different places in the teachers' careers, or even a singular significant event that impacted their perspective or outlook on teaching. Although the interview and focus group questions did not specifically refer to "technology PD", TPD was mentioned by each of the teachers throughout data collection.

Field notes taken from observing teachers during the PD week provided understanding and depth for teachers' stories about TPD and science teaching. Participating in events alongside the teachers helped to build a relationship between the researcher and participants while simultaneously considering the researcher's personal biases and beliefs as a former science teacher and current researcher. During PD sessions and other meetings with the teachers over the PD week, nuances not formally expressed by the teachers during interviews or the focus group were recorded. Field notes documented what was seen and heard from the teacher participants in addition to the location, time, and environment of the interactions (Charmaz, 2006).

At the end of the PD week, a focus group was conducted during lunch on Friday. The focus group generated some teacher reflections about how the PD week prepared them for the upcoming school year and illuminated differences between how teachers report their experiences from the week's PD activities. Finally, the second round of interviews probed teacher thoughts about teaching and PD after the PD week in August. Specific questions for these interviews were crafted after experiencing the August PD week alongside the teachers.

Data Analysis

A large amount of qualitative data was collected, and the coding, processing, and organizing the narratives occurred simultaneously using a grounded theory framework that was appropriate for the topics, trends, and themes that developed (Charmaz, 2006). After reviewing the data, initial *in-vivo* codes were created using the words, events, and ideas of the participants (Charmaz, 2006; Saldana, 2016). Then, *incident by incident* coding was used to review qualitative data from individual participants along with the field observations (Charmaz, 2006). Finally, codes were organized into themes that went beyond specific events or descriptions of experiences (Saldana, 2016).

After the coding phases were complete, grounded theory was used to illuminate larger discourses present in the narratives (Charmaz, 2006) and individual "teacher profiles" were drafted and approved by the teachers. This process provided a "member check" with the participants as themes and larger ideas began to emerge from the qualitative data (Clandinin, 2013). Each teacher was provided a copy of their individual narrative Analysis of data in these areas revealed two major themes: the teachers' perspectives on the teaching profession and their thoughts about TPD.

Results and Discussion

As expected, each of the seven teacher participants had unique career and life experiences that impacted their views on teaching, learning, and TPD. Because grounded theory methods were used, the research did not focus on any specific TPD event, rather TPD emerged as an important topic that organically appeared in teacher retellings of their experiences with PD. There was little consensus on how the teachers would prefer to experience TPD, what types of TPD they need, or what content they would like to learn related to technology. Each participant was assigned a pseudonym, and each teacher was designated as either a *technology enthusiast* or *technology tolerator* based on their attitudes towards technology. These two terms are used to describe these seven teachers and does not imply these are the only two categories of teachers' technology interactions.

Technology Enthusiasts

Technology enthusiasts discussed technology as part of their pedagogy without being asked during interviews. They readily shared the technology applications they use in their classrooms, volunteered to help their peers with technology, and gave examples of how technology made their roles as teachers easier. This group of teachers had some advanced technology skills but remained humble in their abilities to incorporate technology into their daily instruction and also serve as technology mentors for other teachers in their department, on their campus, across the school district, and beyond. Because they enjoy incorporating technology into their instruction, these teachers may also seek out their own learning opportunities with technology. Four teachers out of the seven in this case study met the "technology enthusiasts" description and are described below.

Paula

As a teacher for 25 years, Paula was one of the first Apple Distinguished Educators in the district, and students in her classes were instrumental in co-creating some of Apple's first online interactive biology textbooks. Paula chooses to stay up to date with technology so students can see the relevance, not because it could make her teaching and planning easier. She emphasized more than once that TPD would be better if teachers could simply have some choices in the PD they attend. Paula mentioned that everyone in the science department recently attended the same PD for a technology with no applications for science teachers.

Crystal

Crystal had 12 years of teaching experience and volunteered to help new teachers navigate the district's TPD modules during the PD week. For PD preferences, she had a mild disposition about past “mediocre” PD experiences and decided what she disliked the most was repetition because she had participated in the same TPD over and over. Crystal disliked technology applications that are time-intensive to master and have a steep learning curve before being able to use them with students during class. Finally, if technology is too complicated, takes too much time, or isn’t useful, then TPD is a waste of time for Crystal.

Abby

Abby was entering her seventh year of teaching and was the least experienced teacher in the group of participants. When asked about her previous PD experiences, she explained that she was very comfortable with technology and even said, “technology is my jam”. She expressed frustration at sitting through TPD that repeated basic applications which she either had already mastered or could figure out on her own time outside of formal PD. She recognized that other teachers might need more support with technology and might “know nothing,” but she wanted the district to consider tailoring their TPD experiences using differentiation for teachers.

Constance

Constance was beginning her 37th year in education and because of teaching grant she was once the “first person in my school district to have a computer.” Although she gave examples of using technology to design choice boards for students and creating Google forms to streamline special education documentation, Constance wasn’t seeking out innovative technology applications for her courses. She viewed technology as a tool to accomplish tasks as a teacher, and she was content to find her own technology resources if she needed to learn something new for her role as a teacher. She was willing to participate in TPD and had a positive outlook on being able to find something useful in any PD professional learning opportunity.

Technology Tolerators

The other three teachers in the case study were reluctant to embrace technology and infuse it into their instruction. These technology tolerators use technology because it is required and/or expected by the campus and district administration, even though the teachers may not see the value or usefulness of the technology. The teachers in this group were wary of discussing technology and even appeared physically uncomfortable when they were asked to describe their experiences with TPD. Although the teachers didn’t explicitly state it, they would prefer to have choice in whether or not they use technology and, in some cases, they might prefer not to use technology at all. The “technology tolerators” teachers are described in more detail below.

Melanie

Melanie was the science department head with 17 years of experience, who described her technology comfortability as, "I always say I'm not tech savvy," and rarely discussed technology in her interviews. In terms of TPD, Melanie only associated district training with student data management programs as a TPD session. She said the only new knowledge she gained during the PD week was during an informal conversation with a peer during one of the district-led TPD sessions. Because Melanie was a technology tolerator, she was dissatisfied with TPD options but did not seek out alternative PD experiences or learning about technology for the benefit of her students.

Eddie

Eddie was beginning his 11th year of teaching, after almost 30 years as an engineer and nine years of physics teaching. Some PD assignments were cumbersome for Eddie if they required technology because he admitted that technology is frustrating for him at times. He wants PD experiences to be immediately applicable to the current teaching assignment. He described a TPD assignment by saying, "The [technology] training we need to be doing … I'm not going to be using that." In other words, Eddie wanted technology tools to make his teaching more efficient, but he did not consider how technology might be useful for student learning.

Rachel

Rachel was an experienced chemistry teacher with 21 years of teaching experience who worked with some of the most gifted students in the district. Rachel volunteered she wants choice in the technologies she uses, rather than feeling forced to use applications that may not fit for the content. She admitted, "Obviously I don't know all the technological options out there," but she was willing to learn about different applications. She wants technology to be easy with some immediate usefulness in advanced chemistry courses. Ultimately, Rachel tolerated technology when it was required, but she prefers her traditional teaching methods without technology interference.

Implications

The "technology enthusiasts" and the "technology tolerators" had varying personal and career experiences that impacted their views on teaching, learning, and TPD. Teachers strongly disliked district-sponsored TPD, but their reasons for disliking the PD varied among the teachers. When larger discourses about teacher professional learning are considered, the teachers in this case study independently identified three weaknesses of TPD in their district: differentiation, application, and repetition.

Differentiation

Some teachers struggled with accessing and using the technology applications during PD, while other teachers disliked being forced to learn basic technology skills or applications they already knew. For instance, Paula suggested, "They should do for us what we're asked to do for students, you know, just differentiate, and provide options for different pathways depending on what the needs are." All teachers discussed PD sessions that everyone was required to attend without any differentiation. The teachers suggested that TPD should be differentiated for teachers depending on the subject level and course content they teach and teachers' personal knowledge and skills with technology, similar to recommendations by Li et al. (2020).

Application

During the focus group, teachers discussed a desire to share ideas with their science peers rather than listening to a presenter share examples that are not applicable to their age level, coursework, or teaching style. Some teachers felt forced to learn and use technology tools that did not align with their teaching style and others found the applications were not useful for their teaching needs. Without examples that apply to the advanced chemistry classroom, Rachel is not likely to ever use the technology application with students. Several teachers also disliked the TPD modules assigned during the PD week. For example, Eddie's reasoning for dismissing the training was that he preferred the PD that he perceived as worth his time investment because he could use it in his classroom.

Repetition

The teachers were generally frustrated that the district sponsored certain technology applications over others and required them to be trained year after year on the same one or two technology applications. Rachel explained, "It's not helpful to be told … here is an app and everyone's using and you have to use it." The teachers gave multiple examples of their time being wasted with repetitive TPD training, especially if the district was paying a subscription for a particular technology product.

All seven teachers wanted to learn new technologies, but technology enthusiasts wanted TPD focused on "new technologies" and innovative ideas rather than basic skills. All teachers wanted PD to be differentiated for teachers with different levels of proficiency and needs, and they all want to work with other science teachers during or after a TPD session to find ways to integrate the technology into their science courses. If there is a training session, then teachers want hands-on and/or authentic experiences, rather than watching someone else go through how-to steps.

Although technology is ubiquitous in today's educational system, this group of teachers was disappointed in TPD and how technology supports their instruction. Teachers expressed the need for relevant and engaging TPD that is differentiated and individualized, similar to findings by Zimmer and Matthews (2022). Providing choice in TPD was especially important for teachers since their levels of expertise and use of instructional technologies vary widely (Rubino-Hare et al., 2016). Science teacher educators can support classroom teachers by providing and advocating for constructivist TPD that prioritizes individual teacher choice, differentiation, and variety.

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DRAWING INSPIRATION: HOW EIGHTH GRADERS SEE THEMSELVES THROUGH THE DRAW A SCIENTIST TEST

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Abstract

Retaining underrepresented students in STEM requires fostering their science identity, shaped by external validation and internal self-perceptions, particularly from middle school onward. This study examines the development of science identity among a small group of underrepresented eighth-grade mentees in a pre-health mentoring program. Student science identity was measured through an adapted version of the Draw A Scientist Test (DAST). These findings suggest that while traditional science stereotypes are prevalent among secondary students, mentorship programs that foster recognition and self-reflection can broaden science identity, particularly among underrepresented female mentees. These insights inform targeted mentorship strategies to enhance inclusion and retention of underrepresented students in STEM, promoting diversity and innovation.

Keywords: draw a scientist test, science identity, mentorship, middle school science, pre-health

Introduction

Keeping under-represented students in science, beyond the K-12 classroom and throughout college, is critical for diversity and innovation in STEM fields. To retain their knowledge and contributions, we must ensure students' continued participation. The decision to pursue a scientific career is significantly influenced by the ability to establish a robust science identity (Vincent-Ruz & Schunn, 2018). Science identity is shaped by a combination of external influences and internal values, with a key developmental phase occurring during middle school (Umaña-Taylor et al., 2006). Support from family or educators serves as a critical external factor, while internal self-assessments of scientific capability further solidify this identity. As science scholars advance to university-level education, external validation, particularly recognition from a 'meaningful other' (Carlone & Johnson, 2007), plays a substantial role in directing their path toward a lasting career in science.

This study aims to foster inclusivity in STEM by examining science identity among six eighth-grade mentees in an afterschool STEM/Pre-Health mentoring program at a Title I middle school in a large urban district. Led by undergraduate students of color pursuing STEM careers and guided by faculty, the program empowers underrepresented minority students to prepare for navigating high school, succeed in college, and pursue careers in STEM and healthcare professions. Through the mentorship program, students are given presentations, hear from guest speakers, tour a large university, engage in hands-on activities, and participate in mentor-led discussions with the aim of fostering a supportive environment that bridges aspirations and achievement into STEM skills and career aspirations. The findings from this study indicated positive differences among student drawings collected during and following engagement in the afterschool STEM/Pre-Health mentoring program, suggesting shifts in self-perception and identity.

Objective of the Study

How does engagement in an afterschool STEM/Pre-Health mentoring program affect mentees' science self-perception and identity development?

Theoretical Framework

Previous research has established that mentoring enhances mentee self-efficacy, boosting confidence in their abilities (Chemers et al., 2011). However, there remains a gap in understanding how STEM mentoring shapes mentee science identity—a crucial factor in persistence. Science identity, the ability to see oneself as a scientist doing science, depends upon internal values and external praise (Vincent-Ruz & Schunn, 2018). Identity formation occurs mainly through adolescence, establishing positive and negative perceptions of ethnicity and race (Marks et al., 2020). Studies suggest that science identity is formed in adolescents when a trusted 'meaningful other'—a mentor, teacher, or peer—recognizes their competence and potential. Receiving recognition from a 'meaningful other' made it more likely for undergraduate women of color to remain within their field (Carlone & Johnson, 2007).

Most instruments developed to assess students' images of scientists require a written response. Since not all students can respond properly to written instruments, Chambers (1983) developed the DAST. Through the instrument, students' drawings are rated based on specific characteristics present or missing, helping researchers understand the images of scientists that students hold. The original study looked for seven indicators associated with the standard image of a scientist: (a) Lab coat (usually but not necessarily white), (b) Eyeglasses, (c) Facial growth of hair (including beards, mustaches, or abnormally long sideburns), (d) Symbols of research (scientific instruments and laboratory equipment of any kind), (e) Symbols of knowledge, (books and filing cabinets), (f) Technology, and (g) Relevant captions (formulae, taxonomic classification, exclamations of "Eureka"!, etc.). Two significant conclusions emerged from this study: the stereotypical scientist image appeared among students at both high school and grade school levels, and elements associated with science stereotypes appeared with greater frequency as students advanced through the grades (Chambers, 1983). Since the original development of the DAST, many studies have adapted this protocol to assess students' conceptions of scientists throughout their formative years. Each study has attempted to move the conversation around science identity forward, shifting away from the traditional white, male in a lab coat stereotype and toward increasing representation across diverse genders, races, and abilities.

The theoretical framework of this study is grounded in Carlone and Johnson's (2007) Science Identity Model, which emphasizes recognition, competence, and performance in fostering science identity among underrepresented mentees in the university pre-health mentoring program. Complementing this, Social Cognitive Career Theory (SCCT) (Lent et al., 1994) connects science identity to career persistence, a key goal for retaining underrepresented students in STEM. SCCT posits that self-efficacy, outcome expectations, and personal goals, shaped by contextual supports and learning experiences, drive career choices. Self-efficacy towards science, defined as an individual's belief in their ability to succeed in science-related tasks, may be limited by stereotypes, which DAST seeks to reveal. Mentorship enhances self-efficacy through social persuasion and vicarious learning, aligning with Carlone and Johnson's recognition dimension while linking to career aspirations. Positive outcome expectations motivate personal goals, counteracting barriers like fear of exclusion. SCCT's focus on learning experiences complements DAST, capturing evolving perceptions of scientists. Unlike Carlone and Johnson's identity-focused model, SCCT bridges the connection between identity and STEM retention, guiding mentorship interventions to diversify the scientific workforce.

Methodology

Building on established methodologies (Chambers, 1983; Farland-Smith, 2012), our research team adapted the DAST prompt and coordinating rubric to measure science identity development among six 8^{th}-grade mentees engaged in the afterschool STEM/Pre-Health mentoring program.

Adapting the DAST

The original DAST prompts participants to draw and color a scientist, revealing their perceptions of scientific identity. As previously mentioned, Chambers (1983) identified seven stereotypical indicators (e.g., lab coat, eyeglasses, research symbols). Farland-Smith (2012) refined the original DAST rubric by delineating between stereotypical and alternative depictions. The rubric categorizes drawings by Appearance, Location, and Activity and scores on a scale from Indeterminate (0) to Broader Than Traditional (3). Appearance assesses gender and minority representation, Location evaluates settings (e.g., lab vs. non-traditional), and Activity distinguishes realistic from sensationalized science tasks. Prior to assessing the mentees, our research team piloted the Farland-Smith (2012) DAST version with seven non-science major undergraduate students enrolled in an Honors Contemporary Biology course. Feedback from the students and research team resulted in subsequent refinements.

Further examination of multiple use cases of adapted DAST protocols was incorporated into our rubric (Figure 1) (Brochey-Taylor & Taylor, 2024; Farland-Smith, 2012; Finson et al., 1995; Reinisch et al., 2017; Symington & Spurling, 1990). Adaptations incorporated additional descriptors detailing the scientist's activities and attire, enriching the data collected and providing deeper insight into students' conceptualizations of scientific identity. Our adapted rubric developed for this study was expanded to nine categories: Gender (replacing Appearance), Location, Activity, Skin Tone (Joy et al., 2024), Dress (Chambers, 1983), Symbols of Knowledge, Technology (Finson, 2003), Indicators of Secrecy (Quilez-Cervero et al., 2021), and Symbols of Belonging. Skin Tone, a novel addition, assessed dark, light, or unrealistic tones. Activity and Technology were refined to distinguish chemistry-focused depictions from other disciplines (e.g., biology, astronomy), addressing ambiguity in traditional versus non-traditional portrayals. Scores ranged from -1 (Sensationalized) to 2 (Broader Than Traditional), with a grading scale from -9 to 18 (Figure 1).

The DAST was then administered to the five undergraduate mentors from the afterschool STEM/Pre-Health mentoring program during a planning meeting. Also adapting the prompt, the students were instructed to: "Draw a picture of a scientist, color it with provided markers, and name the scientist." The students were provided with a tub of Crayola's "Colors of the World" markers to facilitate diverse representations of skin tones. Final rubric adjustments were informed by rating the students' pictures (mentors' non-traditional views on gender and skin tone, as well as traditional chemistry-focused stereotypes) and a follow-up discussion.

Figure 1

Our Final Adapted DAST Rubric for an After-School Pre-Health Mentorship Program

Adapted DAST Rubric for an Afterschool Pre-Health Mentorship Program				
	Category Ratings			
Categories	Fully non-traditional=18 Highly non-traditional = 15 to 17 Slightly non-traditional = 11 to 14	Fully Traditional = 8 to 10 Slightly Traditional = 4 to 7	Incomplete = 0 to 3	Slightly Unrealistic= -1 to -3 Highly Unrealistic = -4 to -8 Fully Unrealistic = -9
Gender	Includes a woman or self	Contain an ordinary-looking white male	Cannot be categorized or difficult to determine	Contain a man or woman who may resemble a monster or who has a clearly odd or comic book appearance
Location	Includes a scene that is different from a traditional laboratory setting	A traditional lab with a table or equipment in a normal looking room	Difficult or unable to determine or setting is a classroom	Location resembles basement, cave, or setting of secrecy, scariness, or horror, often with elaborate equipment not normally found in a lab
Activity	Non-stereotypic activities that reflect the work a scientist other than chemist	Stereotypic activity that appears mainly to be chemistry	Difficult or unable to determine	Activity that may include scariness or horror, often with equipment not normally found in a typical laboratory. Fire, explosives, or dangerous work could be included
Skin tone (Joy et al., 2024)	Darker skin tone (outline color)	Light skin tone (outline color)	Skin the color of the paper	Colored with unrealistic color
Dress (Chambers, 1983)	Dress appropriate for the location	Lab coat, glasses, gloves	Uncategorized and/or not science related	Costume (usually part of the comic genre)
Symbols of knowledge (Finson, 2003)	Other than traditional (could be ancient – owl)	Books, pens in pocket, clipboards, chart boards	None	Uncategorized
Technology (Finson, 2003)	Other than traditional: astronomy, field based, etc.	Traditional: chemistry equipment; highly 'lab' based	None	Uncategorized
Indicators of secrecy (Quilez-Cervero et al., 2021)	Other than traditional	Private, keep out, do not enter	None	None
Symbols of belonging	Stickers or t-shirt or other that tells of belonging; more than one person	Without any outward sign of belonging; only one person	None	None

Data Collection

In February 2025, six eighth-grade mentees during the after-school STEM/Pre-Health mentoring program were given the same prompt administered to their mentors and were allowed five minutes to complete the DAST. Of the six eighth-grade student mentees in the mentorship program, three identified as female, two identified as male, and one did not indicate a gender. Following the DAST, the mentors facilitated a short focus group to discuss the students' illustrations and the underlying perceptions they represented. The research team provided the mentees with questions such as "Tell me about your drawing" and "What type of person do you think becomes a scientist?" Following the end of the mentoring program (six weeks later), the six mentees were administered a post-DAST. The focus group was recorded, and the data were transcribed and analyzed according to the second-cycle coding guidelines by Miles et al. (2014). Between the first and second DAST collections, the mentees participated in additional mentoring meetings, a campus tour, and a university lab activity involving dissections guided by medical students. Due to programmatic limitations, the mentees were unable to participate in a focus group following the second DAST collection.

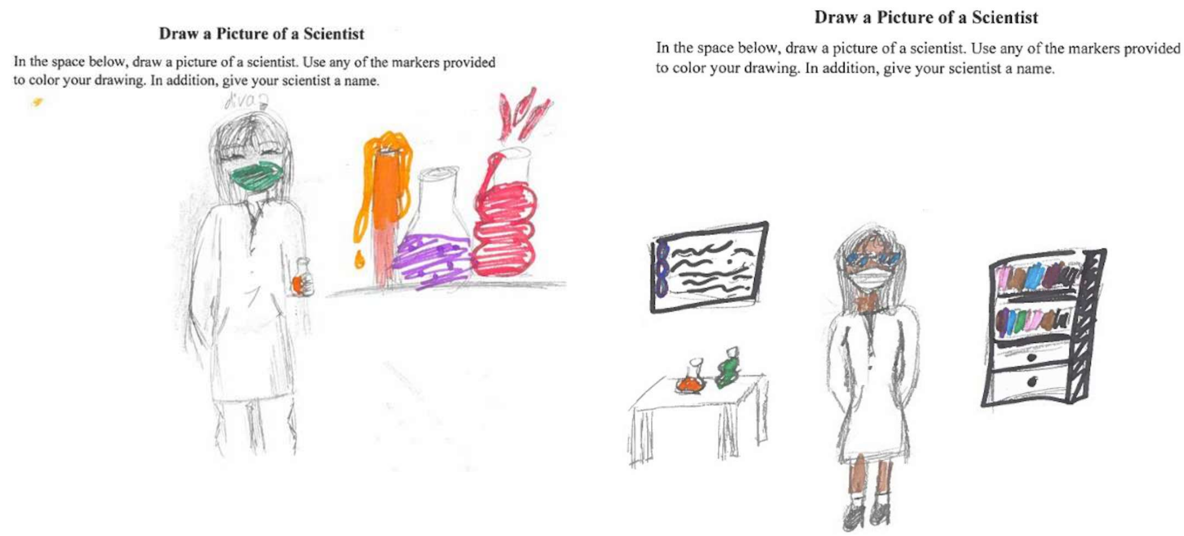
Results

The initial DAST drawings by the mentees all averaged as Slightly Traditional. The drawings depicted stereotypical laboratory settings, chemical-focused activities, and traditional science attire, but lacked symbols of knowledge or secrecy. Three of the mentees portrayed scientists as women or themselves, suggesting personal relevance. Themes that emerged from the focus group included the mentees' emphasis on "chemicals/chemistry" (nine mentions), "mess," and "think," reflecting a sensationalized, lab-centric view (Figure 2). One mentee claimed that "anyone can be a scientist," references diverse activities (e.g., environmental research, finding cures), and featured a darker-skinned depiction, indicating emerging inclusivity.

Interestingly, when compared to the initial DAST, ratings from two female mentees' drawings doubled in score in the post-DAST. The drawings shifted to broader, non-traditional representations with darker skin tones, female features, and symbols of knowledge, suggesting a deepened science identity driven by mentorship (Figure 2). The other four mentees showed minimal change or incomplete drawings, indicating variable engagement. The absence of the second DAST audio limits qualitative insights; however, the visual data highlights the potential of mentorship to foster identity shifts.

Figure 2

Initial DAST–Slightly Traditional (Left) and Post-DAST–Fully Traditional (Right)



Discussion and Implications

The initial and post-DAST results, as well as the focus group, indicate the potential for the evolving science identity of underrepresented mentees in the after-school pre-health mentoring program, revealing persistent traditional perceptions alongside emerging inclusive views. These findings suggest that while traditional science stereotypes persist, mentorship programs that foster recognition and self-reflection can broaden science identity, particularly among underrepresented female mentees. The increased representation of diverse skin tones and activities aligns with calls for inclusive STEM education that reflects students' identities. However, the limited progress among some of the mentees highlights the need for consistent, longitudinal interventions to overcome entrenched stereotypes.

This study highlights the potential of mentorship to foster a science identity and retain underrepresented students in STEM, thereby promoting a diverse scientific workforce. We suggest that future research integrate audio from the post-DAST trial, increase sample size, and employ longitudinal tracking to evaluate sustained science identity changes. Mixed methods, including surveys for self-efficacy and focus groups for mentor-mentee dynamics, will address DAST subjectivity and enrich insights. Leveraging Carlone and Johnson's Science Identity Model (2007) and Social Cognitive Career Theory (Lent et al., 1994) will ensure that assessments capture identity and career outcomes, such as self-efficacy. The adaptations and iterative rubric refinements enhanced the DAST's ability to assess science identity, supporting the study's aim to foster inclusivity in STEM. However, we recommend that further refinement of the DAST rubric may enhance evaluation precision across cohorts. Expanding to the Society for Advancement of Chicanos/Hispanics & Native Americans in Science (SACNAS) and the Minority Association of Pre-Health Students (MAPS) with culturally tailored mentorship will address barriers such as underrepresentation and cultural disconnects. At the same time, mentor training will amplify the impact. Future research should also investigate how mentorship mitigates systemic barriers, such as stereotype threat or limited STEM resources, to enhance career persistence. These insights should inform STEM education practices, including curriculum enhancements that embed identity-building activities and institutional policies that prioritize mentorship, scaling the impact of interventions to cultivate a more inclusive scientific workforce.

Limitations

This study has several limitations related to its design and implementation. The 2024–2025 mentorship program cohort included fewer than twelve semi-regularly attending mentees, with DAST drawings from only six, limiting statistical power and generalizability due to the small, non-random sample. Mentees' pre-existing views on science identity may skew findings, reducing their representativeness. The DAST's reliance on subjective interpretations of drawings and reflections, influenced by artistic ability, biases, or cultural factors, may compromise reliability and objectivity. Restricting data to DAST and debriefings overlooks deeper psychological or behavioral aspects of science identity, which additional methods (e.g., surveys, interviews) could capture. The university's pre-health program has a specific context that limits its applicability to other settings, as institutional or regional factors may shape perceptions. The cross-sectional design provides a single snapshot, missing longitudinal changes in science identity influenced by mentorship or career progression.

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MULTIMODAL RESOURCES IN EML JOURNALS: EVIDENCE OF LEARNING

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Abstract

We explored how emergent multilingual learners incorporate multimodal semiotic resources in journal entries following four investigations and how discourse reflected student engagement in Next Generation Science Standards (NGSS) practices. Data from 28 journal entries from newcomers participating in a summer program were coded using 15 a priori codes derived from three categories of multimodal written text (language, mathematical expressions, and manual-technical operations) and NGSS practices. Affordances were dominate in sequencing terms and technical vocabulary. The limitations for the different modes resided in the journal format privileged written language and mathematical expressions were found. Students used five of eight NGSS practices.

Keywords: multimodal, emergent multilingual learners, discourse, NGSS

Introduction

With changing demographics in the United States (US), there has been increased emphasis on providing equitable, rigorous, standard-based education for the diverse student body found in schools. We were interested in how emergent multilingual learners (EML) make meaning and communicate learning from engaging in inquiry-based, content-rich science as displayed in four daily journal entries. We specifically asked: RQ 1. *How do EMLs incorporate multimodal semiotic resources in their journal entries following an investigation?* and RQ2. *How does multimodal disciplinary discourse in the journal entries of the EMLs incorporate the NGSS practices?*

Conceptual Framework and Literature Review

Our conceptual framework is grounded in sociocultural theory which presupposes learning is social, situated, culturally embedded, and mediated through the resources used (Wilmes & Siry, 2021). From this perspective, students are situated in cultural, social, linguistic, and institutional contexts (Cunningham et al., 2021). Learning is individual and collaborative; involving 'doing' (Siry et al., 2012) as well as 'learning'.

One challenge for EMLs is the connection between language and learning in science. The distinctive elements of scientific language in classrooms present challenges for students in the development of multimodal disciplinary discourse. A variety of features that make science language especially difficult have been documented in research (Oliveira et al., 2019). Examples include the use of nominalizations, lexical density, polysemy, and multimodality.

Lemke (1990) outlined four semiotic modes in science: natural language, mathematical expressions, visual representations, and manual-technical operations. He stressed that scientific literacy includes "the ability to make meaning conjointly" (2004, p. 38) using more than one mode. Bezemer and Kress (2016) emphasized that each mode is specialized and meaning making is the outcome of the integration of modes. A more complex understanding of the array for meaning making and communication in science has evolved over the years (Unsworth et al., 2022).

For students learning English, having practice in when and how to use modes of communication is important (Lee et al., 2013). Within the language mode, giving EMLs opportunities to think about and use the communicative functions of oral and written language is essential (de Oliveira, 2017). In contrast to everyday language and creative/narrative writing, students most often engage with factual and analytical genres in science.

The *Next Generation Science Standards* (NGSS Lead States, 2013) describe eight practices focused on student actions necessary for an inquiry-based science classroom. Researchers quickly addressed the challenges and opportunities the new vision offered for EMLs (Quinn et al., 2012). Lee et al. (2013) stated: "when students, especially English language learners, are adequately supported to "do" specific things with language, both science learning and language learning are promoted" (p. 223).

Research Study

A single case study approach (Yin, 2018) was utilized to examine specific and bounded instances of EMLs' use of multimodal disciplinary discourse in 28 journals following four investigations. During a 3-week summer program students engaged in investigations to answer the question of "who took the T-shirts?" missing from the storage room ("crime scene"). Learning activities were sequenced so students agreed on suspects and data to collect (i.e., ink, blood determination, blood typing). They used journals to record daily activities, including investigations. As a reflective device at the end of each investigation, they used a T-chart to document their practices and their new content knowledge (Price et al., 2023). The *What I Did* and *What I Learned* (hereafter, WID/WIL) entries served as epistemic tools for students and assessment tools for teachers (Hand, 2017).

Participants

Twenty-eight students, ages 11 to 13 (15 males, 13 females), were selected by the district to attend the summer program. Half were newcomers to the US (< one year), from seven countries and spoke five languages. The other half had lived in the US and been enrolled in US schools for most of their lives and spoke Spanish at home.

Data Source, Coding and Analysis

We used a typical classroom artifact – the student journal. Twenty-eight journals contained entries for all four investigations (chromatography, Kastle-Meyer test, blood typing, DNA extraction) where students were asked to use the WID/WIL.

Applying sociocultural theory, we examined how EMLs used multiple semiotic resources and their growing science knowledge as they engaged in situated science investigations. For RQ1, we used codes developed and applied in previous research (Pierce et al., 2023; Weinburgh et al., 2021) with 88% coder agreement. We used three categories (language, mathematical, manual-technical) with a total of 15 codes (*process*, *signal words*, *observation, synthesis*, *academic words*, *causation, explanation, typographical*, *topographical*, *measurement*, *number, symbols, set-up*, *transport*, *container*) examined the data at two levels (Figure 2). For Level 1, the frequency of each category was calculated. At Level 2, we contextualized the semiotic resources used for each investigation utilizing hermeneutics to interpret the entries.

For RQ2, we re-read the entries looking for evidence of a relationship between multimodal disciplinary discourse found in the journals and the NGSS scientific practices.

Findings

Examples used in this section were taken from the journals of two students (AU and CC) to provide specific examples of the claims we make. CC, a 12-year-old male from Mexico, came to the US when he was 11 and speaks Spanish at home. AU, a 12-year-old female from Rwanda, came to the US when she was 11 and speaks Kinyarwanda at home.

RQ1 First-Level Analysis

What I did/What I learned - WID/WIL

The initial coding identified the occurrence and frequency of different semiotic resources used for describing student engagement in the investigation and the learning that resulted (Figure 1). It is evident that affordances of semiotic resources needed for communicating 'doing' (WID) differ from those needed for communicating 'learning' (WIL). Additionally, the resources afforded to the students differ between the specifics of each investigation.

Figure 1

Coding Incidences and Percentages

Language

	L:pro WID	L:pro WIL	Total per task	% per task	L:sig WID	L:sig WIL	Total per task	% per task	L:aca WID	L:aca WIL	Total per task	% per task	L:cau WID	L:cau WIL	Total per task	% per task	L:obs WID	L:obs WIL	Total per task	% per task	L:exp WID	L:exp WIL	Total per task	% per task	L:syn WID	L:syn WIL	Total per task	% per task
Chromotography	99	5	104	23	62	24	86	20	83	63	146	21	2	5	7	19	22	9	31	46	1	24	25	23	1	31	32	18
Kastle-Meyer	108	4	112	25	97	16	113	26	74	81	155	22	7	12	19	51	11	0	11	16	16	25	41	38	4	46	50	29
Blood	98	2	100	22	80	22	102	24	116	122	238	34	1	8	9	24	10	4	14	21	20	10	30	28	4	46	50	29
DNA	136	1	137	30	126	7	133	31	92	59	151	22	0	2	2	5	9	3	12	18	5	7	12	11	6	37	43	25
	441	12	453		365	69	434		365	325	690		10	27	37		52	16	68		42	66	108		15	160	175	

Mathematics

	M:typ WID	M:typ WIL	Total per task	% per task	M:top WID	M:top WIL	Total per task	% per task	M:mea WID	M:mea WIL	Total per task	% per task	M:num WID	M:num WIL	Total per task	% per task	M:symb WID	M:symb WIL	Total per task	% per task
Chromotography	19	23	42	33	46	4	50	36	18	8	26	25	40	8	48	20	1	0	1	1
Kastle-Meyer	8	10	18	14	31	0	31	22	28	0	28	27	33	10	43	18	0	1	1	1
Blood	33	10	43	34	33	0	33	24	15	0	15	14	84	27	111	46	1	67	68	96
DNA	19	5	24	19	25	0	25	18	36	0	36	34	33	5	38	16	0	1	1	1
	79	48	127		135	4	139		97	8	105		190	50	240		2	69	71	

Manual-Technical

	MT:set WID	MT:set WIL	Total per task	% per task	MT:port WID	MT:port WIL	Total per task	% per task	MT:con WID	MT:port WIL	Total per task	% per task
Chromotography	74	0	74	24	50	8	58	21	29	4	33	21
Kastle-Meyer	75	0	75	25	69	11	80	29	0	0	0	0
Blood	71	0	71	23	52	4	56	20	32	3	35	23
DNA	83	0	83	27	71	9	80	29	83	4	87	56
	303	0	303		242	32	274		144	11	155	

Note. For each investigation (Chromatography, Kastle-Meyer, Blood, DNA) there is a column for What I Did (WID), a column for What I Learned (WIL), total per task, and percent per task. This format is used for the 15 codes (7 language, 5 mathematical, 3 manual-technical)

RQ1 Second-Level Analysis

What I Did (WID)

After analyzing code frequency, a second-level analysis used hermeneutics, a sociocultural lens, and the context of each investigation to examine how students integrated multimodal semiotic resources in their journals. In response to the WID prompt, EMLs used different semiotic resources to provide the reader with evidence of how they carried out the investigation.

Manual-Technical. Physical manipulation of materials could only be captured using written entries as a proxy. In CC's entry, manual-technical modality was evident in the manner in which he documented the setting up for an activity by the use of action verbs like 'put' and 'marked' the paper with ink from a pen. AU described assembling materials (*I take the Q tip I put in waterer*) and then described the outcome (*when you finish to put those thing then you wiat it chang calolor it is no change corol*).

Language. EMLs organized entries chronologically to record the sequence of manual-technical actions discussed above. The writing displayed an understanding of sequential connectors to organize the procedure (*First I put Alcohol … Second than I measure … Third than we take the pepa*). Analysis revealed that when responding to the WIDs, EMLs used observations and explanations.

Mathematical Expressions. The use of the mathematical meaning making resources coincided with the *doing* of the science. As part of manual-technical operations, EMLs used mathematical expressions to indicate the measurement using typological words (descriptive), topological words (degree), and numerical (mathematical symbols). This was noted when AU expressed the measurement numerically and topologically with specific degree (*I measure 20 mL*).

What I Learned (WIL)

Manual-Technical. In responding to the WIL prompt, students provided underlying evidence of engaging in learning from the manual-technical operations as they wrote about the technical acts of 'putting' water, ethyl alcohol, phenolphthalein, and hydrogen peroxide on dry blood. CC stated that doing the manual-technical operation led to his knowing the answer (*I also learn what is the proces to test*) to the question of whether the dried substance was blood.

Language. At times EMLs displayed their new understandings in the form of a generalization. AU summarized her new understandings through a more formal statement of her learning (*I leaned that chromatagraphy is the process of solvent the changes separate*). AU incorporated the new term (solvent) in her journal. Similarly, CC synthesized his learning in one generalization (*I lear how to take the DNA from a strawberry*).

Mathematical Expression. There were differences in affordances between 'doing' and 'learning' in terms of mathematical expressions. The usage of mathematical expressions was seldom communicated in 'learned'. The exception was in the frequency and context of learning about blood appears to be due to needing the + and the – for blood type.

RQ2

Journals provided evidence of student engagement across four NGSS practices as students actively obtained, evaluated, and communicated scientific information (#8), planned and carried out investigations (# 3), used mathematics and computational thinking (#5), and constructed explanations (#6). Since the questions were framed by the teachers and the investigations were observational, data did not provide evidence of students engaged in Practices 1, 2, and 7.

Discussion

We examined the WID/WIL entries composed following four CSI investigations. Findings were interpreted through a conceptual framework grounded in sociocultural theory and an understanding of semiotic resources as described by Lemke (1990, 2004).

RQ1 First-Level Analysis

Visual representations were not found, possibly because these EMLs recognized that they had already painstakingly documented observed changes using visuals, and they did not feel the need to be repetitious. Students may also have felt constrained since the T-chart may have limited the amount of space to integrate visuals into the writing.

The type and frequency of codes (*set-up*, *transport*, *container)* for manual-technical can be explained by examining the investigations. The type of investigation limited the potential resources for expressing manual-technical operations (WID) because they only required EMLs to set-up the equipment, transport materials from one place to another, and utilize containers for the materials. EML's frequent use of procedural language in recounting experiences can be attributed to the language resources supporting investigation steps (e.g., first, next). Also, the high frequency of codes for academic words can be explained by the embedded language that emerged as the students engaged in the authentic investigations and the meta-discussions that followed.

As each investigation required different mathematical resources, the frequency of codes for mathematical expressions fluctuated. A higher frequency for WID than WIL is accounted for by the need to use typological and topological indicators during the investigation.

RQ1 Second-Level Analysis

Using hermeneutics to go beyond number counts revealed that the mode selected is critical to knowledge construction as EMLs developed new context-appropriate language and scientific knowledge. This was made evident through their ability to personalize, appropriate, transform, and remake meaning as they described the manipulations of materials during the investigations. As EMLs positioned themselves within the specific actions of the investigation, they engaged in multimodal disciplinary discourse. They pulled from the sociocultural context to mediate their learning through the sequential and interactive use of modes. In each investigation, the multimodal disciplinary discourse is focused on a goal-oriented outcome. The use of different modes highlights the multifunctional use in meaning-making.

Second-level codes revealed that EMLs could engage in the manual-technical mode while failing to describe that they learned to use new equipment (e.g., blood typing trays) and performed new skills (e.g., combine chemicals). This suggests that they did not recognize or value learning a skill, action, or technique as an affordance to support meaning making in science.

RQ2

Science practices and multimodal disciplinary discourse were co-constructed as EMLs manipulated materials and ideas. The multimodal disciplinary discourse in the journal entries indicated which NGSS scientific practices and ways of thinking were used. At the most elemental level, students are to conduct investigations individually or collectively, produce data, make observations and measurements as well as make predictions based on prior knowledge. Progression in the practice ultimately includes testing mathematical, physical, and empirical models utilizing a range of sophisticated tools and data collection. Because the investigations in this study were not open inquiry, they only engaged the EMLs in four of the practices.

Conclusions and Implications

The conceptual framework assumes that all facets of the learning environment interlink to produce a landscape of membership within a community (e.g., summer science program). It is through authentic activities that the learner becomes familiar with, and skilled in, the tools (including discourse) that a culture or community uses within the context. The interpretation of multimodality of science discourse assumes that it is complex and that the interlocking and interdependence of semiotic resources perform a constitutive role in learning science. This research highlights the need to be sensitive to how discourse practices are situated historically, socially, and culturally.

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EXPLORING THE IMPACTS OF A SCIENCE LEARNING MANAGEMENT SYSTEM ON PRE-SERVICE TEACHERS

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Abstract

This mixed-methods pilot study examined the impact of a science-specific Learning Management System on pre-service teachers to determine their science self-efficacy, content knowledge, and future application. Pre-service teachers were given access to EduSmart, an LMS designed to support K-12 science teachers but used in their science methods class to provide instructional experiences. A pre-post test design using the STEBI-B and reflections were analyzed to determine impacts on pre-service teachers' science self-efficacy and content knowledge. Results indicate that the science teaching self-efficacy, science content knowledge, and ability to differentiate science lessons of pre-service teachers increased due to exposure to a science-specific learning management system.

Keywords: pre-service teachers, learning management systems, science content, differentiation

Introduction

Pre-service teachers (PSTs) preparing to teach elementary science often enter teacher preparation programs (TEPs) with limited science content knowledge (SCK) and minimal experience using instructional technology (IT). This limitation often can negatively affect their teaching confidence and ability to implement effective, student-centered science instruction. Developing the integration of subject matter expertise with instructional strategies, pedagogical content knowledge (PCK), is essential for equipping PSTs to teach science meaningfully and inclusively. The purposeful integration of IT, particularly through science-specific learning management systems (SP-LMSs), presents a promising approach to support this development. Science LMSs provide structured, standards-aligned content, interactive simulations, and assessment tools that allow PSTs to engage with science concepts while practicing instructional design. These platforms also offer opportunities for differentiation, reflection, and feedback, which are critical for building pedagogical design capacity and instructional confidence.

This study investigated how EduSmart, a science-focused LMS, supports EC-6 PSTs in developing SCK, PCK, and teaching self-efficacy. This research is grounded in the need for intentional IT that enhances, rather than replaces, instructional practice. Prior studies indicated that

PSTs' perceptions of their ability to use IT are closely tied to training experiences and influence future classroom practices (Kartal & Dilek, 2021; Willis et al., 2014). This study sought to explore how PSTs acquired science content, practiced instructional planning, and reflected on how to apply these tools in diverse classroom settings.

Objectives of the Study

The objectives of this research study were to (a) examine the impact of an SP-LMS on EC-6 PSTs' teaching self-efficacy, (b) explore how LMS engagement supports the development of SCK and PCK, and (c) investigate how PSTs plan to apply the LMS instructional strategies in future classroom practice. To strengthen PSTs' pedagogical design capacity (PDC), the study emphasizes the importance of purposeful instruction that incorporates curriculum resources and opportunities to build both content and pedagogical knowledge (Brown, 2009). By providing access to engaging IT tools and LMS, PSTs can develop a stronger foundation in science education, enabling them to create meaningful learning experiences that encourage students to explore and make connections across scientific phenomena (Darling-Hammond et al., 2017; Willis et al., 2014).

Theoretical Framework and Related Literature

According to Bandura's (1997) social cognitive theory, teacher self-efficacy refers to a teacher's belief in their ability to perform teaching tasks and achieve desired student outcomes successfully. High self-efficacy is associated with greater persistence, openness to new instructional strategies, and a stronger commitment to student-centered teaching (Klassen & Tze, 2014). In science education, self-efficacy is particularly important for PSTs, as it influences their confidence in planning and delivering science lessons (Bleicher, 2007). However, many PSTs report having a low science teaching self-efficacy (STSE) due to limited content knowledge and teaching experience (Palmer, 2011). Incorporating ITs that incorporate inquiry-based learning and scaffold concepts may address these challenges by offering structured, interactive opportunities for practice and reflection.

Bandura (1997) identified four sources of self-efficacy: mastery experiences, multiple experiences, social persuasion, and physiological and emotional states. Engagement with LMS may positively influence these sources. Feedback is often used as a form of social persuasion and reinforces confidence in PSTs' teaching abilities. Although self-efficacy can improve through these experiences (Bandura, 1997), building content-specific knowledge in science and mathematics is essential for creating confidence and instructional effectiveness (Jeffery et al., 2018; Singh, 2022).

This study examines EC-6 PSTs' STEBI-B and reflections to explore how LMS engagement influences their self-efficacy, preparedness, and instructional planning.

Pre-Service Teacher Pedagogical Content Knowledge

Pre-service science teachers often struggle to develop pedagogical content knowledge (PCK), which combines subject expertise with effective teaching strategies, due to limited experience and a shallow understanding of content (Abell, 2008). Traditional science courses often fail to model K–12 instructional practices, making it challenging for future educators to connect scientific concepts to students' everyday experiences (Lenamon, 2019). Instructional technologies and LMS can support PCK development by offering interactive tools and simulations that promote student-centered learning (Gess-Newsome, 2015). As PSTs integrate these tools, they also build technological pedagogical content knowledge (TPACK), which enhances their ability to use technology effectively in instruction (Mishra & Koehler, 2006).

Science Learning Management Systems

The integration of ITs into elementary science education has significantly improved instructional delivery and student learning by supporting differentiated instruction and increasing engagement. Tools such as animations, simulations, and interactive assessments enable educators to present complex scientific concepts in more accessible and varied formats, which helps address diverse learning needs and encourages inquiry-based learning through virtual experimentation and self-paced activities (Kumar & Natarajan, 2020). These technologies play a critical role in developing PSTs' TPACK, enhancing their ability to incorporate digital tools into science instruction effectively (Mishra & Koehler, 2006). Additionally, digital platforms enhance formative assessment practices by providing immediate feedback, enabling students to track their progress, and allowing teachers to adjust instruction based on student performance, thereby supporting both academic achievement and instructional confidence (Shirley & Irving, 2015).

Science-specific LMSs serve as essential platforms in teacher preparation by providing structured environments where PSTs can access, organize, and interact with science content. These systems consolidate multimedia instructional resources (i.e., simulations, virtual labs, and formative assessments) into a centralized space, enabling future educators to explore and refine their instructional strategies (Martin et al., 2019). Through science LMSs, PSTs can experiment with adapting materials and assessments to meet the needs of diverse learners, fostering differentiated instruction and inclusive classroom practices (Sun & Chen, 2016). The immediate feedback capabilities of LMSs further support pedagogical development by allowing users to evaluate lesson effectiveness and comprehension in real-time, which promotes reflective practice and instructional adjustments (Alammary et al., 2014). These features enhance content delivery, foster collaboration, and ultimately contribute to the development of confident and responsive science educators.

Methodology

This mixed-methods pilot study used a phenomenological approach (Moran, 2002) to explore the experiences of 22 EC–6 PSTs as they engaged with EduSmart, an SP-LMS. Quantitative data were collected through pre- and post-administration of the Science Teaching Efficacy Belief Instrument (STEBI-B). PSTs also completed standards-aligned modules that included simulations, readings, and interactive activities targeting areas of low prior performance. Reflections were collected to examine how PSTs perceived the impact of EduSmart on their SCK, instructional planning, and classroom application. Reflection prompts asked PSTs (a) How do you feel EduSmart impacted your science content knowledge? and (b) What did you observe or experience when reviewing the ES resources that you could use to differentiate science student learning?

Researchers independently hand-coded the reflections and then compared their initial codes. Upon revisiting the reflection prompts, they concluded that the themes identified in this study were derived through deductive coding, as they directly aligned with the structure and focus of the prompts. Initial codes include retrieval, differentiation, real-world connection, new learning, lesson summarization, and recollection. Researcher debriefs strengthen credibility and confirmability, aligning with Lincoln and Guba's (1985) criteria for trustworthiness in qualitative inquiry. The researchers confirmed two emergent themes: SCK development and differentiation.

Results and Discussion

Quantitative Results

Following participation in the EduSmart LMS assignments, EC-6 PSTs demonstrated substantial gains in science teaching self-efficacy (STSE). A paired t-test was conducted to determine if a statistically significant mean difference existed in preservice teachers' science teaching self-efficacy from prior to and following program participation in EduSmart. Results of the paired t-test indicated there was a statistically significant mean difference in preservice teachers' teaching self-efficacy from pre- to post-participation, $t(24) = 4.189$, $p = .001$, $d = .799$ (large effect size), $r^2 = .138$ (see Table 1). The average science teaching self-efficacy increased from prior ($M = 77.9$, $SD = 6.5$)

to following participation in the EduSmart program (M = 82.5, SD = 4.9). The EduSmart program had a large effect on the science teaching self-efficacy of the students and 13.8% of the variance in their science teaching self-efficacy is attributable to the program.

Table 1

Science Teaching Self-Efficacy of Pre-Service Teachers

	N	M	SD	*t*-value	df	*p*-value	d	r^2
1. Pre-Science Self-efficacy	25	77.9	6.5	4.189	24	.001*	.799	.138
2. Post-Science Self-efficacy	25	82.5	4.9					

*Statistically significant ($p < .05$)

Results from the survey showed a statistically significant increase in STSE. Notably, following the use of the EduSmart LMS, over 94.8% of PSTs expressed confidence in knowing the steps necessary to teach science concepts effectively, an 80% increase. They also reported a 66.5% increase in their science teaching efforts and the resulting impact on students' science achievement. Additionally, 77.6% of PSTs indicated that students' science achievement was directly related to their teacher's effectiveness in teaching science. Reported confidence levels increased across multiple areas, with a significant improvement observed in their belief that they could help students who are having a difficult time understanding science. These findings suggested that structured engagement with a SP-LMS can enhance both SCK and instructional confidence, supporting the development of effective and reflective science educators.

Qualitative Findings

Science Content Knowledge

The first theme reflects PSTs' SCK, encompassing recall, reinforcement, clarity, and conceptual understanding. Most PSTs found the video delivery through the Instructional Modules (IMs) of the content to be clear, engaging, well-organized, and effectively broke down complex science topics. They helped to refresh prior knowledge and learn new concepts in a simplified manner, which increased their comprehension.

Refreshing Memory. The reflections revealed that EduSmart helped PSTs revisit and deepen their understanding of science concepts. The classification of matter module was frequently cited for its clarity and visual support. One PST shared, "These videos also helped me refresh my memory about information I learned in science as a child." At the same time, another noted, "It helped me get a better idea of the differences [in concepts] because I can visualize what the concepts mean." Another one commented, "I had always thought that only coal and oil were formed from the remains of organisms." This showed how the IMs helped to reinforce prior knowledge, clarify foundational science concepts, and correct misconceptions while introducing PSTs to new insights.

Strengthening the Understanding of Science Concepts. Most PSTs felt that EduSmart significantly enhanced their understanding of science concepts. The visual explanations supported conceptual learning. Many felt that the IMs helped deepen their understanding of concepts. One PST shared, "Prior to this assignment, I did not realize the specific ways fossil fuels form… Now I understand it is because they result from dead plants and animals from millions of years ago." Some also found the virtual labs valuable because they were able to formulate and test hypotheses, observe outcomes, and work through the scientific method. Another PST noted how frightened she was of topics. She recalled how watching the IM activity reduced her fear of learning and said, "The minute that I began watching the videos I was so impressed with the way that they presented the information." This positive response helps increase students' ability to learn complex concepts.

The PSTs felt that the simulations were a powerful tool, helping them increase their understanding of complex concepts, especially those related to electrical circuits. They thought the Circuit Fixer simulation provided a semi-hands-on approach that allowed them to troubleshoot why the light was not working. This provided PSTs with the opportunity to ask questions and form hypotheses to test different circuit configurations. One shared, "This is exactly why I did the simulation because it allows you to make your hypothesis and put together the circuits to see what will work and what will not." The simulations provided PSTs with opportunities to practice problem-solving, which helped solidify their learning and fostered their critical thinking.

Differentiating Science Content

The second emergent theme identified how PSTs would differentiate the content they worked through and provide support to their future students. They felt that EduSmart's built-in features (i.e., text-to-speech, note-taking tools, journal prompts, and graphic organizers) were valuable for differentiating instruction and supporting diverse learners. One PST noted, "It makes differentiation easier as it provides text to speech and note pages for students to use while watching the videos." Another one followed up with, "The World Explorer and IM Companion provided fantastic visuals… which I have learned is the best way to help support your ELL students in learning new content." The flexibility of the resources not only allows PSTs to access and engage with SC in ways that align with their learning styles but also reinforces the importance of providing similar opportunities for their future students.

Discussion

According to Bandura's self-efficacy theory, individuals' beliefs in their capabilities significantly influence their motivation, learning, and performance. Increasing PSTs' science teaching self-efficacy (STSE) is therefore critical to preparing them to teach effectively across multiple content areas. As Bandura posits, mastery experiences are the most powerful source of self-efficacy. Structured engagement with SP-LMS, such as EduSmart, directly supports components of self-efficacy and provides PSTs with opportunities to build content knowledge and gain practical experience, both of which are essential for developing instructional confidence. One component of self-efficacy, mastery experiences, is fostered through repeated, successful interactions with content and activities in SP-LMS. Multiple experiences can be supported as PSTs model teaching strategies and student-centered learning, which helps them envision classroom implementation. Scaffolded prompts, guided reflections, and feedback help to build PSTs' social persuasion. Finally, the positive and simplistic nature of LMSs can reduce student anxiety and confusion by positively influencing students' physiological and emotional states. These components help to increase PSTs' self-efficacy.

Science-specific LMSs, such as EduSmart, appear also to have a profound impact on PSTs' SCK, instructional planning, and teaching self-efficacy (Bandura, 1997). They can provide ways for PSTs and K-12 students to revisit and better understand challenging concepts (i.e., circuits and refraction) while also correcting misconceptions and deepening their understanding of the learning process from a student's perspective. LMSs need to be engaging, student-centered designs that support PST preparation, inspire curiosity and creativity, and use clear visuals followed by virtual labs or simulations, to help solidify student learning. Gess-Newsome (2015) supports this notion, finding that student-centered learning can be enhanced by using interactive tools and simulations.

Providing effective ways to differentiate student learning is also critical to supporting student learning. Embedding differentiated tools into LMSs is imperative to increase access to all students, including PSTs. This will empower educators and teacher preparation programs to create effective and engaging science lessons that foster both PST growth and student success, all of which inform classroom instruction. Kumar and Natarajan (2020) believe that providing simulations makes complex topics more accessible to diverse learners through the use of inquiry-based learning. Providing PSTs with the opportunity to utilize LMS resources such as these and consider how they can apply them to differentiate lessons in their classrooms is critical to supporting all students. Mishra and Koehler (2006) believe that this critical role helps to enhance PSTs' ability to think through how they will incorporate digital tools into their science classroom.

Implications

These findings can help teacher education programs, PST trainers, and PD providers to better understand the impacts of using SP-LMS in their science methods courses. A greater understanding of how to use LMSs for instructional design is critical to providing personalized, differentiated instruction to all students. Teacher candidates could benefit significantly from gaining experience by working in LMSs before entering the field. Administrators should seek new teachers who have experience working with SP-LMSs and who know how to implement different resources into classroom instruction. By equipping PSTs with adaptable, interactive tools and experiences, we not only foster their personal growth and preparedness but also build self-efficacy through meaningful, mastery-based learning.

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LONG-TERM RETENTION OF ANATOMY AND PHYSIOLOGY CONTENT KNOWLEDGE

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Abstract

Anatomy and physiology is a course sequence required for nursing majors and some professional programs. Retention of content knowledge is always important, but especially for these students because future coursework and career skills build on this foundational content. This study examines long-term retention of muscular and nervous system information by examining student responses to a free-response questionnaire administered before the unit, immediately following the unit exam, and again five weeks after the unit exam. We found that there were significant gains in content knowledge immediately after the unit, as well as significant losses five weeks later.

Keywords: anatomy, physiology, education

Introduction

Anatomy and Physiology (A&P) is a two-semester undergraduate course sequence that is foundational for nursing and kinesiology majors as well as some professional programs. The course is very integrative in nature, as organ systems do not work individually, but in conjunction with other systems. Learning how to transfer and apply this content knowledge is important because future coursework in the major and professional school builds on A&P. Therefore, not just a good understanding but also retention of course content is important for success as students move to higher-level coursework.

This study examines long-term retention of muscular and nervous tissue physiology in undergraduate A&P students at a private university. At three different time periods, students completed free-response questions relating to the content over the muscular and nervous systems. They were asked about muscle actions and attachments, to describe how a muscle fiber was stimulated to contract, how the muscle fiber shortens, and how action potentials happen. Students were free to use any mechanism to explain their answer, including sentences, flow charts, or labeled sketches. This assessment was given three times: at the start of the semester, immediately following the unit exam on this content, and five weeks after the unit exam. The content was not taught or reviewed again after the unit exam. With these free-response questionnaires, we sought to determine how much and what types of content knowledge students gain and retain over the course of the semester.

Objectives of the Study

This study seeks to identify how student knowledge changes over time. It is known that knowledge wanes over time if other information or events do not reinforce it (Lindsey et al., 2014). Our research question asks how much and what types of knowledge are retained without further review of the content.

Related Literature

Previous research has examined the role of pedagogy in knowledge retention. Several studies demonstrate effective gains in long-term retention by using retrieval-based testing (Lim et al., 2015; Roediger & Butler, 2011). However, Jakobsson and colleagues (2024) found that there was no impact on an immediate posttest or a delayed posttest when randomizing students in groups to study retrieval-based learning versus discussion. While they found no difference on test scores, retrieval-based testing did increase student motivation.

Nursing education has not been studied as much as medical education, though both involve learning anatomy and physiology (Narnaware, 2022). Medical educators are interested in the ability of their students to retain their knowledge in their future careers as physicians. While some educators perceive didactic medical content retention as a long-standing problem, this is not the case as medical school students demonstrate about 70% retention after one year (Custers, 2010). Another study on medical students examined what types of knowledge decline fastest over time (Haycocks et al., 2024). While they hypothesized that scores for recall/verbatim questions would be higher two years later compared to conceptual understanding, they found that performance on these questions was significantly worse compared to performance on concept/inference questions, indicating that conceptual thinking may be more complex and also more durable than rote memorization.

Other studies investigated the impact of integrating art with science. While Hardiman and colleagues (2014) found no difference in initial learning in astronomy and ecology units, there was significantly better retention with arts integrated with the science content. In particular, grades increased the most for students in the arts group with the lowest levels of reading achievement.

Other groups have found similar increases in long-term retention when integrating art with science (Lysne & Miller, 2017; Rosen-O'Leary & Thompson, 2019).

Methodology

This study includes voluntary student participants enrolled in an A&P course at an American private university. Students at this university are 62% female, and 62.8% white; 17.8% are Hispanic/Latino, and 4.7% are Black. Students enrolled in this A&P course are primarily nursing students (73% of the class), with the second highest group being kinesiology majors (16%). This course consists of 63% freshmen and 30% sophomores. The research design incorporates students enrolled in two different sections of the course, taught by different instructors. For this unit, each of the two instructors has at least 10 years teaching experience, and they used the same learning outcomes, the same unit exam question pool, and the same free response questions.

The unit chosen for this study covers muscular and nervous tissue physiology. This is the first unit in which students encounter more complex physiological processes, and certain content from this unit (such as action potentials) is likely to be referenced again in the second semester of the course. Exam scores from this unit are often 5-10% lower on average than other unit exam scores.

The free-response questions were designed to give students an opportunity to explain what they know without the crutch of multiple-choice options to remind them. The first free-response questionnaire was given in the first two weeks of the semester to determine baseline knowledge, before students covered any material on the unit in class. The second free-response questionnaire was given immediately following the multiple-choice unit exam, when the students should have the highest level of content mastery. The third free-response questionnaire was given at the end of the semester, approximately five weeks after the unit exam. The questions on each questionnaire were the same.

Questions were intended to have students demonstrate their understanding in a way that best suited them, whether that was through writing sentences, drawing a sketch, or creating a flow chart. These were the free response questions administered to all students for all three free response assessments:

1. Name all actions of the zygomaticus major muscle.
2. Name all skeletal attachments of the rectus femoris muscle.

3. Explain how a muscle fiber is stimulated to contract. Include as much detail as possible. Labeled drawings, flow charts, ordered sentences or other ways of explaining are all acceptable.
4. After excitation of a muscle fiber, how does a sarcomere shorten? Describe the steps of the sliding filament mechanism and how these relate to the shortening of the sarcomere. Include as much detail as possible. Labeled drawings, flow charts, ordered sentences or other ways of explaining are all acceptable.
5. Draw a labeled graph of the events of an action potential in a neuron. Label the axes and regions of your graph. Write a few sentences explaining your graph.

All student names were blinded and replaced with a randomized student number before data analysis began. During data analysis, we used pre-determined codes to classify answers. Codes are based on the student's ability to explain the concepts and demonstrate their understanding with expectations appropriate for an undergraduate student. The codes are the following: (a) no understanding, (b) partial understanding, (c) naïve understanding, (d) approaching understanding, and (e) advanced understanding with reasoning. Answers were scored by three individuals familiar with the content. For each question, we achieved an intercoder agreement of at least 90%. A one-way ANOVA was performed to determine if there were changes in average question scores across the three free-response questionnaires.

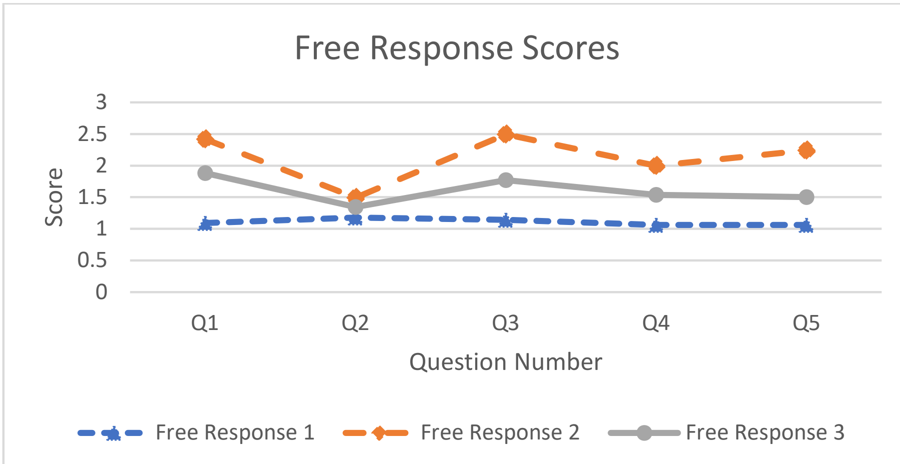
Additionally, the responses were qualitatively examined for emerging themes common among students using the constant comparative method (Glaser & Strauss, 1967). These themes include the creation of drawings by students to answer questions and that some types of knowledge are retained better than other types. Students sometimes remembered how the processes worked but struggled to remember the proper scientific terminology that accompanied it. Content that had been taught with multiple modalities, including speech, drawings, and/or gestures, was better retained by students.

Results and Discussion

The first free-response questionnaire (Free Response 1) given at the beginning of the semester before the unit was taught showed that students brought limited muscular and nervous system content knowledge with them into the course. While some of these students had the opportunity to learn about some of the material from previous classes, such as high school or college biology or psychology, students on average scored in the "no understanding" range with a score near 1 for all questions (Figure 1).

Figure 1

Free-response Questionnaire Scores



The second free-response questionnaire (Free Response 2) given immediately following the unit exam demonstrated growth in the students' abilities to explain content without the crutch of simply recognizing correct multiple-choice options. Students made significant gains on all questions and averaged a score of 2 indicating "partial understanding." Gains were highest for question 1 over muscle actions, question 3 on muscle contraction stimulation, and question 5 on action potentials (Table 1).

Table 1

Percent Gain and Loss Over Time

Question	Percent Gain Between Free Response 1-Free Response 2	Percent Loss Between Free Response 2-Free Response 3	Net Percent Gain Between Free Response 1 - Free Response 3
1	120%*	22%	72%*
2	27%*	10%	14%
3	118%*	29%*	55%*
4	45%*	23%*	45%*
5	102%*	33%*	35%*

*$p<.005$

The third free-response questionnaire (Free Response 3) given five weeks after the unit exam showed knowledge loss in a significant decrease in the average score for questions 3, 4, and 5. Generally, the more knowledge that was gained between Free Response 1 and Free Response 2, the higher the percentage of the loss between Free Response 2 and Free Response 3. Question 1 on muscle actions saw a 22% decrease in average score, question 3 on muscle contraction stimulation saw a 29% decrease, and question 5 on action potentials saw a 33% decrease in score. The students still exhibit a net gain in their knowledge for all questions, despite a decrease over time after the conclusion of the unit (Table 1).

In addition to scoring responses, we also analyzed the free-response questionnaires for emerging themes. These themes included using drawings to explain their answer, as well as issues with using proper scientific terminology in their responses. There were wide variations in the completeness of answers, whether the student used sentences or drawings to explain themselves.

Student Drawings

Students often chose to create a drawing to answer one or more of the free response questions. Both instructors explained the content for question 3, explain how a muscle fiber is stimulated to contract, by creating a board drawing and adding to it over time as the processes were explained. In their free response answers, students often copied these drawings to answer the question, and the student drawings highly resembled the drawings the instructors made during class. For question 4, explaining how a sarcomere shortens, the instructors did not create drawings on the board, but several students created their own drawings anyway to answer the question. However, there was wide variation in how detailed any of the drawings were, such as whether or not the structures were labeled properly, and if the drawing was complete or incomplete.

Lack of Proper Terminology

Students often struggled to properly use scientific terminology to explain processes in the free response questions. Students often were able to explain the gist of their ideas with their drawn pictures, but the proper scientific terminology was often lacking. For example, to explain the sliding filament mechanism (question 4), Student 2024-282 (Free Response 2) wrote “Ca2+ binds to (can’t remember protein name).” Student 2024-276 (Free Response 2) answered for question 4 “myosin grabs actin sight [*sic*], pulls actin sight, lets go using ATP, moves to new actin sight.” At this point, students had just taken the multiple-choice unit test, which is a required graded assessment for the course, so their knowledge should have been at its highest point, but they still struggled with coming up with terminology by themselves. Students were able to demonstrate some of their knowledge with sketches and drawings, although they struggled with the proper scientific vocabulary and labeling all the components on their sketches. In Free Response 3 given five weeks after the unit test, the number of labels and descriptions of drawings decreased. The shapes of lines students used to indicate structures or slope of a graph are mostly correct. However, labeling and explanation of what the drawing entails is lacking, and someone unfamiliar with the content would not understand what the drawings are representing.

Conclusion of Results

Students gained significant ability to answer free response questions on the muscular and nervous tissues after instruction on the content, but also lost significant knowledge in the five weeks following. The content on the questions was referenced a limited amount, if any, during those five weeks after the unit test. In general, the more knowledge that was gained during the unit, the more knowledge was lost afterward. Overall, students still gained significant knowledge from the unit, despite the loss over time after the conclusion of the unit. While students still scored higher on the end of semester Free Response 3 compared to their baseline knowledge measured with the beginning of semester Free Response 1, additional review or incorporation of the material after the unit test may be helpful to increase retention.

Implications

Some undergraduate science courses, such as A&P have the reputation of being "gatekeeping" or "weed out" courses because students must achieve a grade of C or better to continue with coursework in the student's chosen STEM major and achieving that grade can be difficult due to the volume and/or complexity of the content. For many, failure to pass the course will mean the end of the student's planned career in a science profession. Nationally, this course has a 30-50% drop/fail/withdraw rate (Lunsford & Diviney, 2020; Marwaha et al., 2021). Performance on a unit exam is an indicator of how students understand the material, but often instructors do not measure how much of that material is retained over time. Understanding how much content knowledge is lost or retained is valuable information that can inform teaching and assessment design. This study gives insight into how much and what types of knowledge are retained in an undergraduate A&P course.

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TEACHERS' PERSPECTIVES ON WILDFIRES

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Abstract

This study investigated teachers' understanding about wildfire, its causes, and effect on humans. We used an anonymous survey method and collected data from K-12 educators. Findings indicated that most of the participants (69%) did not conceptualize wildfire as uncontrolled fire and only 18% mentioned human impacts on climate change or how it affects wildfires. Additionally, most of the participants (75%) did not have enough knowledge about the positive effects of wildfires or didn't think to share them. Some of them (25%) knew that wildfires have a positive effect but were not very clear about how wildfires can benefit humans.

Keywords: teacher, K-12 educator, wildfire, misconceptions, conceptual understanding

Introduction

Wildfires are one of the most pressing environmental challenges in many regions of the United States. As global temperatures continue to rise, the frequency and intensity of wildfires are increasing, leading to profound impacts on both human societies and natural ecosystems. Promoting public awareness of wildfire science and fire safety practices is essential for reducing risks and building resilience in communities situated in fire-prone landscapes. Teachers play a crucial role in shaping students' understanding of how climate, vegetation, and human activities shape wildfire behavior and help students think critically about how we can respond to environmental challenges. This supports students in seeing fire as a natural process, not just a destructive process. However, teachers often face significant obstacles in teaching Earth's climate (Carroll Steward et al., 2024). These difficulties are largely due to a lack of confidence in their science content knowledge, challenges aligning climate-related topics with curriculum standards, and uncertainty about how to effectively incorporate these subjects into their teaching (Bhattacharya et al., 2021; Carroll Steward et al., 2024). Research also shows students frequently have trouble understanding climate concepts and hold misconceptions about how Earth's climate system functions (Bhattacharya et al., 2021). More importantly, if teachers have misconceptions that often leads to the transmission of inaccurate scientific concepts to the student that can result in developing persistent misconceptions in students. It also reduces the teacher's ability to explain concepts clearly or address student's misconceptions effectively (Fikri et al., 2023; Karakaya et al., 2021). Therefore, addressing teachers' knowledge gaps on wildfires is crucial because integrating wildfire-focused content into K–12 education can enhance students' understanding of these complex ecological challenges (Restaino et al., 2024). This study aims to identify prevalent misunderstandings and provide insights for improving wildfire-related science education. We address three research questions:

1. How do teachers conceptualize the impact of wildfires on humans?
2. How do teachers define wildfire?
3. How do teachers conceptualize the relationship between human activity, climate change, and the frequency or intensity of wildfires?

Theoretical Framework and Related Literature

Wildfires play a dual ecological role as both destructive forces and essential natural processes. In many regions, wildfires help in nutrient cycling, biomass removal, seed germination in fire-adapted species, and maintaining biodiversity (Pausas & Keeley, 2019). However, climate change, land-use alterations, and urban growth have disrupted natural fire regimes and resulted in a megafire impact on not only ecological systems but also on human health, infrastructure, and economies (Reid et al., 2016). In order to help students develop environmental literacy, teachers must possess accurate knowledge of wildfire science. Unfortunately, many studies have documented misconceptions among teachers regarding environmental issues. For example, Plutzer et. al. (2016) conducted the first nationally representative survey of 1,500 secondary science teachers in the United States to explore how they present climate change in their classrooms. Results showed 30% of teachers emphasized natural causes of global warming, and 12% avoided emphasizing human causes. About 31% of teachers presented contradictory messages, teaching both the scientific consensus that humans caused global warming and that natural causes are equally significant. Liu et al. (2015) investigated in-service teachers' attitudes, knowledge, and teaching practices related to global climate change (GCC), particularly in Native American communities in the Midwestern U.S. Findings indicated that although most teachers expressed concern about GCC and recognized it as an important issue, some teachers demonstrated skepticism, attributing climate variability to natural cycles rather than human activity. Moreover, many teachers demonstrated limited understanding of climate change processes, and they confused the greenhouse effect with ozone depletion.

Research on teacher misconceptions is not limited to the United States. Abasto et al. (2025) investigated misconceptions of climate change among a group of Chilean teachers. While no significant difference in understanding was found between the science and non-science teachers, overall teachers had misconceptions regarding the definition of a greenhouse gas (e.g., absorbing infrared vs. ultraviolet radiation) and the minimal sunlight absorbed by these gases. Also, many teachers held the misconception that the sun primarily emits ultraviolet radiation. A study on 197 Saudi science teachers in Riyadh revealed teachers had a high level of awareness about climate change, but could not differentiate between climate change and global warming. Also, they had confusion about the role of the ozone layer in global warming. A notable percentage of teachers (41.4%) believed that climate change heats the world evenly (Almazroa, 2024). Tang (2025) found Indonesian upper-secondary school teachers had misconceptions about the effectiveness of various solutions for climate change. For example, they ranked household recycling as more effective than family planning, which has a greater impact. Furthermore, if teachers have misconceptions, their self-efficacy for teaching the topic may be affected. Tang (2025) revealed that although teachers had a high willingness to teach climate change, they did not feel equipped with the necessary knowledge and skills to do so confidently. Therefore, addressing teachers' knowledge of wildfires is important.

We choose phenomenography as a theoretical framework for this research because it takes into account the different ways in which people experience and understand a phenomenon (Marton, 1981). Phenomenography does not assume a single, unified truth, but instead assumes that different people, in this case teachers, experience a given phenomenon in different ways (Orgill, 2018). This was used as teachers need to both understand a scientifically accurate definition of a given phenomenon and are also as influenced by everyday perceptions of that same phenomenon as their students, potentially resulting in different understandings. In phenomenographic research, the researcher(s) collect open-ended data and then analyze the data to identify common themes that may represent the different conceptions, then summarize those themes highlighting the key similarities and differences among them. Phenomenography has overlaps with phenomenology, but the difference lies in whether the researcher is focused on the essence of the phenomenon (phenomenology) or the experience of that phenomenon (phenomenography). While we are seeking to identify the myriad ways teachers may understand wildfires, a key assumption of phenomenography is that there are a limited number of ways that a given phenomenon can be understood (Tight, 2016). Phenomenography is helpful for advancing wildfire education research as it can assume both that there may be multiple truths in the understanding of wildfires but also there are only so many ways it can be understood in a scientifically accurate way. Thus, we can uncover the myriad truths, identify misconceptions, and use those to inform teacher education.

Methodology

We used an anonymous survey for data collection. The survey included 22 questions; most were open-ended questions with some multiple-choice questions. Survey questions asked about teaching background (grade level, subject, licensure), demographics (gender, age group, state, type of area), or wildfires. Questions related to wildfires focused on four general areas: definition of wildfires, location of wildfires, human impacts, and ecological relationships with wildfires. For this paper, we focused on the following four questions from the survey: How do you define wildfire? Where can wildfires occur? How do humans impact the frequency and severity of wildfires? and How do wildfires impact humans?. Surveys were sent to K-12 educators who are currently working in classrooms as full time teachers, long-term substitute teachers, or in a practicum/student teacher placement. Surveys were distributed via emails publicly available on district or school websites, via flyers at conferences, or via email to university instructors to share with pre-service teachers. The surveys were sent to a variety of educators (e.g., in public, private, and charter schools) across the United States. Teachers did not receive any incentives for returning surveys. Collected data was analyzed by thematic analysis (Merriam & Tisdell, 2016). A spreadsheet was used to organize and code the data. Two researchers independently coded a subset of the data to identify patterns and themes. Crosschecking was conducted through peer debriefing, where discrepancies in coding were discussed and resolved collaboratively. Final coding decisions were made through consensus to maintain accuracy and reduce bias. Among the participants, 50% were female, 63% primarily taught science, and 50% taught in high school. Additional information about the grade level and subject taught by each survey respondent and their location can be found in Table 1; quotes are identified in the text by teacher number. As this is a pilot study, the variation in backgrounds of the small number of participants was a pleasant surprise. The questions chosen for analysis were identified as questions that, based on responses, had clear wording that was easy to interpret for respondents.

Table 1

Grade Level, Subjects Taught, and Locations for Respondents to Survey

Teacher	Grade level	Subject	Region of US	Type of Area
1	High School	Environmental Science	East	Suburban
2	High School	Biology, Earth Science, Ecology	East	Rural
3	Middle School	Science and Math	East	Suburban
4	Middle School	Science	East	Suburban
5	High School	Biology	West	Suburban
6	Elementary	All subject	West	Suburban
7	Middle School	Math	Midwest	Urban
8	Middle School	Biliteracy	Midwest	Urban
9	Middle School	Language Arts and Social Studies	Midwest	Urban
10	Middle School	Math and Science	Midwest	Urban
11	High School	English	Midwest	Urban
12	High School	Biology	Midwest	Urban
13	High School	Math	Midwest	Urban
14	Elementary	All core subjects	West	Urban
15	High School	Science	West	Suburban
16	High School	Career technical education	West	Suburban

Results and Discussion

Definition and Location of Wildfire

In response to the definition of wildfire, 31% of the participants defined it as uncontrolled, and 12% of respondents mentioned wildfires were always unintentional. While an uncontrolled fire fits an accurate definition, sometimes humans set wildfires intentionally. At times, the fire can be set for a good reason (e.g., a controlled burn to maintain a prairie), but then become uncontrolled. A few participants (25%) mentioned only forests or trees or wilderness and did not address whether wildfires are intentional or not. In addition, some respondents mentioned wildfires could be uncontrolled, unintentional, and happen in the wilderness. For example, one participant wrote: "Off the top of my head, a fire that happens in the wild? I know there are planned and controlled fires but I believe a wildfire is unplanned and difficult to control" (Teacher 7). Most of the participants did not conceptualize wildfire as uncontrolled fire. When they responded to the question of where wildfire can occur, most of the participants (87.5%) first said wildfire can occur anywhere. Among them, some mentioned (78.6%) anywhere with fuel, forest, wood, vegetation, or plant life. Some of them confused wildfires with forest fires and were not clear about where wildfires can occur. Although there is no research on teachers' understanding of wildfires, this result is similar to Tedim and Leone's (2020) study where experts from different disciplines (e.g., Forestry, Biology, Architecture, etc.) conceptualized wildfire in different ways. They lacked a shared common understanding of wildfires. A forest fire indicates a specific location for a wildfire – in a wooded, forested area – rather than defining a different type of fire than a wildfire. It is unclear whether the teachers, however, understand that these terms (forest fire and wildfire) are synonymous.

Relationship between Human Activity, Climate Change, and Wildfires

In response to the cause of wildfires, half of the participants (50%) mentioned climate change, but only 18% mentioned human impacts on climate change or how it affects wildfires. Moreover, 43% only mentioned accidental causes. This result is similar to the Plutzer et al. (2016) and Liu et al. (2015) studies where the authors also found teachers avoided including human induced causes for global warming and climate change in their answers. Another reason some mentioned (12%) was the impact of human encroachment on natural areas, for example, "Increased population equals increased need for housing and building in all areas" (Teacher 16). So, they thought population growth leads to increased demand for housing, resulting in more people living in natural areas, which in turn contributes to more frequent and severe wildfires. In addition, one participant said, "We contribute to droughts and may not service brush areas which would increase the likelihood of a fire" (Teacher 5). Contributing to drought conditions is a direct cause whereas depleting water resources is an indirect or implied cause.

Impact of Wildfire

Most of the participants (75%) mentioned negative effects of wildfires such as loss of property, loss of lives, pollution or air quality concerns, or loss of wildlife. Only a few (25%) mentioned positive effects. In the positive effects, some of them mentioned a healthy forest but they did not explain how. For example, one participant wrote, "Can spread and burn human structures, can decrease air quality harming respiratory and circulatory systems. Wildfires benefit humans by maintaining healthy and diverse biomes" (Teacher 12). Most of the participants did not seem to have enough knowledge about the positive effects of wildfires or didn't think to share them. Some of them knew wildfires can have a positive effect but were not very clear about how wildfires can benefit humans. A similar result was found by Masri et. al. (2023) where a higher proportion (58.3%) of people in Southern California viewed wildfires as a major threat to the ecosystem.

Implications

The findings of this study have important implications across multiple domains. The results highlight the need for targeted professional development programs that address specific scientific misconceptions about wildfire. These should integrate fire ecology, the effects of climate change, and human-wildfire interactions to help teachers develop accurate, nuanced understanding. Such training can help prepare educators to present wildfire science in ways that are culturally and regionally relevant. For example, evidence-based confrontation is a strategy that could be used by including real world case studies to challenge inaccurate beliefs and encourage teachers to test their explanation through inquiry-based tasks and guided reflection. For example, if we were to conduct professional development for teachers in Nevada, we might use a case study on the Rancho Fire that recently burned over 1400 acres of land near Reno. This example would not only include a real-world case but also one that is locally relevant. Teachers could also be paired with wildfire experts or experienced educators to construct their new understandings. As there were no clear patterns based on the location of teachers, this type of training should not be limited to only teachers living in typically fire prone areas. As our climate continues to change, we are seeing large wildfires affecting areas that traditionally did not see wildfires in the past. For researchers, this study opens new doors to further research on the origin of misconceptions around wildfires and their impact on teaching practices. For policy makers and curriculum developers, this study highlights the need for integration of wildfire science into the school curriculum and also includes its connection to climate change to ensure comprehensive environmental literacy. Wildfires are an opportunity to include real-world, current impacts of climate change into the K-12 curriculum. Furthermore, this study has broader implications for fostering environmental literacy and resilience within communities. A well-informed teacher can create a learning environment that encourages students to explore mitigation strategies, sustainable land management practices and adaptive behavior to live in fire prone areas.

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TEACHING ETHICS AND INQUIRY THROUGH *THE ICEPICK SURGEON* AND PRIMARY SOURCES IN SCIENCE

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Abstract

This paper explores how integrating mentor texts and primary source documents can enhance scientific literacy in secondary science classrooms. Using "The Icepick Surgeon" *by Sam Kean as a mentor text, the lesson engages students in ethical inquiry and historical analysis through disciplinary literacy practices of obtaining, evaluating, and communicating information. A five-day instructional sequence supports student engagement with narrative nonfiction, archival materials, and guided reflection activities. Classroom examples demonstrate how this approach deepens understanding of scientific content and fosters critical thinking. Implications for practice highlight how science educators can meaningfully embed literacy and ethics into content instruction.*

Keywords: disciplinary literacy, mentor texts, ethics, secondary science

Introduction

The National Academy of Sciences (1996) defines scientific literacy as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civil and cultural affairs, and the engagement in economic productivity." MacKenzie (2023) explains that, for students, being scientifically literate means understanding how scientific knowledge is acquired, its limitations, and the continuing pursuit of scientific inquiry. However, in today's world, there are signs that students are not proficient in science, leading to a less scientifically literate population. As of 2019, only 22% of twelfth-grade students were deemed proficient in science, leaving a large majority of the population behind and showing no improvement from the 2015 or 2009 results (NAEP Report Card: Science, n.d.).

Within the Common Core State Standards (CCSS) for English Language Arts, an intersection of science and literacy is evident to "ensure that high school students are prepared to access and use science texts" while also pointing to "the importance of reading and understanding science texts….to prepare students for citizenship" (National Academy of Sciences, 2014, p. 7-8). Introduced in 2013, the Next Generation Science Standards (NGSS) developed Science and Engineering Practices (SEP) with the CCSS in mind to identify pertinent literacy connections to the specific demands within the discipline of science (NGSS Release, 2013). These practices include:

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Construction explanations (for science) and designing solutions (for engineering)
- Engaging in an argument from evidence
- Obtaining, evaluating, and communicating information (NRC, 2012)

It is the last SEP: Obtaining, evaluating, and communicating information that this paper focuses on as a basis for the lesson presented, utilizing *The Icepick Surgeon* by Sam Kean (2021), various primary sources, including images and journal articles, and the Primary Source Analysis Tool from the Library of Congress (Library of Congress, n.d.).

Objectives of the Study

The purpose of this paper is to explore how science educators can develop students' scientific literacy by integrating mentor texts and primary source documents into secondary science instruction. The SEP of *Obtaining, Evaluating, and Communicating Information* emphasizes the importance of students' ability to engage with a variety of scientific texts, interpret evidence from multiple sources, and effectively communicate their ideas—a practice that mirrors the real-world work of scientists and aligns closely with disciplinary literacy goals (NGSS Lead States, 2013; National Research Council, 2012).

To address this need, this paper presents a lesson model that utilizes "*The Icepick Surgeon"* by Sam Kean (2021) as a mentor text, along with primary source documents such as images, journal articles, and newspaper articles. This lesson explores the rise of lobotomies and the ethical controversies surrounding neurological research in the 20th century. These materials are paired with the Library of Congress Primary Source Analysis Tool to help students engage with texts in meaningful ways (Library of Congress, n.d.). The objective is to demonstrate how narrative nonfiction and historical documents can deepen students' understanding of epidemiology while simultaneously strengthening their literacy, inquiry, and critical thinking skills.

Related Literature

Content Area Literacy

Content area literacy has been defined as "the level of reading and writing skills necessary to read, comprehend, and react to appropriate instructional materials in a given subject area" (Bean et al., 2011, p. 5). The reading and writing skills emphasize a set of generalizable skills that can be used across multiple content areas (Chauvin & Theodore, 2015). With the adoption of the NGSS in 2013, there is an open door for science teachers to incorporate literacy into their science curriculum.

Disciplinary Literacy

Shanahan (2012), a major contributor to the field, notes that disciplinary literacy is *not* just a new name for content area literacy but rather is rooted in the uniqueness of each of the academic disciplines, that is "the knowledge and abilities possessed by those who create, communicate, and use knowledge within the disciplines" (Shanahan & Shanahan, 2012, p. 8). However, others argue that disciplinary literacy has its foundation in content-area literacy and utilizes many of the same approaches, drawing from previously existing content-area reading strategies (Dunklery-Bean & Bean, 2016). While the debate over which literacy framework to adopt continues, this author chooses to agree with Dunkerly-Bean & Bean (2016) that the existing content area literacy strategies have been "modified to align with a particular interpretation of the learning needs" of the specific discipline they are used for (p. 464).

Mentor Texts

Mentor texts are defined as "pieces of literature that both teacher and student can return to and reread for many different purposes" (Dorfman & Cappelli, 2017, p. 6). While mentor texts are typically utilized to model writing styles and the writing process, this author has integrated them within her science instruction in an attempt to expose students to a multitude of writing within science (Laminack, 2017). It is recommended that teachers read and analyze the mentor texts before using them within classroom instruction; that is, the teacher should be as comfortable with the texts "as a worn pair of blue jeans" (Laminack, 2017; Dorfman & Cappelli, 2007, p. 3). While many scholars believe that a specific mentor text should be revisited on multiple occasions, this author has only ever used specific mentor texts to supplement content standards within her science classroom (Sturgell, 2008; Dollins, 2016; Laminack, 2017).

The particular book used within this lesson, *The Icepick Surgeon* by Sam Kean (2021), takes readers on an engrossing and horrifying historical tour of how the search for information can go horribly wrong (Robb, 2021). Laid out in chronological order, Kean (2021) explores numerous wrongdoings perpetuated in the name of science: Cleopatra's dark doings in Egypt, the intersection of modern science and the transatlantic slave trade, Scottish graverobbers and anatomist Robert Knox, Thomas Edison's support of the electric chair, the medical abuse of Tuskegee and Joseph Mengele's experiments on prisoners of Auschwitz, and the work of Dr. Walter Freeman who performed lobotomies in the 1950s—the focus of this particular lesson.

Primary Sources

The Library of Congress (n.d.) defines a primary source as "a document, letter, eye-witness account, diary, article, book, recording statistical data, manuscript, or art object." When utilized in classroom instruction, primary sources aid students in gaining a richer understanding of the topic at hand and gathering evidence to create their own conclusions as they read (Nokes & De La Paz, 2023). To help gather evidence from primary sources, graphic organizers should be utilized, while allowing small group collaboration, asking questions that require students to analyze the text (Nokes, 2023). Fortunately for classroom teachers, the Library of Congress (n.d.) provides a Primary Analysis Tool that guides students through the examination of diverse primary sources in a structured format, supporting differentiation and accessibility for all learners. In addition, the Library of Congress (n.d.) provides access to a library of pre-selected Primary Source Sets on a variety of topics.

Classroom Practice

This lesson, titled: Icepick Surgeon Ambition: Surgery of the Soul, correlating with the chapter of the same name, includes three days of reading the aforementioned mentor text, analyzing primary source documents, reflection, discussion, and two days of synthesizing knowledge into a one-pager. A one-pager is a classroom strategy first developed by AVID, which allows students to take what they have learned from multiple sources and put the points of interest onto a single sheet of paper (Cult of Pedagogy, 2019). This lesson also incorporates instructional strategies of The Fundamental Five: a framed lesson with student-friendly learning objectives and a closing product, frequent small group purposeful talk, and writing critically (Cain & Laird, 2011). Primary sources for this lesson were obtained through the Library of Congress, highlighting early initial reports of Dr.

Walter Freeman and lobotomies (Henry, 1936; Henry, 1941; Henry, 1948; The Associated Press, 1949; Miller, 1967).

In addition, several pre-selected primary source images were used for analysis, including drawings from Dr. Walter Freeman's book, *Psychosurgery in the Treatment of Mental Disorders and Intractable Pain*, historical photographs, medical diagrams, and archival material related to Dr. Freeman's work and patients. Full citations and image sources are available upon request (Freeman & Watts, 1950).

Each day, students engaged with excerpts from the text, analyzed primary source documents using the Library of Congress Primary Source Analysis Tool, and participated in structured reflection activities to synthesize their learning framed by a learning target of: examine the impact of past neurological research by observing, reflecting on, and questioning primary source documents, engaging with a mentor text, and synthesize my learning into a Six Word Story and a One-Pager.

On Day One, students are introduced to a historical case study (Henry, 1936) and begin exploring the primary source materials that describe early brain surgeries. Once students are allowed to read the initial section titled "Case History Given" (Henry, 1936), students are paired up for small group purposeful talk with guiding questions:

- What surprises you about the description of the patient's changed behavior?
- What questions do you have?
- Develop a hypothesis about 'the operation.'

Students are then given time to read the remainder of Henry's article (1936). After some solo reflection time, students are again paired up for small group purposeful talk with guiding questions:

- Compare your hypothesis with the article.
- What surprises you?
- What questions do you still have?

Next, students are again given time to read articles from Henry (1941) and Henry (1948), and after some solo reflection time, students are again paired up for small group purposeful talk with guiding questions:

- What do you notice first?
- How do these descriptions compare to what you read in the Henry (1936) article?
- How do these descriptions compare to each other?

To round out Day One, students read an article from The Associated Press (1949), and after some solo reflection time, students are again paired up for small group purposeful talk with one guiding question: What does the award suggest about how the procedure was regarded at the time?

As part of framing the lesson, students are prompted to respond to the various readings of the day with a six-word story to synthesize their evolving understanding. Launched in 2006, the Six-Word Memoir project began with a question on Twitter: "Can you describe your life in six words?" (Smith, 2022). By utilizing this strategy, students can engage deeply with the curriculum and can "generate conversation or catalyze independent reflection" with only two real 'rules': only six words can be used, and the words should be ones that "students believe to be true and are exclusively their own" (Smith, 2022).

Day Two expands the investigation and analysis by introducing visual primary sources: medical illustrations and archival photographs. After some solo reflection time and group discussion, students are asked to isolate *one* image to fully analyze. Using the Primary Source Analysis Tool, students observed, reflected on, and questioned the images through structured prompts (Library of Congress, n.d.). As students read select passages from Chapter 8 of *The Icepick Surgeon*, they begin exploring the connections between Dr. Egas Moniz and Dr. Walter Freeman and the emergence of the transorbital lobotomy. Through paired discussions and solo reflection, students evaluate Freeman's practices through both historical and ethical lenses:

- To what extent can Walter Freeman's promotion of lobotomies be justified by the medical context of his time?
- How did Freeman's actions challenge the ethical responsibilities of medical professionals in balancing innovation with patient welfare?
- What surprised me?
- What did the author think I already knew?
- What challenged, changed, or confirmed what I already knew?

To round out Day Two, students are asked to synthesize their learning into a *new* six-word story to show a progression in their learning from Day One through Day Two.

On Day Three, instruction centers on the consequences of scientific misconduct and shifting public perceptions of experimental medical treatments. To engage students for the final day of reading and analysis, students read an excerpt by Godin & LeBlanc (2020), which examines the post-lobotomy era and the disproportionate impact of psychosurgical procedures on marginalized populations. Then, students complete the reading of Chapter 8 of *The Icepick Surgeon*, analyzing the historical and ethical context for the societal response to Dr. Freeman's controversial practices and eventual professional decline. To wrap up Day Three, students are again asked to synthesize their learning into a *new* six-word story to show a progression in their learning from Day One through Day Three.

Classroom Examples

To conclude the lesson, on Days Four and Five, students created one-pagers that synthesized their learning across the three days of instruction, focused on *The Icepick Surgeon* and primary source analysis. This culminating task asked students to visually represent their understanding of the historical, scientific, and ethical dimensions of Dr. Walter Freeman's transorbital lobotomies. Students were encouraged to include key vocabulary, ethical questions, relevant quotes, and visuals to demonstrate their thinking and learning. The following examples showcase how students made meaningful connections between science, history, and ethics while engaging in disciplinary literacy practices. These artifacts serve as evidence of how mentor texts and primary sources can foster critical thinking and content understanding in secondary science classrooms. Images of student work are provided in black and white for the conference proceedings; however, color versions can be made available upon request.

Figure 1

Student-Created One-Pager Synthesizing Key Ideas from The Icepick Surgeon and Related Primary Sources

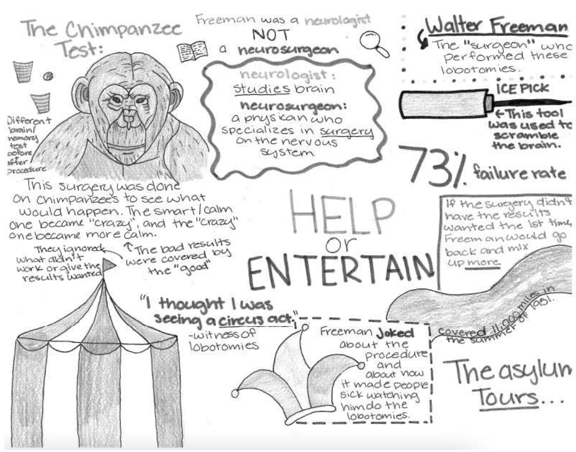


Figure 2

Student-Created One-Pager Synthesizing Key Ideas from The Icepick Surgeon and Related Primary Sources

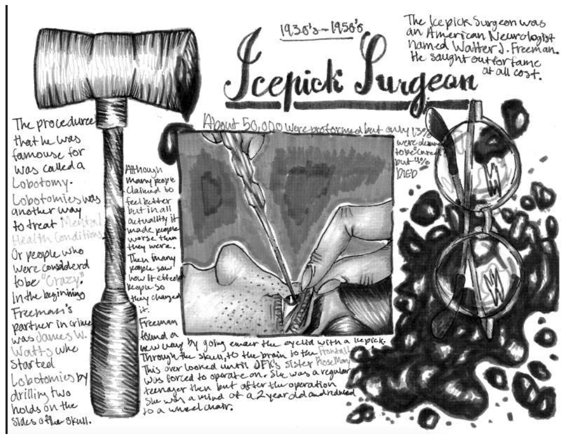
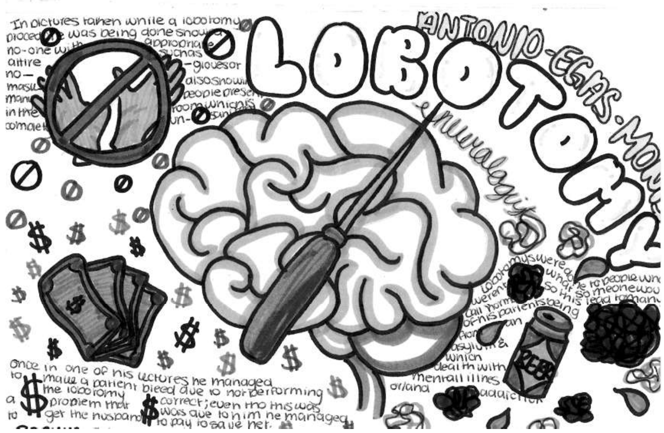


Figure 3

Student-Created One-Pager Synthesizing Key Ideas from The Icepick Surgeon and Related Primary Sources



Implications

The outcomes of this lesson underscore the value of integrating mentor texts and primary source documents into secondary science instruction. By engaging students in both narrative and historical analysis, educators can promote deeper scientific understanding while simultaneously developing critical literacy skills. These classroom experiences demonstrate how disciplinary literacy practice of obtaining, evaluating, and communicating information—central to both the NGSS and CCSS—can be authentically embedded within the content instruction. This approach not only supports content mastery but also invites students to engage with ethical complexities, historical contexts, and real-world scientific decision-making. As science educators continue to seek meaningful ways to improve engagement and proficiency, the use of rich texts and inquiry-based tools provides a replicable, standards-aligned strategy for fostering scientific literacy and preparing students to read, think, and act like scientists.

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TEACHER INTERVENTIONS IN A DIALOGIC CLASSROOM: AN INTERNATIONAL CASE STUDY IN MIDDLE SCHOOL SCIENCE

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Abstract

This study examines two international middle school science lessons and identifies discursive teacher interventions used to introduce and connect scientific concepts. Using Scott's teaching narrative framework, each classroom dialogue is analyzed to pinpoint specific interventions in a dialogic classroom to further develop and operationalize how teachers shape and mark ideas in practice.

Keywords: dialogic, teacher interventions, shaping ideas, marking ideas

Introduction

Educational research has established that dialogic classrooms in which students and teachers are "co-inquirers" engaging in collaborative meaning-making results in higher learning and engagement (Reznitskaya, 2012). Language and discourse are far from a simple means to an end but rather the very tools used to make sense and build meaning out of the world around us. The teacher provides the opportunities to "engage in forms of discourse grounded in dialogic function" (Scott, 1998). However, despite dialogic, inquiry-driven instruction being considered a best practice in education, it is relatively rare in real-life classrooms (Michaels & O'Conner, 2013). This is hardly surprising given the multiple barriers to facilitating productive academic discussion. Dialogic interactions, while fruitful, are often time-consuming and anxiety provoking, especially when teachers are keenly aware of the time constraints from pacing requirements and content standards (Chin, 2006; Michaels & O'Connor 2013). Additionally, there may be a lack of familiarity with how to facilitate a dialogic classroom due to the inherent unpredictability of group discussions as well as the underdeveloped skill of guiding, prioritizing and ignoring student contributions in real time (Michaels & O'Connor, 2013; Soysal & Soysal, 2024). Classroom discussion involves a wide array of sociocultural variables that are difficult to predict, manage, and direct especially when balancing the interactive nature of said discussions with any given content and skill-based goals. The teacher's role is to provide opportunities through the medium of language to scaffold the students' understanding. Nevertheless, opportunities alone do not inherently prompt meaningful learning, but rather scientific understanding can be achieved through intentional and responsive interventions.

The concept of teacher interventions in service to a dialogic classroom is noble but ultimately ineffective if not operationalized. Teaching is a highly complex set of interactions that are constantly in flux even minute by minute, therefore any hope of impactful research lies in its ability to be made accessible to classroom participants.

Objective of Study

The purpose of this study is to expand the meaning and significance of "shaping ideas" and "marking key ideas" from Phillip Scott's Teaching Narrative in an effort to operationalize the definitions (1998). The researcher seeks to identify an array of specific tools and techniques used by teachers when developing a conceptual line in an inquiry-based lesson and to compare and contrast discursive styles in two distinct classrooms.

Related Literature

Researchers have examined ways that teachers use language and discourse to control, guide, and shape student learning (Bansal, 2018; Chin, 2008; Edwards & Mercer, 2014). While many studies analyze snapshot moments and extrapolate from specific interactions to wider rules and patterns, Phillip Scott (1998) weaves the various interventions into a teaching narrative that is divided into 3 strands and associated pedagogical interventions; the first of which is "Marking Ideas" and "Shaping Ideas". While this framework takes into consideration that discursive learning occurs over long periods of time and is situated in a much broader classroom context, the operationalized meaning of these two interventions is never fully explained. Scott continues to expound on discursive interventions in *Meaning Making in Secondary Science Classrooms* written with Eduardo Mortimer (2010). They express reservations about curriculum trends that focus on the "doing" in the classroom-experiments, activities, or tasks rather than viewing the primary instructional tool to be language. This harkens back to the concept that doing science is talking science and that language is the primary tool of teaching and learning (Lemke, 1990). Talking allows students to engage in in-depth meaning making which transforms into learning. The authors explore the ways in which meaning is constructed in a science classroom through developing the scientific story. Learning is staged by a teacher who plans a script that is rehearsed between all participants to make the scientific story available to all learners with the stated goal of internalizing scientific concepts via accessing school science language. They present an analytical framework that organizes different parts of teacher-student interactions breaking down how the teacher makes the scientific story available to all students. Other contributions to teacher interventions include Chin's cataloguing of teacher questioning strategies (2008) and Michael and O'Connor's "talk tools" (2015). The language used to describe classroom interactions shifts even further away from the emphasis on teacher control. No longer do teachers direct and control the dialogue, rather they support, collaborate, and provide opportunities. The research question addressed in this study is: Which discursive interventions do teachers use to develop the conceptual line?

Methodology

In order to examine classroom interactions, I selected videos from the 1999 Third International Mathematics and Science Video Study that fit the pattern of dialogic/interactive lessons (Mortimer and Scott, 2003). One video is of a force and motion lesson from an 8th grade class in Australia and another is a density and buoyancy lesson from an 8th grade classroom in the Czech Republic. I initially read through the transcripts to gain a sense of the whole while paying attention to the overarching tone and feel of the lesson. On the second reading, I annotated and observed patterns of interactions in order to sense the varying styles of teaching. Teacher interventions were previously applied such as the Teacher Question series and joint construction of knowledge from Lemke (1990), cued elicitation of student contributions and reconstructive recaps from Edwards and Mercer (2024) along with the characteristics of Reflective Discourse such as the Reflective Toss from van Zee and Minstrell (1997). After identifying the a priori themes from research, I then added emergent themes such as coaching students to initiate questions, encouraging argumentation, and explicitly pointing out the significance of certain student utterances. Using the initial examples and brief descriptions of Shaping ideas and Marking ideas from Scott's Teaching Narrative (1998), I sorted the identified interventions into both categories and then separated them between question-based interventions and discussion-based interventions then applied a frequency count.

Results and Discussion

While analyzing the ways in which the teachers specifically intervened to introduce, sustain, and develop understanding regarding scientific phenomena, the following interventions were identified as well as examples and further characteristics elaborated.

Shaping Ideas

The first three interventions came in the form of questions directly posed to students as opposed to the final five interventions that came in the form of statements in a discussion clearly designed to elicit a response. The primary function of these interventions was to advance student understanding along a progression of ideas leading students to authentic "discoveries" via their own thoughts, prior knowledge and logic.

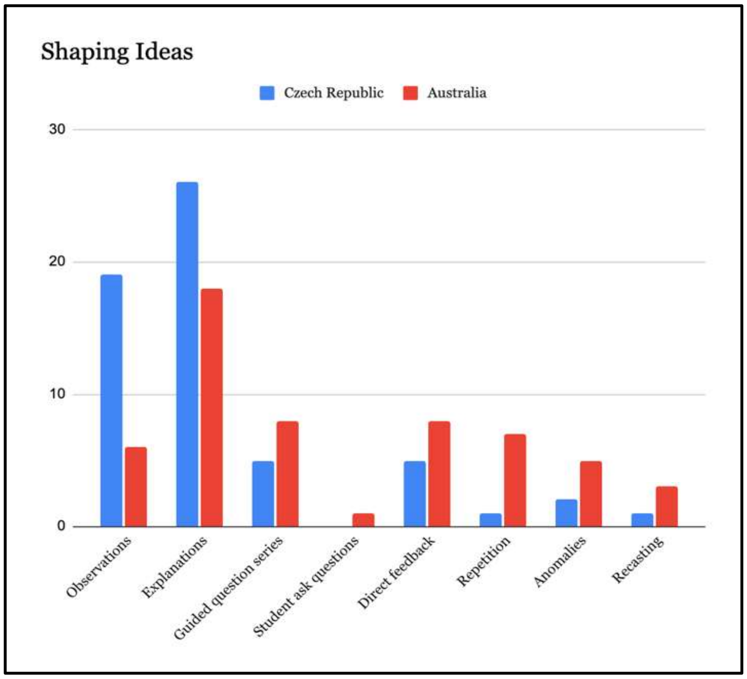
Figure 1

	Teacher Action	**Description**
1.	Eliciting student observations	Teacher asks what the students see or notice about a particular phenomena
2.	Eliciting student explanations and opinions	Teacher asks student to elaborate on their thinking and make implicit understanding explicit
3.	Guided question series	Series of close-ended questions to lead to a particular conclusion
4.	Coaching students to ask questions	Reversing roles and encourage students to practice inquiry and form their own questions
5.	Direct feedback about correctness	Directly reinforcing if an idea is correct or incorrect
6.	Repeating student ideas to elicit elaboration	Teacher repeats a student contribution in order to encourage the student to elaborate on their idea
7.	Drawing attention to anomalies	Pointing out parts of a working theory that do not fit
8.	Recasting	Rephrasing student ideas in scientific language

Shaping Ideas Teacher Actions and Descriptions

Figure 2

Observed Shaping Ideas Teacher Actions Counts for Czech Republic and Australia Teacher Videos



When the identified interventions were counted during the course of the video, a pattern emerged in that the teacher in the Czech Republic relied heavily on asking questions to guide the discussion, specifically focusing on requesting student observations and explanations of thinking. On the other hand, the teacher in Australia relied more on discussion-based interventions in which he posited statements or reflected back a student's response. He used a wider variety of interventions and explicitly coached students to ask questions themselves and to engage in argumentation.

Marking ideas seemed to come at pivotal moments when the teacher no longer was attempting to move the class along but rather to understand a concept in depth and from multiple perspectives. The following interventions were identified as was in which the teacher would mark or emphasize key ideas in a discussion.

Marking Ideas Coding

Figure 3

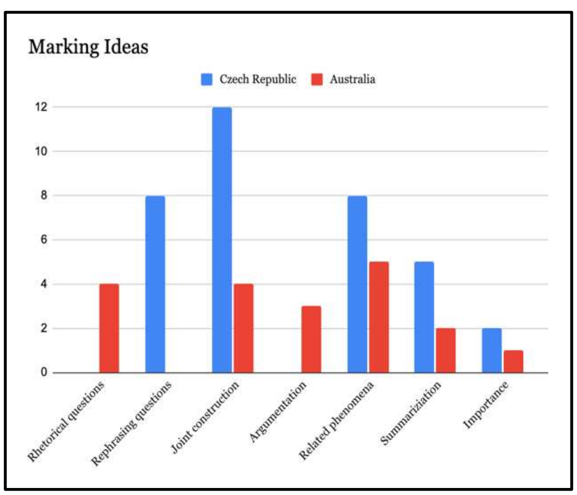
Marking Ideas Teacher Actions and Descriptions

	Teacher Action	Description
1.	Rhetorical questions	Posing a question not meant to be answered to emphasize a point
2.	Rephrasing questions	Asking a question multiple ways to highlight its significance
3.	Joint construction of knowledge	Building consensus as a team using “we” language
4.	Encouraging Argumentation	Asking students to make a claim and defend it with thinking or evidence
5.	Related phenomena	Applying ideas to outside scenarios in order to deepen understanding
6.	Summarizing student ideas	Aggregating and synthesizing student knowledge and ideas
7.	Explicitly pointing out importance	Directly telling students that an idea is important

The first two interventions – Rhetorical Questions and Rephrasing Questions – are interventions in the form of asking questions. The remainder are discussion-based interventions that are used to solidify student understanding of key concepts or anchor points. It is at these moments in the discussion that the students must concretize a key idea in order to progress forward in their thinking and understanding.

Figure 4

Observed Marking Ideas Teacher Actions Counts for Czech Republic and Australia Teacher Videos



The frequency counts provided evidence that the Czech Republic teacher highly favored joint construction of knowledge. In fact, in watching her video, the viewer genuinely gets the sense that we are on a journey together and all voices and input are needed. As observed in the Shaping Ideas frequency counts, the Czech Republic teacher favored certain interventions while the teacher from Australia had a more even distribution among interventions again favoring discussion over and above questions.

Implications

Intentional discursive interventions are critical to fostering academically productive talk (Soysal & Soysal, 2024). In examining the TIMMS transcripts, my goal was to define and operationalize a definition for Shaping and Marking ideas that provided a more robust explanation of its significance. The videos revealed that the teachers worked to shape ideas through dialogic interactions in which the teacher builds initial understandings of a concept, similar to building understanding. Shaping ideas in both classrooms took the form of the teacher paying close attention to the classroom contributions and selectively responding to key interactions in order to move an academically productive discussion forward in a collaborative manner. This correlates with the idea of teacher noticing in which a teacher pays close attention to the classroom dialogue and selectively constructs interactions to deepen students' grasp of crucial concepts (Sherin & van Es, 2021). The operationalized and expanded definition of Marking ideas includes solidifying understanding the details and nuances of a concept by examining it through multiple perspectives, thereby deepening understanding. In effect, it transfers the teacher's ability to notice varying ideas and select the key ideas that will propel further learning to students. At these moments in the discussion, the teacher slows the pace of the content in order to strategically emphasize the foundational piece upon which the next level of understanding will be built. If students miss these key ideas, then subsequent development of learning will be hampered.

The Czech Republic classroom relied more heavily on questioning while shaping ideas and discussion-based interventions while marking ideas. The Australian classroom relied more on discussion-based interventions while shaping ideas and had fewer interventions overall aimed toward marking ideas. While the two classrooms use different techniques, the overall focus in both is learning through dialogue with teacher interventions used to "diagnose and extend students' ideas and to scaffold students' thinking," (Chin, 2006). Both classrooms incorporated a blend of discussion-based and question-based interventions in different proportions all the while embodying "values of receptivity, reciprocity, openness, high regard in the potential of all children to make meaning through talk, and respect for all individuals," (Bansal, 2018).

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BIOLOGY BEYOND THE MANUAL: SHIFTING FROM FORMULAIC TO FORMATIVE INQUIRY-BASED LABS

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Abstract

We present an examination of the redesign of an introductory biology lab, transitioning from cookbook labs to inquiry- and problem-based learning. We explore implementation, engagement, and outcomes, while emphasizing 21st Century Skills like critical thinking and collaboration, alongside essential lab techniques for scientific work. Results indicate improved understanding and enthusiasm for biology.

Keywords: 21st century skills, inquiry-based learning, introductory biology, undergraduate education

Introduction

Conventional Introductory Biology lab courses often emphasize rote techniques, leaving students disengaged and unprepared for authentic scientific inquiry. Beginning in Spring 2024, we redesigned the first-year lab sequence into a single standalone course centered on four inquiry-based projects, integrating lecture and lab work to foster experimentation, data analysis, and critical thinking skills. Each project culminates in a unique science communication deliverable—a popular science article, research poster, oral presentation, or scientific paper—honing communication skills for diverse audiences. Lab notebooks enhance knowledge retention through handwritten planning, while skills-based assessments replace traditional lab practicals, focusing on practical research techniques. Supported by TA and peer interactions, the course cultivates 21st-century skills (NRC, 2012), boosting engagement and preparing students for scientific careers. Early feedback showed improved preparedness, with refinements planned for Fall 2025 to scale this inquiry-driven model.

Objectives of the Study

The objectives of this study are to:

1. Evaluate the impact of a redesigned introductory biology lab, integrating inquiry- and problem-based projects, on student engagement, critical thinking, and 21st-Century Skills development, and

2. Assess the effectiveness of project-aligned, skills-based assessments and lab notebooks in enhancing mastery of lab techniques and scientific communication for real-world scientific careers.

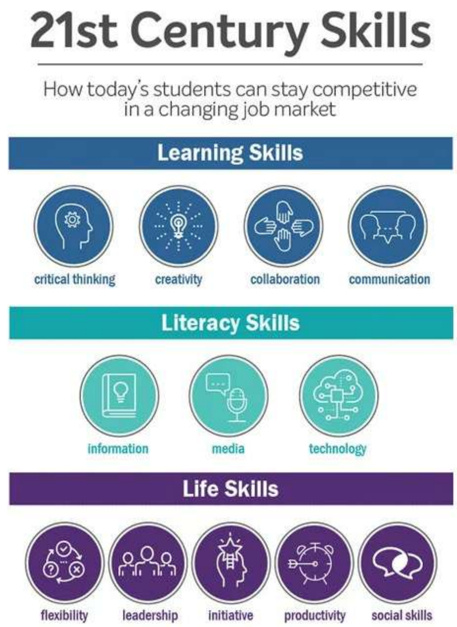
Instructional Framework

Traditional college laboratory courses, particularly in STEM fields, involve hands-on experimentation and observation to complement theoretical knowledge gained in lectures. Students engage in activities like conducting experiments, gathering and analyzing data, and drawing conclusions based on their findings, often working in groups under the guidance of a professor or teaching assistant (Hofstein & Lunetta, 2004). However, most of the experimental protocols typically follow pre-determined procedures to obtain specific, expected results similar to following a recipe in a cookbook (Modell et al., 2000). Inquiry-based teaching fosters students' ability to ask questions, design and conduct investigations, use tools to collect data, critically analyze evidence, interpret relationships, develop explanations, and communicate scientific arguments (NRC, 2000). Although college level lab courses increasingly promote inquiry-based, hands-on science, authentic experimentation is rarely achieved. Instead of engaging in extended, systematic exploration of personally meaningful questions, students often participate in disconnected, time-bound activities focused on using science equipment. These activities, while part of a sequence aligned with the scientific discipline's structure, often lack clear motivation or context for students, who may not grasp the underlying logic, making the sequence seem disjointed and unclear (Schauble et al., 1995). Lab course design should be targeted towards closing these gaps between concepts and execution of experiments (Hakim & Hamidah, 2025).

Another common feature of STEM courses in Higher Education is the prioritization of delivering content knowledge. The assumption is that a strong foundational knowledge alone enables graduates to enter the workforce fully prepared for their careers (Care & Anderson, 2016). Unfortunately, many essential skills are not obtained through study and examination. Lab courses aim to teach these skills, but without emphasis on the practical aspects, students undervalue the importance of mastering these tools. The concept of 21st Century Skills, identified by educators, business leaders, and policymakers as critical for success in a rapidly changing, digital society, extends beyond content mastery to include abilities like analytic reasoning, complex problem solving, and teamwork. These skills, rooted in deeper learning, differ from traditional academic skills by focusing on practical competencies for workplace success.

Figure 1

21st Century Skills for a Digital Society



21st-century skills are primarily based on the educational theoretical framework of constructivism, which emphasizes that learners actively build their own knowledge through experiences rather than passively receiving information (MacBlain, 2018). This is further supported by frameworks like the United States Department of Education (2009) Partnership for 21st Century Learning (P21) which outlines specific skills like critical thinking, communication, and collaboration (Figure 1), and guides educators in incorporating these into their teaching methods, such as project-based and problem-based learning (iCEV, 2024).

Methodology

The original Introductory Biology I & II lab courses, designed for first-year students at a private four-year university, paired a one-hour lab with a three-hour lecture. This traditional model was ineffective for our goals, prompting a redesign into a standalone three-hour course with one hour of lecture and four hours of lab per week, split into twice weekly two-hour sessions. The lecture is team-taught by two instructors, and the lab is supervised by six graduate TAs. An average of 200 student enrollments per semester is standard. Many of the experiments from the previous two courses were incorporated into the new format. The experiments consistently worked well and were popular with the students as evidenced by anecdotal feedback solicited during informal discussions. This strategy reduced the cost of implementation, in both financial and mental capital, as new supplies or significant time commitment from faculty and staff were not required. Planning sessions identified key scientific skills within these experiments, and the lab sequence was restructured into four cohesive modules, each building on prior skills: foundational concepts and techniques, an inquiry-based molecular lab, a project-based biodiversity lab, and a final inquiry-based lab where students design and execute their own experiments.

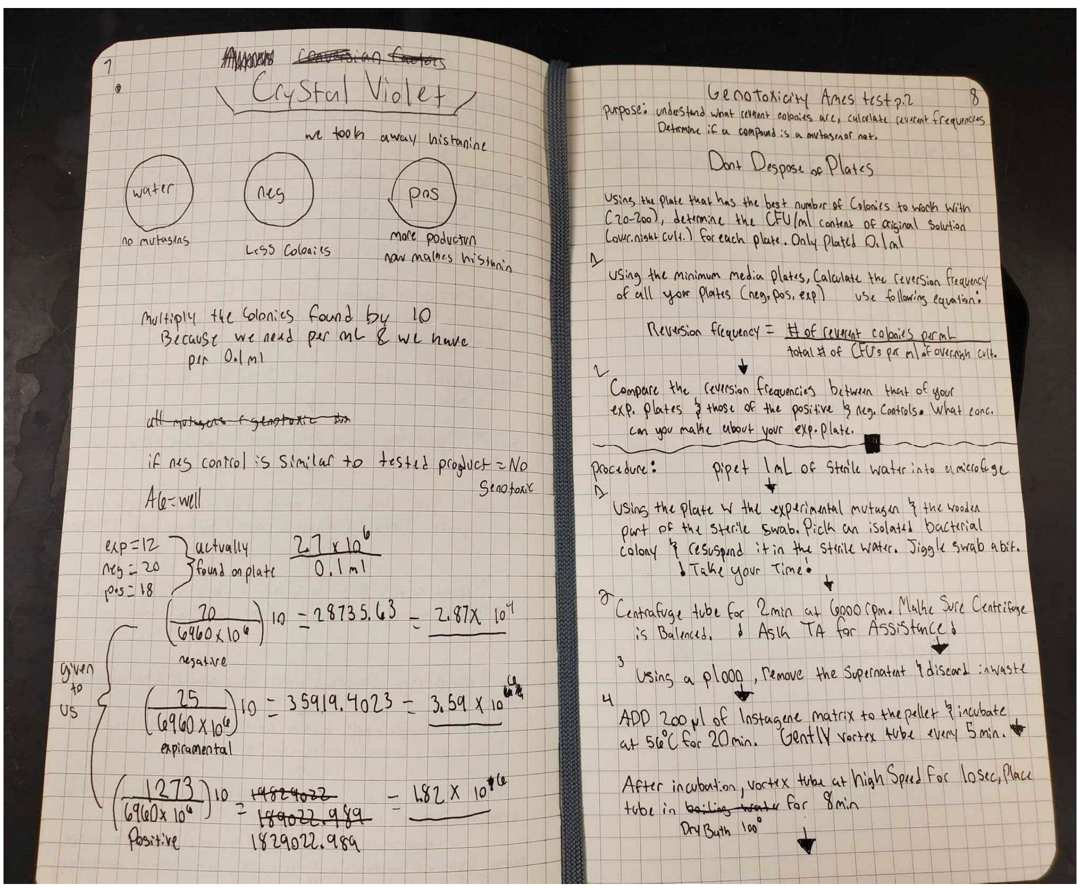
Effective science communication is critical for public understanding and informed decision-making, as poor communication, such as in the climate change debate, can lead to mistrust and impact policy and funding (Brownell et al., 2013). There are few opportunities for students in STEM majors to hone their communication skills in their coursework, and rarely do first year courses incorporate these learning experiences in their curriculum. The original labs limited communication practice to a scientific paper and oral presentation based on predictable "cookbook" experiments. The redesign addressed this by adding a research poster and a popular science article. The poster prepares students for professional conference presentations, while the article teaches them to convey complex science to the general public. To foster collaboration and life skills, the course incorporates structured group work, with students in groups of four conducting experiments and preparing deliverables. TAs monitor group dynamics to ensure equitable participation, enhancing peer learning and interpersonal skills for professional settings.

Another innovation addressed the unsuitability of the mid-semester and final lab practical. The lab practical in biology courses seems a ubiquitous component of the student lab experience. However, students often perform poorly on these summative assessments due to stress and performance anxiety, despite having the necessary skills and knowledge. These were replaced with four skills-based assessments that occur towards the end of each module, where students demonstrate practical skills acquired during their lab work in a less stressful format, reducing anxiety and focusing on practical application. During the assessment, students are individually observed by TAs, and given a second opportunity to repeat the task if they are not successful on the first attempt.

A key component of success in the course centered around the introduction of lab notebooks. Previously, students were provided with access to experimental protocols and background information to prepare them for lab work. Often, students chose to print these materials and bring them to class without reading beforehand. This resulted in students who were unprepared to complete their lab work within the allotted time. Cognitive research supports that handwriting notes enhances knowledge retention by activating brain regions like the visual, motor, and sensory cortices, outperforming digital note-taking or passive reading (Van der Weel & Van der Meer, 2024). Prior to arriving, students are now compelled to create an entry for each lab day that contains a statement of objective, the experimental procedure, and appropriate tables and graphs for recording results. Students are directed to write the procedure in their own words, rather than copy directions verbatim, which forces students to read the protocol with more intention and deeply engage with the material (Figure 2). They are not permitted to bring any printed documents to class and can only rely on their notebook records. This process of writing is designed to enhance retention and understanding of the content.

Figure 2

Lab Notebook Example



Classroom Implementation

The redesigned course integrates 21st-century skills through its focus on the core components of inquiry-based learning, group collaboration, innovative communication deliverables, lab notebooks, and skills-based assessments. Each component is strategically designed to prepare students for professional and academic success in a modern context.

Critical Thinking

Lab notebooks require students to analyze and rewrite protocols, fostering engagement with the scientific process. Skills-based assessments, such as calculating CFU/ml or distinguishing primary versus secondary sources, demand analytical reasoning.

Creativity

Inquiry-based labs encourage creative experimental design, while communication deliverables require innovative approaches to presenting complex concepts.

Collaboration

The course explicitly incorporates structured group work, with students organized into groups of four to conduct experiments like micropipetting and gel electrophoresis. These activities require shared responsibilities, collective problem-solving, and troubleshooting, fostering teamwork. Group preparation of the science communication deliverables further promotes collaboration as students negotiate how to visualize and present data.

Communication

Posters, oral presentations, and research papers teach students to convey research concisely and visually for a professional audience, while popular science articles hones their ability to communicate complex ideas clearly to non-experts. Group discussions enhance verbal communication and peer learning.

Information Literacy

Lab notebooks develop information literacy by compelling students to synthesize experimental protocols and background information in their own words. Skills-based assessments, such as identifying primary versus secondary sources, further reinforce the ability to critically assess and use scientific information.

Media Literacy

The popular science article requires students to adapt scientific content for a general audience, considering how information is presented and consumed in non-academic contexts. Designing research posters also introduces students to visual media, teaching them to balance text, graphics, and data for effective communication in professional settings.

Technology Literacy

Hands-on lab activities build technology literacy by requiring proficiency with laboratory equipment. Creating tables and graphs in lab notebooks and designing posters often involves using digital tools, further enhancing students' familiarity with technology.

Flexibility

Skills-based assessments promote flexibility by allowing students a second attempt to demonstrate proficiency, encouraging adaptation to feedback. The modular course structure requires students to adapt to varying experiments and deliverables, fostering versatility in applying skills across contexts.

Leadership

Group work provides opportunities for leadership, as students must coordinate tasks, make decisions about experimental design, and delegate responsibilities within their groups.

Initiative

Lab notebooks encourage initiative by requiring students to prepare thoroughly before class, taking ownership of their learning by creating detailed entries without relying on printed protocols.

Productivity

The course's two-hour lab sessions and modular design maximize hands-on practice, while using existing experiments and prepared notebooks ensures efficient delivery and student output.

Social Skills

Collaborative experiments and deliverables develop interpersonal skills, with the TA structure modeling effective interactions and fostering a supportive learning environment that values process over grades.

Outcomes

Feedback was solicited from students, TAs, and instructors, through both mid-semester and end of semester surveys. Results indicated a strong positive shift in lab experiences. Students commented how they felt more prepared than their peers who had taken the previous format and expressed a higher satisfaction and desire to remain in STEM. Academic success was also measured through statistical analysis of grades. On an A-B-C-D-F scale, the average letter grade shifted from a normal distribution to a negatively skewed distribution, which demonstrated an increase of the proportion of students achieving A's versus B's and a marked decrease of students failing the course.

Implications

The redesigned lab course, with improved student engagement and preparedness, indicates that inquiry- and problem-based learning can be effectively integrated into other STEM courses. This approach nurtures 21st-century skills such as critical thinking, collaboration, and communication, which are vital for modern scientific careers. Institutions might consider transitioning from traditional cookbook labs to project-based curricula to better prepare students for authentic scientific inquiry. To facilitate this shift, providing faculty and TAs with training on designing and guiding problem-based projects could enhance implementation and student outcomes across various educational contexts. Early positive feedback and planned refinements for Fall 2025 suggest the potential for a scalable model. Departments could explore piloting similar inquiry-driven designs in other lab courses, using the four-project structure as an adaptable framework. This approach may align with administrative goals to standardize STEM education while prioritizing active investigation over rote procedures, with flexibility for discipline-specific adaptations. Incorporating diverse communication formats helps students tailor findings for different audiences, a practice that could be broadly adopted to prepare students for scientific teamwork and effective dissemination. Regular communication training, supported by peer and TA interactions, may further strengthen these skills. The use of lab notebooks highlights their value in organizing experiments and fostering scientific identity. Educators could consider adopting handwritten lab notebooks as a standard tool across lab courses to enhance planning, retention, and critical thinking. Replacing traditional lab practicals with project-aligned, skills-based assessments better prepares students for research by focusing on mastering relevant techniques. This shift could be implemented in other lab courses to ensure career readiness, with ongoing refinements guided by student and TA feedback. Future research could explore the long-term effects of this redesign on students' academic and professional success in scientific careers. Studies might investigate how inquiry-based labs impact STEM retention, career preparedness, and the application of 21st-century skills in workplace settings.

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SECTION II: MATHEMATICS

WHEN PART-WHOLE FALLS SHORT: EXPLORING ADULT LEARNERS' PERSISTENT FRACTION MISCONCEPTIONS

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Abstract

Despite years of experiences with fractions, many students enter college with significant gaps in their understanding of fractions (Bentley & Bosse, 2018; Lee & Boyadzhiev, 2020; Siegler & Lortie-Forgues, 2015; Sullivan, 2024). Research previously conducted with younger students indicated that many struggles with fractions stem from a dominant part-whole understanding, often based on gap reasoning strategies. This study examines the prevalence of adult learners' use of gap reasoning when comparing fractions and how this impacts their reasoning in problems requiring a measurement-based conception of fractions.

Keywords: undergraduate education, number concepts and operations, rational numbers, mathematical knowledge for teaching

Introduction

The link between students' understanding of fraction concepts and success in future coursework (e.g., algebra readiness) and overall mathematical achievement is well-documented (Booth & Newton, 2012; Siegler et al., 2012; Torbeyns et al., 2015). Unfortunately, research has shown that many students arrive on college campuses with significant gaps in their understanding of fraction concepts (Bentley & Bosse, 2018; Bonato et al., 2007; Lee & Boyadzhiev, 2020; Siegler & Lortie-Forgues, 2015). Preliminary research of university developmental mathematics students (Sullivan, 2024a), consistent with earlier research involving 4th and 7th grade students (Barnett, 2016; Sullivan, 2024b), found that nearly 30% of students seem to have a dominant part-whole conception of fractions. That is, when there is uncertainty, they see fractions as a relationship between two quantities, not as a quantity of a size of unit. As a result, when comparing fractions such as 5/6 and 7/8 reasoning students often state they are equal because "both are one piece away from the whole".

Objectives of the Study

In this study we intend to examine the nature of adult learners' conception of fractions and their relationship guided by three questions:

1. How prevalent is a part-whole fraction scheme (PWS) based on gap reasoning in undergraduate students reasoning about fraction concepts?
2. How successful were students in reasoning about questions that require a measurement conception of fractions?
3. What associations exist between students' reasoning that suggested a dominant PWS based on gap reasoning and their reasoning on problems that required measurement conceptions of fractions?

Theoretical Foundation

One challenge in learning fractions is that they involve five distinct conceptions: part-whole, measurement, operation, quotient, and ratio (Behr et al., 1983; Kieren, 1980). This study focuses on distinguishing between part-whole and measurement conceptions. From a part-whole view—common in many textbooks (Sadlier, 2019)—a fraction m/n means m parts out of n equal parts. In contrast, a measurement conception, aligned with Common Core Standards (CCSSI, 2010) interprets m/n as m iterations of the unit fraction $1/n$, emphasizing fractions as a tethering of quantities and sizes of units.

Wilkins and Norton (2018) describe a developmental progression from part-whole to more advanced measurement-based fraction schemes. In our previous research with elementary and developmental math students (Sullivan, 2024a, 2024b), many students constructed accurate area models to compare 5/6 and 7/8, but incorrectly concluded they were equal. This suggests they either overlooked unit size or relied on gap reasoning, where comparisons are made based on proximity to the whole (e.g., "both are one piece away").

Some students made statements such as "sixths are bigger pieces than eighths" when comparing unit fractions like 1/6 and 1/8, suggesting partial measurement reasoning. However, many defaulted to gap reasoning, e.g., claiming 1/6 is greater than 1/8 because "1 is closer to 6 than 8" (Sullivan, 2024b). This flawed logic happens to yield correct answers when comparing unit fractions or same-numerator fractions, making it difficult to detect and correct.

Recognizing unit size is a prerequisite for transitioning to the Measurement Scheme for Unit Fractions (MSUF) (Wilkins & Norton, 2018). In MSUF, students iterate the unit fraction to reconstruct the whole, coordinating parts with the unit. This iteration distinguishes MSUF from the static, ratio-based reasoning of PWS, where m/n is viewed as m shaded parts out of n, rather than m measures of 1/n. For example, 5/6 is interpreted as 5 shaded of 6, not as 5 iterations of 1/6.

Students operating within PWS can often build area models but struggle with number line placements, despite both requiring partitioning. The number line emphasizes relative magnitude and location—concepts that require coordination of units and lengths. PWS learners often lack a clearly defined unit, which hampers their ability to reason about fractions as measurable quantities.

Beyond MSUF, two more sophisticated schemes—Measurement Scheme for Proper Fractions (MSPF) and Generalized Measurement Scheme for Fractions (GMSF)—involve determining unknown wholes given either proper or improper fractions (Wilkins & Norton, 2018). These require partitioning a given fraction to find the unit (1/n), then iterating to reconstruct the whole. However, our study centers on the foundational transition from PWS to MSUF.

Methodology

To explore the three research questions discussed earlier a 17-item pre-diagnostic instrument was developed by the authors to examine adult learners' understanding of fractions, specifically their use of part-whole and measurement schemes. The assessment included 10 multiple-choice and 7 short-answer items, with three requiring written explanations to detect gap reasoning. Relevant items are detailed later.

The instrument was administered across six distinct undergraduate mathematics courses at a midwestern university: two developmental mathematics courses ($n = 320$), three general education mathematics courses ($n = 321$), one statistics course ($n = 21$), and an additional 24 students who did not specify a course code, resulting in a total sample of 696 predominantly freshman and sophomore students. The assessment was delivered electronically in class via Qualtrics during the first week of the fall semester. Students were instructed to complete the instrument without the use of technological aids or written calculations, relying solely on mental reasoning to solve each problem.

A rigorous data screening process was conducted to ensure response validity. The dataset was examined for incomplete responses, as well as for responses that fell outside the predefined acceptable time thresholds for instrument completion (360 sec < response time < 1200 sec). All responses were coded for accuracy, with each item scored dichotomously (1 = correct; 0 = incorrect). Additionally, specific items with the potential to indicate gap reasoning—namely, Q2, Q9, Q7, and Q11—were further analyzed and coded to determine whether students' responses suggested gap reasoning (1 = yes; 0 = no). This coding is referenced as Q2GAP, Q9GAP, etc. later in the paper.

Given the electronic administration of the instrument, some flexibility was required in coding student responses. For example, Q12 asked students to determine the length of a bar relative to the whole. Since the assessment was completed on a computer screen without access to measurement tools, responses of both 1/5 and 1/6 were considered acceptable, acknowledging potential perceptual variations in estimating fractional lengths. Decimal equivalents were also accepted.

The internal consistency of the instrument was evaluated using Cronbach's alpha, yielding a coefficient of .805. According to established guidelines (Nunnally & Bernstein, 1994), this value indicates good reliability, suggesting that the instrument effectively measures a consistent construct. As such, the instrument can be considered a reliable tool for identifying a dominant part-whole scheme (PWS) based on gap reasoning and measurement conceptions of fractions. However, further analysis may be warranted to examine individual item contributions and refine the instrument for optimal performance.

To assess the construct validity of the instrument, an item-total correlation analysis (Nunnally & Bernstein, 1994) was conducted. Results indicated that 8 items exhibited strong correlations (≥ .50) with the total score, while the remaining 9 items fell within the moderate range (.30–.49). These findings suggest that all items contribute meaningfully to the overall construct validity of the instrument. Nevertheless, there is potential for further refinement to enhance the precision and robustness of the measurement.

Student responses to the items relevant to this article are shown below. These are separated into items that may reveal gap reasoning, which is an over-reliance on a part-whole scheme, and items that may provide insight into the nature of students' measurement fraction schemes.

Figure 1

Fraction Conceptions Instrument

#	Item (N = 696)			
	Part-Whole Scheme: Gap Reasoning			
Q2	Two pizzas are the same size. Carlos ate 5/6 of one of the pizzas and Terrell ate 7/8 of the other pizza. Who ate more pizza?			
	A Carlos (16.9%)	B* Terrell (58.3%)	C (Gap) They ate same amount (23.3%)	D Impossible to know (1.5%)

Q3 Two whole medium pizzas are represented by the figure [two circles partitioned into 8 equally sized pieces with 5 pieces of the first circle shaded and 7 pieces of the second circle shaded]. How much of **one** medium pizza is represented by the figure.

A (Gap)	B*	C	D
8/12	11/8	8/8	Cannot determine
(22.9%)	(58.3%)	(11.5%)	(5.1%)

Q7 Jackson ran 8/9 of a whole mile and Bri ran 11/12 of a whole mile. Who ran further?

A*	B	C (Gap)	D
Bri	Jackson	They ran the same	Cannot determine
(59.8%)	(18.2%)	(20.4%)	(1.3%)

Q11 Length A is 19/16 of a whole mile. Length B is 16/13 of a whole mile. Which of the following statements is true?

A	B*	C (Gap)	D
Length A is greater than Length B. (18.5%)	Length B is greater than Length A. (46.4%)	Length A and B are the same. (29%)	Cannot determine (4.7%)

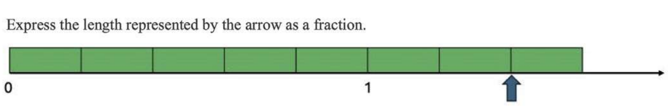
Measurement Schemes

Q5 Which measurement (in inches) is the blue arrow showing on the tape measure? [Picture of tape measure with blue arrow pointing at 4 3/8.]

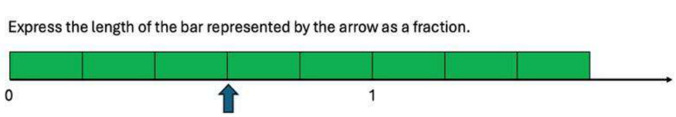
A	B*	C	D
4 6/4	4 3/8	4 6/8	5 5/8
(6.7%)	(59.9%)	(32.4%)	(0.6%)

	Correct	Incorrect
Q6	(42.1%)	(57.9%)
Q8	(53.5%)	(36.5%)
Q9	(42%)	(58%)

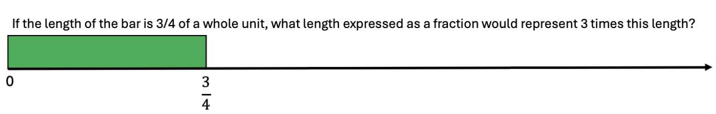
Q6



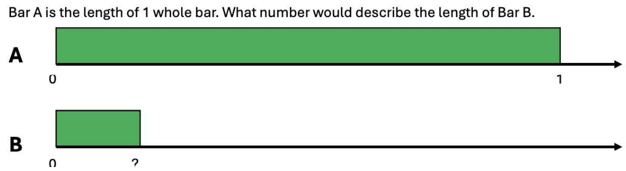
Q8



Q9

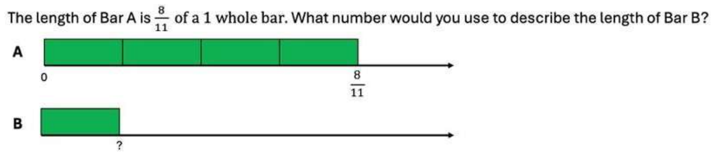


Q12



(42.1%) (57.9%)

Q14



(64.3%) (35.7%)

Results and Discussion

This study investigated the fraction conceptions of adult learners by analyzing responses to diagnostic items designed to assess the prevalence of gap reasoning (indicative of a dominant part-whole fraction scheme) and the ability to reason about fractions from a measurement perspective. A summary of results of selected tasks on the diagnostic assessment relevant to the three research questions is shared.

Prevalence of DPW

Results indicate that a significant proportion of adult learners continue to rely on a dominant part-whole conception when working with fractions. Over 20% of students demonstrated gap reasoning across multiple items, including 23.3% who claimed “they ate the same amount” in Q2—reflecting a comparison of quantities rather than an understanding of fractional magnitude. Chi-square analyses revealed significant associations between Q2 and other items that seemed to be associated with gap reasoning (Q3, Q7, Q11, and Q5). These findings highlight the need for instruction targeting the transition to measurement conceptions.

Performance on Measurement-Based Items

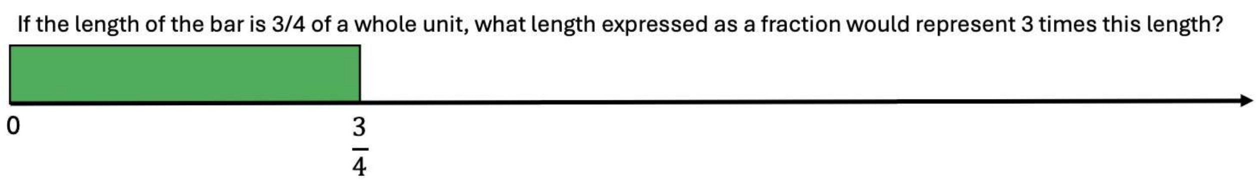
Students demonstrated limited success on items requiring a measurement scheme for unit fractions (MSUF). For instance, only 42.1% of students answered Q6 correctly, and nearly 20% of those who erred selected 7/8—a response indicative of part-whole reasoning rather than iteration of a unit fraction. Similar patterns were observed on Q8 and Q9, where common incorrect responses reflected an inability to coordinate the unit fraction with the whole. These findings indicate that students who rely on part-whole reasoning struggle to apply measurement-based fraction strategies, particularly when reasoning about improper fractions or iterating composite units.

Associations Between PWS and Measurement Reasoning

Further analyses showed moderate associations between Q2GAP and incorrect responses to measurement tasks, Q6 (.282), Q8 (.246), and Q9 (.288), reinforcing the idea that dominant part-whole reasoning hinders success on measurement-based tasks. One of the more interesting relationships is related to Q9 shown in Figure 2.

Figure 2

Question 9



This item involved a higher level of complexity because there were no partitions and students were required to iterate a composite unit, 3/4, multiple times to determine the length of a new bar. Interestingly, of the 398 who responded incorrectly approximately 40% of students responded with an answer of an equivalent fraction to 3/4, 9/12. A Chi-square test for independence was conducted comparing the gap reasoning anchor question Q2GAP and correct responses to Q9. The test revealed a statistically significant association between Q2GAP and Q9, χ^2 (1, 686) = 56.73, $p < .001$. The effect size measured by Cramer's V was .288 indicating a moderate relationship between gap reasoning responses to Q2GAP and Q8. What was most fascinating is the range of student responses, shown in Figure 3. Many of these responses are less than or equal to the length of the original bar, 3/4.

Figure 3

Responses to Q9

1/4	1/3	9/20	3/5	3/4	4/8	9/16	8/12	9/12	0.8	3 1/4	1	1 1/2	1 3/4
3/12	6/7	4/3	5/8	3/5	6/12	4/4	12/18	6/8	3/7	11/12	12/12	1 1/4	12/13
12/4	12/4	12/3	9/5	27/4	12/9	6/4	3/2	12/16	15/4	3 3/4	12/13	1 2/4	12
9/3	4	2 2/5	3 2/12	2 3/4	3 1/2	3/2	9						

Overall, these findings underscore the persistence of dominant part-whole reasoning in adult learners and highlight the need for targeted instructional interventions that support the development of measurement-based fraction conceptions.

Implications

These findings have important implications for the teaching of fractions in elementary classrooms. While part-whole conceptions provide a foundational understanding of fractions, greater emphasis should be placed on the initial development of fraction-as-measure conceptions (Sullivan, 2024b), as they play a critical role in the development of other fraction concepts (Lamon, 2007). Two possible suggestions to support this emphasis is to continue to utilize the word label beyond second grade to denote the size of the unit of the fraction when students are first exposed to fractions (e.g., 7 eighths instead of 7/8) and engage them in mental activities (e.g., partitioning and iterating) that are foundational to the development of measurement schemes (Wilkins & Norton, 2018).

Moreover, it is essential to develop screening tools that enable educators to identify students who rely on gap reasoning. The results of this study indicate that students who adopt these reasoning strategies often persist in using them throughout their academic careers, potentially hindering their ability to engage with more advanced mathematical concepts.

Limitations

This study has two main limitations. First, students' reasoning was inferred from their responses from an electronically administered diagnostic assessment rather than directly observed, which may limit the accuracy of conclusions about their fraction conceptions. Second, the sample was drawn from a single Midwestern university and may not represent students with different educational experiences or mathematical backgrounds. These limitations restrict the generalizability of the findings and highlight the need for future research with broader samples and more direct assessments of reasoning.

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STANDARDS ACADEMY: A PROFESSIONAL DEVELOPMENT PROGRAM TO ENHANCE TEACHERS' MATHEMATICAL KNOWLEDGE FOR TEACHING

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Abstract

This pilot study examined the effects of the Standards Academy professional development workshop on teacher practices and student learning outcomes. The Standards Academy is a four-day professional development workshop that focuses on content knowledge acquisition and teacher practices related to mathematics education. Eleven teachers and 182 fifth and sixth grade students participated in a quasi-experimental study comparing treatment and comparison groups. While observation data showed improved teaching practices among participants, no significant differences were found in student learning outcomes. Gains in teacher mathematical knowledge for teaching were inconsistent. Findings highlight the complexity of linking teacher professional development to student achievement.

Keywords: professional development, teacher education, math, content knowledge

Introduction

There is a need for more research that connects professional development of teachers to student learning outcomes (Gersten, et al., 2014). Thus, the researchers designed a pilot study to investigate how a professional development (PD) workshop influenced mathematics teacher practices and student learning outcomes. In June of 2024, 73 teachers attended the Standards Academy (SA) professional development workshop. The workshop was four days and included approximately 24 hours of professional learning. Teachers were divided by grade level, with each cohort focusing on a single mathematics domain aligned to their curriculum and standards. Each grade level cohort was guided by a Regional Math Specialist from a university in the western United States. The workshop had a focus on helping teachers deepen their understanding of mathematics standards and grade level content (fractions for teachers of grades 3-5 and ratios and proportional thinking for teachers of grades 6-8) to develop a more nuanced understanding of the content and effective pedagogical approaches to support their respective students.

Objective of the Study

The objective of this study was to determine the effects of attending a four day workshop (Standards Academy). The researchers wanted to know if the workshop had any effects on the mathematical content knowledge and teaching practices of the teachers, as well as if it had an effect on student learning outcomes.

Related Literature and Theoretical Framework

Many K-8 teachers lack the requisite training and do not understand the mathematics content they are expected to teach well enough to adequately assist students in reaching high levels of mathematics understanding (Ball et al., 2005; Venkat & Spaul, 2015). Mathematical knowledge needed for teaching is different from the mathematical knowledge one typically acquires as a student of mathematics (Adler et al. 2006; Ball et al., 2008; Lesseig, 2016). Educators' knowledge of mathematical content significantly impacts how they address students' mathematical understandings (Ball et al., 2005; Hill et al., 2005; Mapolelo & Akinsola, 2015). Furthermore, the impact of teachers' mathematical knowledge rivals the effect of socioeconomic status on student gain scores, suggesting that enhancing teachers' content knowledge could be an important tool to achieving equity in mathematics (Ball et al., 2005). To address this challenge, the Standards Academy (SA) was generated as a professional development workshop for teachers to explore research-aligned strategies focusing on deepening their mathematical knowledge for teaching with an emphasis on specialized content knowledge (Ball et al., 2005; Superfine & Li, 2014; Thanheiser, et al., 2010). The SA, guided by the frameworks of Ball, et al. (2008), Hill et al. (2008) and Castro Superfine & Li (2014), enabled teachers to enhance their content knowledge and teaching practices.

This study is guided by the framework of *Mathematical Knowledge for Teaching* (MKT) (Ball et al., 2008), which emphasizes specialized content knowledge teachers need to effectively teach mathematics beyond what is typically acquired as learners of the subject. The SA was designed to strengthen this type of knowledge and support shifts in instructional practice. The study also draws on Guskey's (2002) Model of Teacher Change, which posits that professional development influences classroom practices first, leading to improvements in student learning outcomes. Together, these frameworks highlight the complex and iterative relationship between teacher learning, practice, and student achievement, providing a lens through which to interpret the mixed findings of this pilot study.

Methodology

Participants and Setting

There were two phases of the research. In Phase 1, the 56 teachers who attended the SA workshop on a college campus fully participated in the research. Phase 2 included eleven fifth- and sixth-grade teachers and their 182 students. Five teachers were in the treatment group (attended SA), and four in the comparison group (did not attend SA). Snowball sampling was used to find the comparison participants (Hatch, 2023). There was one exception with one set of two teachers who were both in the treatment group who shared one counterpart who was in the comparison group.

Research Design

This study employed a mixed-method research design (Creswell & Plano Clark, 2017) to address the following research questions:

1. What are the effects of the Standards Academy professional learning experience on a teacher's specialized content knowledge and mathematical knowledge for teaching?
2. How are teachers' mathematical teaching practices influenced by attending the Standards Academy?
3. How are student learning outcomes affected by having a teacher who attended the Standards Academy professional learning experience?

The researchers worked under the assumption that if teachers improved their mathematical knowledge for teaching, they would be more effective teachers and therefore students would exhibit increased learning outcomes, which aligns with the work of Hill, et al. (2005), Campbell et al. (2014), Tchoshanov et al. (2017), and Guskey (2002). The tool used to increase teachers' mathematical knowledge for teaching was the SA workshop.

Data Collection and Analysis

This pilot study used four data sources: Teacher Knowledge Assessment System (TKAS) (Hill et al., 2004) for teacher participants in the domains of proportional reasoning for grade 6-8 teachers and number concepts and operations for grade 3-5 teachers, a post workshop survey, teacher observations, and student assessment scores. All the data was quantitative except for the coding of the survey responses (Creswell, 2017).

During Phase 1 of the SA workshop, 63 teacher participants took the TKAS assessment to measure growth in their mathematical knowledge for teaching. This was done as an aggregate to measure the growth as a group and not individually. Also done during the workshop, 56 teachers completed a post workshop survey. The post-survey had 13 questions, some such as "On a scale of 1 to 10, how would you say your experience at SA will impact your instructional practices as a teacher or the work you do as an administrator? A response of 1 would mean it will have little or no impact on your instructional practice/work, a response of 5 would mean it will have some impact on your instructional practice/work, and a response of 10 would mean it will greatly influence your instructional practice/work." A 10-point Likert scale was used to capture greater sensitivity in participant responses, reduce central tendency bias (Joshi et al., 2015), and because using an even number scale is appropriate if the participants are familiar with the topic (Chyung et al., 2017).

During Phase 2 of the research, the eleven teacher research participants contacted one of the researchers prior to teaching their students their math unit(s) related to the SA domain of ratios and proportions or fractions. The researcher then went to each classroom and administered a pre-assessment to students of the teachers in the comparison and treatment groups. Each student took a pre-assessment using the NAVVY assessment system by Pearson. This assessment aligned with the mathematical domain and standards that was the focus of the SA workshop — ratios and proportions for sixth grade and fractions for fifth grade. Once the teacher felt they had taught all the content from that domain (i.e., ratios and proportions, fractions), they contacted the researcher to administer the post-assessment to students, which was the same assessment as the pre-assessment. This allowed for change scores that could measure growth in student learning from pre-assessment to post-assessment. The time between pre- and post- student assessment varied by class, as some curriculums had all related standards in one or two units and some curriculums used a spiral approach, and the standards were spread throughout the year. The range was between five weeks and five months.

Each teacher was observed by one researcher two times using the validated Mathematics Classroom Observation Protocol for Practices (MCOP2) observation tool (Gleason, et al., 2017). The observations took place while the teachers, both comparison and treatment, were teaching lessons related to the specific domain from SA. This was done in their own classroom. The span between observed lessons of the same teacher was one to three weeks. The observations looked at teaching practices as well as student engagement or student learning modalities. Some of the observation criteria included, "Students engaged in exploration/investigation/problem solving," and "The teacher's talk encouraged thinking." While the use of a single observer introduces the potential for researcher bias, this limitation is considered acceptable within the context of a pilot study, as the primary aim is to test feasibility and refine methods for a larger-scale investigation (Creswell & Plano Clark, 2017; Van Teijlingen & Hundley, 2001). There was no individual teacher TKAS data, only aggregate data, so their mathematical knowledge for teaching was unknown on an individual level. This is a factor that will be altered in a post-pilot study.

To analyze the data, both qualitative and quantitative measures were used. Data were analyzed to determine if any significant growth in teacher mathematical knowledge for teaching could be observed using the TKAS after the four day SA workshop. Pre- and post- TKAS aggregate scores of 56 teachers were compared using statistical analysis of the correlation coefficient, the t score, and the effect size.

Qualitative post-survey responses collected via a Google document were systematically coded and organized into thematic categories (Saldana, 2022) using ATLAS.ti (25.0.1) software to identify patterns and emerging insights (2025). The narrative result, along with Likert scale (Likert, 1932) questions were used to determine how teachers perceived SA would impact their instructional practices in math.

Data from the teacher observations were analyzed to determine if teachers who attended the SA workshop had better observation scores than the comparison group. An independent samples t-test was used to compare MCOP2 observation scores between the treatment and comparison teachers. Similarly, independent samples t-tests were also used to compare change in score from pre- to post-test between treatment and comparison students.

Linear regression was used to explore if teachers with higher MCOP2 observation scores also had students with higher changes in their score. Additionally, linear regression was used to examine the impact of the number of years a teacher had taught math in their current grade and treatment status on student outcomes.

Results

Teacher Data: TKAS

Fifty-six teachers completed both the pre- and post-TKAS assessments. The results regarding the impact of the SA workshop on teachers' mathematical knowledge for teaching were mixed. Teachers who participated in the SA workshops that focused on fractions, which would be teachers who taught grades 3-5, showed a positive correlation between growing their knowledge and attending the SA workshop, however, the change is not statistically significant at the 0.05 level ($p \approx 0.16$). However, teachers who taught ratios and proportions (grade 6-8 teachers), showed a negative correlation between growing their knowledge and attending the SA workshop which was statistically significant.

Table 1

TKAS Pre and Post Assessment Data

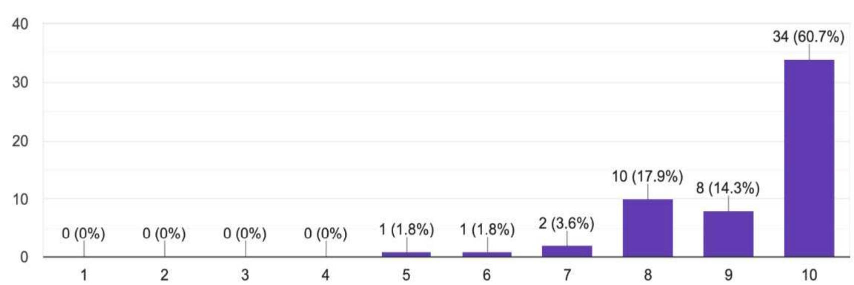
	Correlation Coefficient	T Score	Effect Size
Cohort 1 grades 3-5	0.7284	1.4431	0.2268
Cohort 1 grades 6-8	0.7164	-2.6438	-0.5432
Cohort 2 grades. 6-8	0.6726	-0.6236	-0.1080

Teacher Data: Post-Workshop Survey

To address RQ2, participants completed a post-survey following the PD workshop. Survey responses indicated that teachers perceived the SA as highly valuable, citing the inclusion of rich tasks, hands-on activities, and practical resources as particularly beneficial. Participants emphasized the usefulness of observing modeled tasks, making explicit connections to standards and mathematical big ideas, and exploring strategies for effective classroom implementation. Collaboration with peers and grade-level standards alignment identified as supportive features of the workshop. Overall, teachers reported increased confidence and deeper content understanding. Participants overwhelmingly self-reported that their experience at SA will significantly impact their instructional practices.

Figure 1

Participants' Response to 'How would you say your Experience at Standards Academy will Impact your Instructional Practices as a Teacher?'



Student Data: Pre and Post NAVVY Assessment Change Scores

Results show that students in both the treatment and comparison group had similar changes from the pre-assessment to the post-assessment. The differences were not significant between the treatment and comparison student groups, $t(178) = 0.15$, $p = .88$, $d = 0.02$. In grade 5, treatment and comparison students had similar scores, $t(80) = 0.17$, $p = .87$, $d = 0.04$. In grade 6, treatment and comparison students had similar scores, $t(98) = 0.19$, $p = .85$, $d = 0.04$.

Table 2

Change Scores of Student Pre- and Post- Assessment Data

Grade Level	Treatment % Change	Comparison % Change	Total % Change
Grade 5 % Change	22.27%	22.94%	22.60%
Grade 6 % Change	15.32%	14.21%	14.90%
Total % Change	18.13%	18.69%	18.37%

The *t-test* compared group means to assess whether observed differences were statistically significant. In this study, the small *t-values* and nonsignificant *p-values* indicated no significant differences in student outcomes between the treatment and comparison groups, suggesting the treatment had little impact on student learning outcomes.

Teacher Data: MCOP2 Observation Data

The results from the teacher observations indicated that teachers who participated in the SA workshop had higher MCOP2 observation scores than teachers who did not participate in the SA workshop. MCOP2 observation scores were significantly higher among treatment teachers than comparison teachers, $t(7) = 2.39$, $p = .048$, $d = 1.61$. Four of the five highest MCOP2 scores were from the treatment group, with one teacher in the comparison group scoring the fifth highest, suggesting the treatment had a positive impact on teaching practices as defined by the MCOP2.

Table 3

Regular Demographic and Informational Table

School	Raw Score*	Percent	Group Average
1C	59	55	55.75
2C	44	41	
3C	47	44	
5C	89	83	
1T	91	85	82.4
2T	94	87	
3T	96	89	
5T	103	95	
5TT	61	56	

**Note:* The total possible raw score was 108.

Observation Scores of Treatment and Comparison Teacher Participants

The data showed that MCOP2 observation scores and treatment status were not significant predictors of student outcomes, $F(2,179) = 0.06$, $p = .95$, meaning that teachers with higher MCOP2 observation scores did not have students with higher scores on their pre- and post-assessments. However, teachers who had been teaching math for their current grade level longer showed higher student learning outcomes, $F(2, 154) = 9.41$, $p < .001$ with a nine percent increase for every year the teacher had taught in that grade level.

Discussion

In this pilot study, teachers who participated in the SA workshop did not have students with higher student learning outcomes than teachers who did not participate. This was contrary to the findings of previous research (Ball et al., 2005; Hill et al., 2005: Mapolelo & Akinsola, 2015). Results from the TKAS indicated mixed effects of the SA on teachers' mathematical knowledge for teaching. Teachers who participated in the SA workshop did show higher MCOP2 observation scores than teachers who did not participate, although this finding should be explored further with more teacher participants and more interrater reliability.

Despite teachers reporting that the SA workshop would positively impact their instructional practice, and despite higher MCOP2 observation scores among treatment teachers, no corresponding increase in student learning outcomes was observed. This may be due to several factors, and the small sample size should also be considered when interpreting the implications. Future studies should control for teacher-level variables, such as pre-existing mathematical content knowledge, by including baseline measures prior to the intervention and increasing the sample size. The results should position researchers to investigate how to ensure that teaching practices and content and pedagogical knowledge can transfer from the teacher to student learning and what aspects of a mathematics PD experience will translate to increased student learning outcomes. Several factors can be studied to continue this research such as what is taught during a PD experience, how knowledge is transferred from the PD facilitator to the teacher, if there is a discrepancy between what is taught by the facilitator and how teachers interpret the learnings, or if there are barriers to implementation once teachers are in their classrooms.

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SECTION III: INTEGRATED STEM

TEACHER CANDIDATES' PERSPECTIVES ON AI:
A STEM VS. NON-STEM ANALYSIS

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Abstract

This study examined secondary school teacher candidates' (TCs) perspectives on AI integration in education. Through the qualitative analysis of the pre-and post-survey data and the essays from 17 TCs across two institutions, including 9 STEM and 8 non-STEM education majors, we found diverse attitudes towards AI integration. In particular, the following three main themes emerged from the comparative analysis between the two groups: (a) the potential benefits of AI for teachers, (b) the perceived positive impact of AI on student learning, and (c) the propensity towards AI-infused teaching practices. The findings indicate marked differences in AI integration readiness and willingness between STEM and non-STEM TCs.

Keywords: artificial intelligence, AI-infused teaching practices, STEM, teacher candidates

Introduction

Integrating Artificial Intelligence (AI) in education is not a novel concept. In recent years, we have seen a surge of interest in how AI could transform teaching and learning. Baidoo-Anu and Ansah (2023) and Crompton and Burke (2023) present the potential of AI as a powerful educational tool to personalize learning experiences and streamline administrative tasks, while Borenstein and Howard (2021) and Karran et al. (2024) highlight ongoing challenges from stifling student creativity to ethical concerns.

Teacher perspectives are crucial as the studies by Ertmer et al. (2012), Ghimire and Edwards (2024), and Rana (2012) have demonstrated the significant impact of teachers' beliefs and attitudes in the successful adoption and implementation of educational technology. Hence, understanding teacher candidates' (TCs) perspectives is especially critical as they are in a unique position to evaluate the emerging AI-infused curriculum.

Objectives of the Study

While the existing research (Ayanwale et al., 2022; Fundi et al., 2024; Pak et al., 2024) examined the inservice teachers' attitudes towards AI, how TCs, in general, and STEM TCs, in particular, perceive AI implementation remains underexplored. Thus, we investigate secondary school STEM and non-STEM TCs' perspectives on AI integration.

Related Literature

Integration of AI in education has recently gained a rapid scholarly and professional interest. This is evident from the position statements by professional organizations (e.g., NCTM, 2024; NEA, 2025; USDE, 2023), the numerous scholarly publications (e.g., Borenstein & Howard, 2021; Crompton & Burke, 2023; Cukurova, 2024; Egara & Mosimege, 2024; Holstein et al., 2019; Karran et al., 2024; Pak et al., 2024; Rogers, 2000; Shi et al., 2024; Zhou, 2023), and the calls for clarity and advocacy for thoughtful, effective utilization of AI (AMTE, 2024; Crompton & Burke, 2023; Egara & Mosimege, 2024). This heightened enthusiasm, however, is tempered by a historical pattern of educational systems' apprehensive adoption and integration of new technologies (Hazzan-Bishara et al., 2025). The discrepancy between the potential of new technologies like AI and the pace of their integration highlights a need to investigate the perceptions of educators who will ultimately implement these teaching and learning tools.

A growing body of literature underscores various benefits of AI adoption in educational settings. These range from automating routine administrative tasks and managerial duties to facilitating highly individualized, adaptive assessments that permit teachers to dedicate more time and focus on the instructional objectives and student engagement (Crompton & Burke, 2023; Egara & Mosimege, 2024; Shi et al., 2024). While these benefits are promising, the discourse around AI in education is also marked by persistent challenges, such as ethical considerations, students' social and emotional disconnectedness, and their over-reliance on AI (Borenstein & Howard, 2021; Karran et al., 2024; Rogers, 2000).

Beyond the general beliefs and attitudes, research has consistently highlighted divergent views towards educational issues exhibited by STEM TCs and their non-STEM counterparts (Looi et al., 2020; Hartmann et al., 2022). Our study extends this line of inquiry by examining whether the differences in perspectives manifest vis-à-vis their perceptions of AI. This focus is particularly relevant given the active AI initiatives within STEM education disciplines (AMTE, 2024; NCTM, 2024; UNESCO, 2023). Consequently, our study, undertaking a comparative analysis of STEM and non-STEM TCs' attitudes towards AI integration in secondary education, aims to provide insights into developing more effective and targeted AI-integration strategies within teacher education programs.

Our conceptual framework employs Davis' (1989) Technology Acceptance Model (TAM), which posits that individuals' adoption and use of technology are primarily influenced by two factors: *perceived usefulness* (the extent to which technology is believed to enhance performance) and *perceived ease of use* (the degree to which technology is believed to minimize effort). In this study, TAM frames TCs' perspectives on AI integration in classroom settings. We qualitatively analyze their reflections to discern perceptions of AI's usefulness for lesson planning, instructional strategies, and student learning, as well as their concerns relating to adoption challenges. Our adapted TAM framework enables a qualitative understanding of TCs' attitudes toward AI integration.

Methodology

To investigate secondary school STEM and non-STEM TCs' perspectives on AI integration, this study employed a qualitative research design. The participants were 17 TCs from two universities: one located in the Southern region and the other in the Northeastern region of the U.S. Specializing in secondary education, the TCs comprised the following grade-level standings: 11 sophomores, 1 junior, 1 senior, and 4 Master of Arts in Teaching candidates. Moreover, at the time of the data collection, 9 TCs majored in STEM education (6 in Mathematics and 3 in Sciences) while 8 TCs majored in non-STEM subjects (4 in English Language Arts and Reading, 3 in Social Studies/History, and 1 in a broad range of subjects: Art, Physical Education, Dance, Music, Theatre, and Languages Other Than English).

For the online survey, we utilized Microsoft Forms as our primary data collection tool. We formulated the open-ended survey questions to elicit TCs' perspectives on AI and its plausible roles in lesson planning and delivery, the perceived relationship between teachers and AI, the impact of AI on instructional strategies, and the benefits and challenges of AI integration in education. These survey items align with the core construct of the TAM framework (Davis, 1989; Silva, 2015). The below represents a sample of the explicit questions:

- How do you ENVISION incorporating AI-powered tools or platforms in LESSON PLANNING and DELIVERY within your subject area?
- Describe the ideal ROLE of TEACHER in facilitating teaching and learning in your classroom context.
- What specific AI TOOLS or APPLICATIONS do you envision using to enhance student LEARNING EXPERIENCES?

- What potential BENEFITS do you expect AI integration to bring to your teaching practice and student learning outcomes?
- In what ways do you think AI could support DIFFERENTIATED instruction and PERSONALIZED learning experiences?

Additionally, the participants composed reflective essays detailing their previous AI exposures and projecting their conceivable AI uses in their classrooms.

To analyze the collected data, we employed a thematic analysis approach by initially reviewing the survey responses and the essays to identify the preliminary patterns. To facilitate a comparative analysis, we then grouped the participants into STEM TCs and non-STEM TCs. Through an iterative review analysis, three overarching themes emerged: (a) the potential benefits of AI for teachers, (b) the perceived positive impact of AI on student learning, and (c) the propensity towards AI-infused teaching practices.

Results and Discussion

The participating STEM and non-STEM TCs displayed striking differences. The STEM TCs were consistently optimistic in viewing AI as a valuable tool to enhance teaching and learning while the non-STEM TCs expressed significant reservations. Below and due to the page limitation of this proceeding, we depict each theme with the applicable quotes.

First, the STEM and non-STEM TCs showed diverging opinions about the potential benefits of AI for themselves as teachers. For example, the STEM TCs expressed optimism about AI streamlining lesson planning and teaching ("cut down on time used to prepare lessons" and "efficient and saves me time to work on other things like executing the lesson"). Moreover, these candidates held promising views on AI's capacity to generate ideas, formulate diverse problem sets, and discover relevant resources, ("giving good ideas to use," "many ways to solve a math problem or input on how to structure a topic," and "useful in finding more teaching resources"). These views align with the literature on technology integration as augmented resources (Ertmer et al., 2012; Shi et al., 2024). The non-STEM TCs, on the other hand, garnered diverse views. Some candidates acknowledged the AI's potential, but others expressed reservations about its concrete value and in minimizing the teacher roles ("Not so sure… but I cannot think of any specific benefits yet," "I don't think there will be any [benefits]," "I don't see AI as a huge benefit to my classroom," and "I don't think it will bring any [benefits]").

Second, the STEM TCs widely perceived the positive impact of AI to enhance student motivation and creativity and to facilitate differentiated learning opportunities ("Students can be more creative" and "more motivation, or more interest in the subject"). This outlook resonates with the literature on AI-facilitated, personalized learning. Contrarily, most of the non-STEM TCs expressed their hesitation, skepticism, and uncertainty even though a few candidates acknowledged that AI could serve as a useful supplementary resource ("I am not sure about benefits for my students," "I don't see AI as a huge benefit to my classroom," and "an additional resource to students to enhance their learning and understanding").

Third, the STEM TCs envisioned a high propensity towards AI-infused teaching practices, such as streamlining tasks to create assignments and lesson plans, generating practice problems, and ensuring accurate solutions ("make assignments and activities," "create resources to use within the classroom," "It can help me outline lesson plans and make corresponding worksheets," "helpful in lesson planning in the forms of creating worksheets and creating problem sets for the students," and "I may use AI for more ideas to incorporate real-world word problems for the tests"). Again, for the non-STEM TCs, they conveyed cautious, limited interest in the broader use of AI ("I don't plan on using ai, unless it makes something that could grade a paper instantly then I'll use that"). Some even suggested restricting AI in brainstorming activities because AI could homogenize student reasoning while others tersely concluded that they envisioned not using AI at all ("I may allow the use for ideas for brainstorm only but not for their writing" and "I think it anathema to the act of teaching and learning"). When asked to recall their awareness of specific AI tools, both groups acknowledged their limited familiarity. Nonetheless, several STEM TCs mentioned ChatGPT and Gemini.

Above, the noted divergence may stem from the inherent nature of STEM disciplines. They often involve computational thinking and problem solving through logical, systematic approaches that naturally align with the algorithmic structure of AI (Looi et al., 2020). Conversely, non-STEM fields that frequently emphasize the qualitative aspects of learning and teaching, such as critical thinking, creativity, and nuanced human interaction, might perceive AI as a potential inhibitor.

This study addresses a gap in the literature by demonstrating marked differences in AI integration readiness between the surveyed STEM and non-STEM TCs. Specifically, the findings reveal that the STEM TCs' pragmatic approach aligns with exploring AI's utility while the non-STEM TCs' hesitancy reflects concerns about qualitative, less algorithmic aspects to teaching and learning (Hartmann et al., 2022).

Implications

Our study's limitations include its relatively small sample size of 17 TCs from two institutions. This constrains the generalizability of the findings. Additionally, the reliance on the self-reported survey data and essays, while they provide rich qualitative insights, may include biases.

Nonetheless, the study underscores marked differences in AI integration readiness and willingness between the two secondary school TCs: STEM and non-STEM. The observed disparities in AI readiness likely stem from variations in their teacher education curricula and prior individual exposure to AI technology. STEM education programs, by their nature, tend to offer more opportunities for technology-infused learning–thus, fostering a receptive mindset towards AI. This suggests a necessity for differentiated approaches in teacher education programs regarding AI integration. For instance, STEM TCs could benefit more with specialized training that focuses on practical AI applications and pedagogical innovations that integrate AI tools into coursework, coupled with sufficient practice opportunities (Ertmer et al., 2012; Flores et al., 2014; Galindo-Domínguez et al., 2024). Conversely, to gain more exposure and to build a foundational understanding of the benefits and capabilities, non-STEM TCs might appreciate introductory programs or tailored workshops on AI-infused education (Ayanwale et al., 2022; Fundi et al., 2024; Shi et al., 2024)

Moving forward, the mathematics teacher education community could conduct research: with larger and more diverse groups of TCs to validate our findings; to examine the perspectives of TCs with varying degrees of prior AI familiarity; to attain a more robust picture of how TCs' views had evolved through their programs and as they transition into practicing teachers; and in longitudinal studies to track the development of the STEM and non-STEM TCs' attitudes towards AI as it becomes a more integrated and integral part of our lives.

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USING ARTIFICIAL INTELLIGENCE TO FOSTER AND EXPAND TEACHER CANDIDATES' REFLECTIVE PRACTICE

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Abstract

With the growing use of artificial intelligence (AI) technologies, it is imperative to research tools and methods to support the preparation of teacher candidates. An essential part of teacher preparation is supporting reflective practice. This qualitative study explores using Swivl Mirrors AI technology to support teacher candidate reflections within STEAM and mathematics methods courses. Results show that 69 teacher candidates benefited from using the AI technologies, noting that authenticity, the modality, and immediate feedback were beneficial. Teacher candidates and instructors found this method of reflection to be more favorable than written reflection. Implications are also discussed.

Introduction

Technological advances continue to impact the teaching field. It has increased the availability of resources while increasing the need for teachers to critically evaluate the use of these resources. Now, teachers can use Artificial Intelligence (AI) to create a lesson plan or a rubric. AI can be used to enrich teaching and learning (UNESCO Education 2030, 2023) and will drastically change the field (Zawacki-Richter et al., 2019). In leveraging AI technology, a student-centered approach coupled with effective pedagogy and assessment is optimal (Ali, 2024; Rudolph et al., 2023). In a literature review synthesis, Xu and Ouyang (2022) found that most of the AI applications had positive effects on academic performance within STEAM education. The use of AI in teacher preparation is a relatively understudied area. When it is, it mirrors classroom practice such as using AI to generate and refine planning and instruction ideas (e.g., Maiorca et al., 2024). To address this gap, this study explores how educator preparation can leverage AI to increase teacher candidates' reflective practice.

Literature Review

Teacher Preparation and Reflective Practice

Reflection is a powerful tool of transformation with a focus on "continuous improvement and professional growth" (Juma, 2024, p. 2843). To be effective, teachers must continually self-regulate, analyze, change, and adapt (Schön, 1983). Teacher preparation is expected to develop reflective practitioners (AMTE, 2017; NSTA & ASTE, 2020). Reflection aids in combating teacher candidates' assumed knowledge and understanding of teaching and learning (Lortie, 1975; Smagorinsky & Barnes, 2004), which can cause cognitive dissonance from the reality of teaching presented within their teacher preparation (Griful-Freixenet et al., 2020). Teacher candidates are likely to be largely concerned with being liked and getting their assignments completed (Fuller, 1969; Killian et al., 2013; Livers et al., 2021). Evolution of these concerns to increase teacher preparedness include being concerned about their influence and impact on their students because of their coursework and field work (Livers et al., 2021; Smith et al., 2013). To support the evolution and foster a reflective practice, teacher candidates need opportunities to reflect (Pino-Fan et al., 2022).

Teaching and Learning with Artificial Intelligence

AI is poised to change the field of education (Zawacki-Richter et al., 2019). Rudolph et al. (2023) recommend against harsh resistance to AI tools within teaching and learning. Instead, an approach that is student-centered with pedagogy and assessments is optimal (Rudolph et al., 2023). Celik and colleagues (2022) concluded that AI can benefit teachers with all three parts of the instructional cycle: planning, teaching, and assessing. Academic benefits for students have also been found within STEM education (Xu & Ouyang, 2022). Elementary teacher preparation programs are behind in revising the program curricula to incorporate AI (Grover, 2024). For teacher preparation, teacher educators must help teacher candidates make sense of the uses and benefits of AI (Redmond- Sanogo et al., 2024) because it can help teachers improve their instructional practice (Jamal, 2023).

Objectives of the Study

The purpose of this qualitative study was to explore perceptions of the influence of Swivl Mirror AI technology on teacher candidate reflections. We seek to answer the following research questions:

1. What are teacher candidates' perceptions of the influence of Swivl Mirror AI technology on their reflections?
2. What are elementary methods instructors' perceptions of the influence of Swivl Mirror AI technology on teacher candidates' reflections?

Theoretical Framework

As we consider teacher candidates' perceptions using AI-supported reflections, we ground the study in Fuller's Concern Theory (Fuller, 1969). Teacher preparation programs work to prepare teacher candidates to be reflective practitioners with a focus on student learning and success. Fuller (1969) examined the concerns of teacher candidates and identified three stages in which they progress: concern with self, concern with task, and concern with impact. We portray these stages within a tree metaphor that we created in Canva to highlight teacher candidates' growth as their concerns change over time (see Figure 1).

Methodology

To gain insight into a specific group of teacher candidates implementing AI technology for reflection, we designed a qualitative study. The single case involves teacher candidates from a single semester from two different points in their teacher education program.

Figure 1

Fuller's Stages of Concern

Participants

Teacher candidates from an inclusive elementary (PK–5) teacher preparation program at a large, public, comprehensive, predominantly White institution in the Midwest participated in the study. Participants were recruited from a junior level elementary mathematics methods course and a sophomore level STEAM methods course. 47 teacher candidates enrolled in STEAM methods voluntarily gave consent and completed the final reflection and 22 teacher candidates enrolled in elementary mathematics methods, for a total of 69 participants. Sixty-two percent of sophomore participants were first year students due to participation in college credit programs in high school.

The two instructors for these courses were also participants. Both are white females. One instructor has expertise in science and STEAM education and is an early career scholar. The other has expertise in mathematics and STEAM education and is a mid-career scholar.

Data Collection and Analysis

Data for this study included culminating reflections using Swivl Mirrors at the close of the semester and anecdotal and semester-long reflection notes from the two instructors. Swivl Mirror provided personalized feedback designed to enhance reflective skills and encourage engagement. The Mirror leveraged AI to evaluate sentiment, thinking, and reflective skills. Instructors programed their own questions. For this study, the instructors assigned the following question: How has using the Swivl Mirrors influenced your ability to reflect? Swivl Mirrors then generated follow-up questions. We only analyzed the agreed-upon question at the close of the semester. Teacher candidates used Swivl Mirror for all their reflection activities within the course.

Although this single case did not aim to develop a grounded theory (Glaser, 1978), we used this approach for analysis. In a three cycle analysis, open codes were combined to form themes and then themes were analyzed to develop conclusions. The reflections were also coded according to the type of concern (a priori codes; Elliott, 2018) exhibited by the teacher candidates. The instructor reflection and anecdotal notes data were combined to conduct thematic analysis to capture broad patterns (Braun & Clarke, 2006).

Results

Teacher Candidate Perspectives

Teacher candidates' perspectives were based on analyzing all teacher candidate reflections together and not specific to the sophomore or junior year. Teacher candidates' perspectives overall emphasized the use of Swivl Mirrors enhanced their reflective practice primarily due to immediate feedback. Three main themes emerged from the data analysis: (a) deep, authentic reflection, (b) verbal modality, and (c) immediate, actionable feedback.

Teacher candidates described that the Swivl Mirror AI technology assisted them to reflect more meaningfully compared to when they had to provide written reflections. Many teacher candidates found this process to be eye-opening by assisting them to recognize both successes and areas of improvement. One teacher candidate captured this theme with the following, "It made me think about things I wouldn't have thought of on my own." Another teacher candidate said, "I realized how much I had actually learned."

Teacher candidates found that the verbal modality allowed for real-time expression. Many teacher candidates preferred speaking over writing as noted by one teacher candidate who shared, "It's easier to say what I'm thinking than write it down." Talking appeared to help the teacher candidates to process ideas better and say what they actually felt, as noted by this teacher candidate's response: "I feel like my reflections are more authentic."

The immediate, actionable feedback was a key aspect in fostering reflection for the teacher candidates. Teacher candidates noted they could adjust their work or teaching strategies and that it helped increase their understanding of the content, as documented by this teacher candidate, "The feedback helped me see what to improve right away." Additionally, teacher candidates attributed the feedback to gaining confidence and being more self-aware and responsive. One teacher candidate noted the how the Swivl Mirror "helped me get better at speaking on the spot."

While some teacher candidates saw the AI technology as innovative; others found it impersonal or inaccurate. A few students (4%) expressed skepticism about talking to a machine. These students had doubts about AI's ability to interpret their tone or meaning. Two students specifically noted that because they are more monotone or didn't have a lot of facial expression, the AI technology gave them lower scores for tone or sentiment. These scores were not factored into the instructors' analysis, but it was instant feedback given to the students by the AI technology.

Connection to the Theoretical Framework

The teacher candidates' responses were also coded in relation to Fuller's Concern Theory (1969): self, task, and impact. This coding allowed the instructors to explore the focus of the final reflection for the course. While this data does not reveal a change in concerns over time, as we did not have a pre-post, we compared the teacher candidates who were in their STEAM course that is taken in the sophomore year (Spring) and those in their elementary mathematics methods course that is taken in their junior year (Fall). In terms of the reflections, more sophomores (62%) were concerned with self, while the juniors were more concerned with impact (55%). Juniors in the program have spent more time observing students and in-service teachers in the field, accumulated more time authentically practicing teacher skills, and engaged in more traditional modalities of critical reflection in other coursework. These differences between sophomore and junior-year experiences may influence the summary data shown in Table 1.

Table 1

Concern Coding by Group and Stage of Concern

Group	Self	Task	Impact
STEAM Methods	29	15	3
(Spring Sophomores)	62%	32%	6%
Elementary Math Methods	7	3	12
(Fall Juniors)	31%	14%	55%

Note: Percentages reflect the proportion of coded concerns in each category for the respective group.

Instructor Perspectives

The instructors noted in the anecdotal notes that the modality, feedback, and time were all assets to using the AI technology. The video recordings and transcripts seemed more personal and authentic compared to previous written reflections. The instructors expressed positive feelings about the instant feedback that students received and found it to be a valuable time-saver in their reflections. The overviews could be quickly incorporated into their teaching. One instructor noted in a reflection, “After reviewing the feedback, I was able to address the students' uneasiness about differentiating in small groups into a class activity to help them feel more confident.”

There were implementation challenges that were identified from the anecdotal notes and instructor reflections. The instructors found that setting up groups and creating new assignments were time-consuming and not always accurate in connecting the correct student groups. Some students were hesitant and unsure about the vulnerability of being recorded or completing the reflection in front of others. This led to poor-quality audio reflections when students attempted to keep their voices low. One instructor created a private space for students to interact with the Swivl

Mirrors, but only one student could use it at a time. The technology was not compatible with Google Pixel phones and did not work with the Safari browser. Additionally, responses to implementation problems from Swivl Mirror support were not prompt. While the feedback was helpful, some of AI analysis was unclear for the qualities tone and sentiment.

Discussion and Implications

The use of Swivl Mirrors enhanced the reflective practices of these teacher candidates aligning with Xu and Ouyang (2022) that AI applications have positive impacts on students' learning. Using AI for reflective practices appeared to foster a dynamic interaction, allowing teacher candidates to articulate their responses more freely than through written reflections. The authenticity of verbal reflections can lead to deeper insights into strengths and areas for growth for the teacher candidates.

Teacher candidates' concerns, as expressed in their reflections, can be analyzed, whether written or verbal. Within this analysis, it was noted that sophomores were more concerned with self, and juniors were more reflective about impact. This finding aligns with Fuller (1969) and may be attributed to juniors' simultaneous field placement and engaged in more reflective activities. If teacher preparation programs aim to enhance teacher candidate reflections, instructors within these programs can support teacher candidates in their growth and address their concerns through meaningful reflection activities (Pino-Fan et al., 2022). Strong reflection includes a focus on the impact of actions (Schön, 1983), and the AI technology shows promise to impact instructional decisions (Jamal, 2023).

As with any new technological tool, instructors will experience time-intensive activities to incorporate the tool into their instruction in a meaningful way. Likewise, instructors will need time to plan and prepare their lessons. Although these were identified as challenges, the results are likely to be expected. The Swivl Mirror AI analysis scoring of tone and meaning was less helpful to both the teacher candidates and the instructors. There could be bias in the length of the reflection. Additionally, more information is needed for the equitable assessment of tone and dialect.

This study had limitations. First, the study is reliant on final reflection data. Future studies could include reflections throughout the courses as well as interviews and/or focus groups. It would have been helpful to include freshmen and seniors to compare the types of concerns that teacher candidates experience. Future studies could also investigate reflection beyond one teacher preparation program or extend into the reflection of practicing teachers.

Conclusion

The results of this study highlight some issues with using AI. Smart phone accessibility and compatibility, browser compatibility, cost, or the comfort level of non-traditional students with the technology all must be considered as teacher preparation incorporates the use of AI. There is potential in utilizing AI in conjunction with coaching, mentoring, and professional learning.

To cultivate this transformational reflection process, AI has the potential to provide meaningful and timely support. Recognizing the value of verbal reflections combined with immediate feedback, teacher candidates will likely develop stronger teaching strategies and greater confidence in their abilities. This focus on enhancing reflective practices not only benefits individual growth but could also lead to a more cohesive and supportive learning environment.

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EFFECTIVENESS OF SCIENCE AND MATHEMATICS TEACHERS ACROSS THREE LEARNING MODALITIES POST-COVID-19

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Abstract

Learning modalities implemented for reopening during COVID-19 impacted effectiveness of science and mathematics teachers in high-need local educational agencies (HN-LEAs). The distribution of learning modalities was very similar between Title I and SRSA/RLIS eligible HN-LEAs, with approximately half of each reopening in a hybrid fashion. From 2019 to 2022, students who initially returned to learning in-person had higher graduation rates and performance on science and mathematics tests than those who returned to remote or hybrid learning environments. However, these differences were already present in the 2018–2019 pre-pandemic baseline, suggesting reopening choices reflected yet-to-be-determined disparities between districts.

Keywords: high-need local educational agency, teacher effectiveness, learning modality, COVID-19, pandemic

Introduction

Traditional research on school district responses to past emergencies focused on episodic, localized events such as the impact of what was previously one of the most widespread and costly disasters (NOAA, 2019), Hurricane Katrina (e.g., Cannon et al., 2009; Loder-Jackson & Sims, 2008; Phillips & Herlihy, 2009). However, closing and reopening of US schools in response to COVID-19 was far from episodic or localized. An event such as this was predicted, almost 20 years ago by Laprairie and Hinson (2006), who argued that deadly flu outbreaks or bioterrorist attacks would disrupt education in the future as hurricanes had in the past, and that states and local districts should prepare for this inevitability by developing guidelines and infrastructure to move instruction virtually. Despite early warning and advances in virtual and distance education, very little infrastructure or guidelines were in place when COVID-19 hit. In 2020, K-12 schools transitioned to virtual instruction, and during the course of COVID-19, teachers and students experienced learning modalities they had not encountered before or with which they had little experience.

Objectives of the Study

This project examines (a) which learning modalities were utilized by HN-LEAs during COVID-19, and (b) how school reopenings during COVID-19 impacted middle school and high school science and mathematics teacher effectiveness in HN-LEAs.

Related Literature

Learning modalities are defined according to the Center for Disease Control (CDC) as being In-Person (five days per week face-to-face), Remote (all instruction online/remote), or Hybrid (any one of many combinations of remote and face-to-face) (HHS, 2022). Although districts reported returning to the classroom with one of these modalities, the Institute of Education Science (2022a, b) found inconsistent implementation related to school characteristics (e.g., demographics, geographic location). The complexity of teaching is increased by this implementation as well as shifting contexts (e.g., student demographics, school environment, political climate). Shizari et al. (2022) stressed that effectiveness differentiates across disciplines as well as across cultural and organizational contexts. Effectiveness is defined as the "ability to produce the required results or capacity to produce output" (Akram & Malik, 2021, p. 140). Cantrell and Kane (2013) did not find a 'silver bullet' for detecting effectiveness but three widely used measures are structured observations of teaching, student achievement, and student perception of the teacher. Teacher effectiveness measures in this study focused on student achievement and included standardized mathematics and science scores, as well as high school graduation rates, beginning with the 2018-2019 academic year, since student standard scores or academic gains are readily available across school districts and are not subject to concerns with retrospective data collection.

Methodology

Sample Selection

The details of the sample selection and exclusion criteria are provided in (Shi et.al., 2024; Weinburgh et al., in press) using data from large public datasets (i.e., US Department of Education (USDE, n.d.), National Center for Educational Statistics (NCES, 2022), and Health and Human Services public data (HHS, 2022; DHHS, 2022). Four HN-LEAs were randomly selected per US

Census Division (n=36). In order to include a diversity of HN-LEAs, within each division, two HN-LEAs were eligible for Title I Funding (USDE, n.d.), and two were eligible for Small, Rural School Achievement (SRSA) (OESE, n.d.-a), or Rural or Low-Income School (RLIS) (OESE, n.d.-b) programs. In addition, the districts were verified to meet the economic criteria of having either at least 20% or 10,000 children participating in free or reduced lunch. The final section included 36 districts located in 20 states. Exclusion criteria included service agency listings, independent charter districts, districts without all grades K-12, and districts that did not report their learning modalities.

Determination of Learning Modality

RQ 1: What learning modalities were used by HN-LEAs beginning in Fall 2020?

In this study, HN-LEAs (hereinafter "districts") are grouped, for all years of analysis, by the learning modalities implemented Fall 2020. In-Person, Remote, and Hybrid Learning modalities were defined according to the CDC (HHS, 2022).

Time Points

The research period includes four academic years, starting from 2018-19.

- 2018-2019 academic year: pre-COVID-19 pandemic baseline when teaching and learning occurred in in-person classroom settings.
- 2019-2020 academic year: COVID-19 pandemic began and teaching and learning shifted to a virtual environment starting in March 2020 for the remainder of the academic year. While graduation rate data were available for the 2019-2020 academic year, standardized testing was suspended and thus not available.
- 2020-2021 academic year: districts reopened with a variety of learning modalities and, for all the years in this study, districts are grouped by the Fall 2020 Learning Modalities.
- 2021-2022 academic year: majority of districts return to fully in-person.

Determination of Teacher Effectiveness

RQ 2: How did the use of different learning modalities contribute to STEM teacher effectiveness in HN-LEAs?

Multiple measures were used to operationalize teacher effectiveness at the district level, from the 2018-2019 academic year (pre-pandemic) through the 2021-2022 academic year, including high school graduation rates, and four standardized test scores: high school mathematics, high school science, middle school mathematics, and middle school science. The tests given varied across districts but were consistent within districts over time. For the middle school tests, 8th grade was chosen unless the district only administered both tests in 7th grade. Districts often reported standardized End of Course tests (e.g. Algebra I, Biology) for their high school measures of mathematics and science proficiency rather than being grade specific; but other districts choose to administer tests like the ACT to all of their students at a particular grade for their reported measures. Once districts were identified for inclusion in the study, the data sets used for teacher effectiveness were retrieved from public-facing school or district level webpages or from the relevant state department of education websites. In cases where data could not be located, districts were contacted to either provide the data, or to clarify why it was not available. Data were not publicly reported by some districts that served a small number of students in order to protect student privacy in compliance with the Family Educational Rights and Privacy Act.

Data were not imputed, and a complete case analysis was used, whereby, for any specific measure, districts were excluded from analysis and data visualizations if data were missing for that measure in any year. Imputing the data was not appropriate for at least two reasons: (a) data were collected over a time period whereby it was anticipated that the data would change across time points, and (b) data are missing differently from different groups and so do not appear to be "missing completely at random" or even “missing at random” (van Buuren, 2018).

Results and Discussion

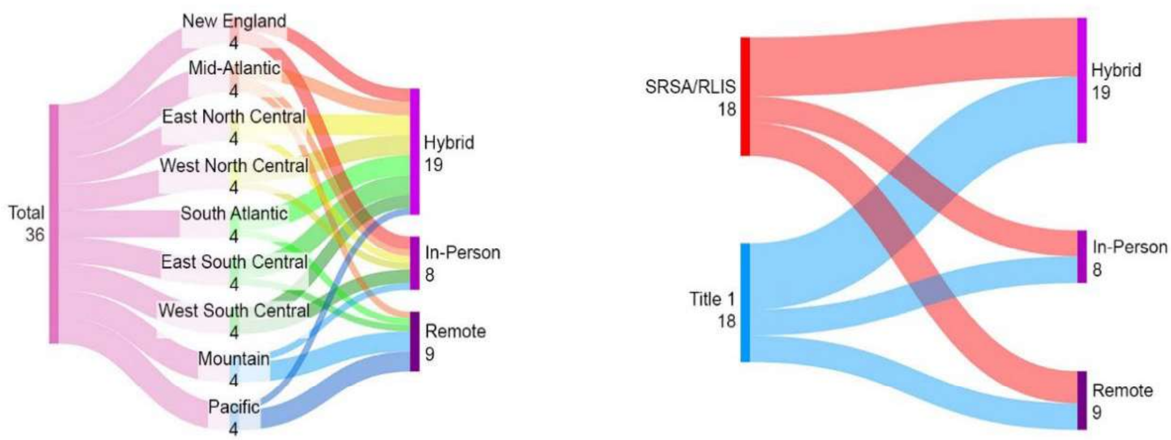
Learning Modality

Approximately half of the representative HN-LEAs (53%) reopened with a hybrid learning modality, and approximately a quarter reopened with remote (25%) and in-person (22%) modalities (Figure 1a). For eight of the nine Census Divisions, only two of the three learning modalities were utilized within their districts, and for the remaining Division, Mid-Atlantic, all three of the learning modalities were utilized. Hybrid instruction was used as a learning modality option in eight of the nine Census Divisions; in-person instruction was used in six; and remote instruction was used in five. When the Divisions are grouped by Census Regions, it was noted that none of the districts included in the study from within the Midwest Region (i.e., East North Central and West North Central Census Divisions) used remote instruction.

There was no distinction between learning modalities used by the HN-LEAs participating in the different federal programs. Distribution across learning modalities was similar between Title I and combined SRSA/RLIS districts with 56% of Title 1 and 50% of SRSA/RLIS districts reopening with a hybrid learning modality; 22% of Title 1 and 28% of SRSA/RLIS districts reopening remotely; and 22% of both Title 1 and SRSA/RLIS districts reopening in-person (Figure 1b).

Figure 1 a and b

a. *Learning Modalities Used by Four Randomly Selected HN-LEAs in Each of Nine Census Divisions* and b. *Learning Modalities Used by Eligibility for Federal Program Type*



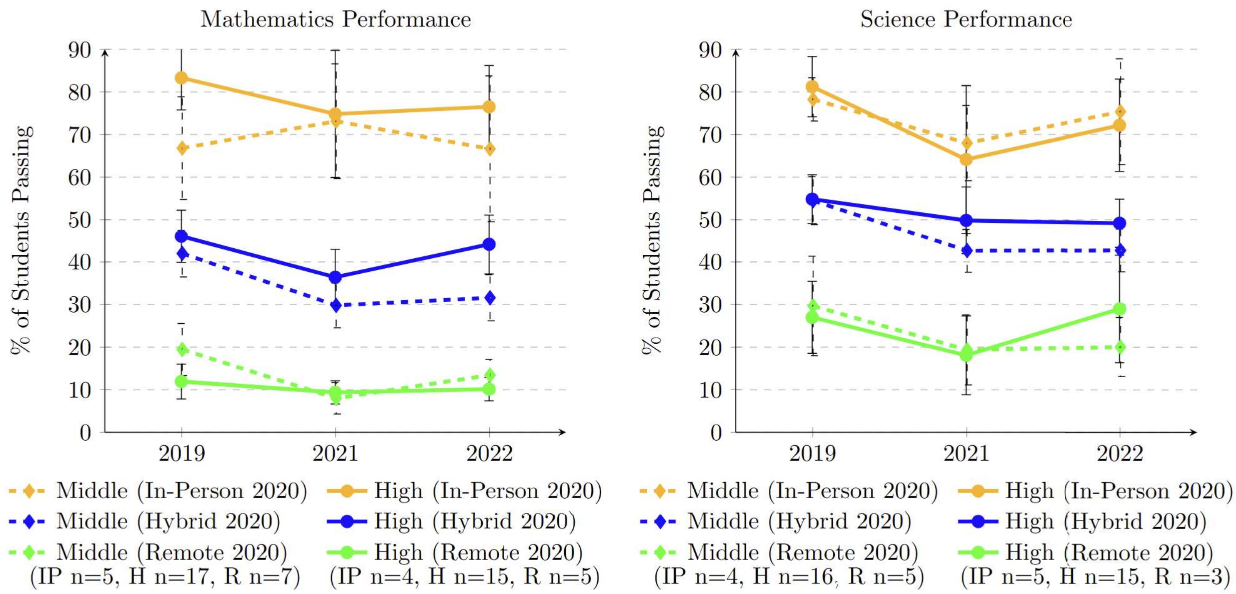
Note: a. Census Regions are color-coded: Red – Northeast; Yellow – Midwest; Green – South; Blue – West. b. Within each Census Division, two HN-LEAs were Small, Rural School Achievement (SRSA) or Rural or Low-Income School (RLIS) and two were Title I.

STEM Teacher Effectiveness

From 2019 to 2022, students who initially returned from the COVID-19 shutdown to in-person instruction performed better than those who returned to remote or hybrid instruction as show in Figure 2a Mathematics, Figure 2b Science, and Figure 3 graduation rates. These findings were consistent across all time points, including the pre-COVID-19 baseline year.

Figure 2a and 2b

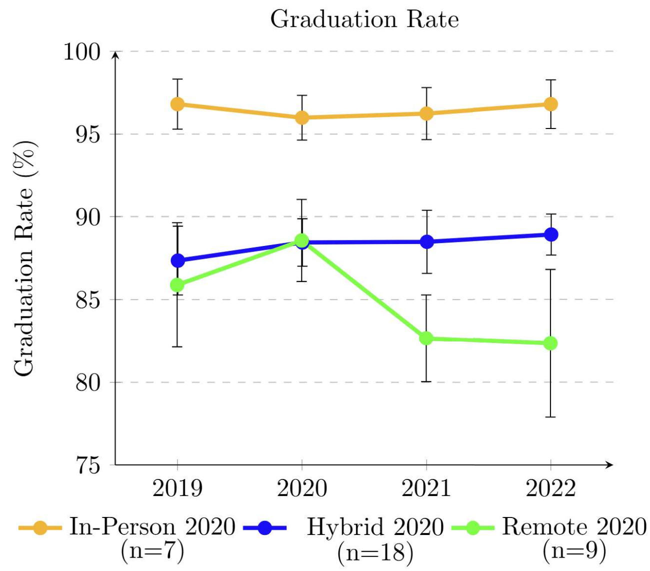
Mathematics (a) and Science (b) Performance for Middle and High School



Note: a. Students who initially returned from the COVID-19 shutdown in-person (IP) had higher standardized mathematics performance levels than students who returned remotely (R) or in a hybrid (H) manner across time points, including the 2018-2019 academic year prior to the pandemic (ANOVA: middle school $n = 29$, $p < 0.05$). b. Students who initially returned to in-person instruction after the COVID-19 shutdown also tended to have higher standardized science performance levels than students who returned remotely or in a hybrid manner across time points including the 2018-2019 academic year prior to the pandemic.

Figure 3

Graduation Rate



Note: Students who initially returned from the COVID-19 shutdown in-person had higher high school graduation rates than remote or hybrid students across time points, including the 2018-2019 academic year prior to the pandemic, $p < 0.02$ (Tukey HSD), $n = 34$. Despite baseline differences, data suggest a possible negative impact on graduation rates for remote instruction.

Implications

This study found that high-need districts across the country made choices at comparable differential proportions about the learning modality they would use to reopen their schools following the COVID-19 shutdown. Since these proportions were similar across the total sample and within both the Title I sample and the combined SRSA/RLIS sample, and the sample was drawn using a random sampling technique, it is reasonable to infer that these patterns are representative of the broader high-need districts' learning environment, and possibly generalizable to similar educational contexts at the national level. Further, findings across the Title I and combined SRSA/RLIS samples suggest rural and urban schools made choices in similar proportions and that these decisions were made at the local level.

More importantly, this study included the 2018-2019 academic year as pre-COVID-19 baseline data that was unimpacted by COVID-19. Inclusion of this time point is critically important for the interpretation of teacher effectiveness data during the pandemic. If the baseline data had not been included, we might have incorrectly concluded that there was a differential impact of teacher effectiveness based on the way in which HN-LEAs returned to instruction in the Fall of 2020. Rather, inclusion of this timepoint demonstrates that the districts that chose to open in-person were substantially more successful at meeting educational standards at all time points compared to the districts that chose to open remotely or in a hybrid fashion. The districts that made the choice to open in-person that Fall were already largely meeting the educational needs of their students as demonstrated by more than 80% of their high school students passing their mathematics and science standardized tests prior to the pandemic. This is in stark contrast to the high-need-districts that made the choice to open remotely and failed to meet the educational needs of their students as demonstrated by less than 30% of their high school students passing their science standardized tests prior to the pandemic and even fewer (less than 15%) passing their mathematics tests. This suggests that the choice to open in-person was part of a larger successful approach taken by these high-need districts to support their teachers' effectiveness and students' achievement. Future research should aim to identify how districts that elected to reopen in-person differ by identifying the factors that distinguish these districts from those that elected to reopen to remote or hybrid instruction. Furthermore, interpretation of research concerning learning modalities during COVID-19 should be conducted with caution, particularly if baseline pre-COVID-19 measures are not included for comparison.

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BAY TO SCHOOLS: IMPACTING TEACHERS AND STUDENTS THROUGH I-STEM EDUCATION

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Abstract

This exploratory case study examined perceptions of an Integrated STEM program that incorporated engineering design and scientific inquiry across 12 schools. Drawing on survey responses from 14 teachers and classroom observations, the study examined how students addressed erosion-related challenges in Galveston Bay. The findings revealed that 1,403 students participated in hands-on, inquiry-based learning experiences. Thematic analysis of coded survey responses and field notes revealed two key outcomes: (a) increased student engagement through experiential learning and (b) enhanced understanding of erosion and mitigation strategies. Findings highlight the value of situated STEM learning in fostering real-world problem-solving, ecological awareness, and interdisciplinary thinking.

Keywords: integrated STEM, environmental education, engineering design, situated learning, place-based education

Introduction

Exposing students to complex environmental concepts at an early age is crucial for laying the foundation to address environmental issues and positively impact the environment by developing solutions to complex problems. Sondergeld et al. (2014) noted that when students understand the intricacies and consequences of natural processes and events, they will be better prepared to take action. Connecting students with nonformal organizations that focus on creating environmental stewards through place-based educational experiences is one of the best ways to teach students.

School districts across the southeast Texas region lack funding for field trips to Galveston Bay due to the residual effects of Hurricane Harvey and the COVID-19 pandemic. To ensure equitable access to and education about the Galveston Bay Watershed, non-formal environmental educators must partner with public, private, and charter schools to bring the Bay into the classroom. This study examined how the Bay to Schools program enhanced the knowledge and appreciation of the Galveston Bay estuary system among teachers and students through environmentally integrated STEM (I-STEM) workshops, which focused on engineering shorelines. The researcher sought to understand K-12 teachers' perceptions of how engineering activities impact students' understanding and engagement of the Bay and to gain insights into K-12 teachers' application of environmental education. This study conducted a teacher survey with five open-ended questions related to the STEM workshop's impact on students, what the students were doing, and how the standards aligned with the activity. The researcher believes these findings will inform practice and future studies.

Objectives of the Study

The objectives of this research study were to examine (a) the impact of the Engineering Shorelines activity on student engagement and (b) teachers' perceptions of how an I-STEM program can impact student learning and understanding of natural processes affecting Galveston Bay.

Conceptual Framework and Related Literature

This study is grounded in the Integrated STEM (I-STEM) framework (Kelley & Knowles, 2016) and informed by situated learning theory (Lave & Wenger, 1991). For this study, integrated STEM (I-STEM) is defined as "the approach to teaching the STEM content of two or more STEM domains, bound by STEM practices within an authentic context to connect these subjects to enhance student learning" (Kelley & Knowles, 2016, p. 3). The I-STEM framework situates STEM learning through a pulley system analogy where each STEM discipline acts as a strand. The pulley rope represents the community of practice, the social and collaborative environment in which integrated learning occurs. As the pulley moves, students experience how each strand connects with other disciplines and the importance of contextual learning.

With a dearth of comprehensive understanding of STEM education, the I-STEM framework (Kelley & Knowles, 2016) operationalizes key concepts in STEM education by using situated STEM learning. Situated learning theory complements the I-STEM framework by emphasizing that knowledge is created through active participation in meaningful tasks within specific social, cultural, and physical environments (Lave & Wenger, 1991). Therefore, supporting the idea that knowing and doing are intertwined, and the acquired knowledge becomes "situated" within interactions between social, cultural, and physical environments (Greeno & Moore, 1993). Utilizing an integrated STEM approach in learning often provides students with a well-rounded understanding of addressing problems and creating solutions. Situated learning perspectives and integrated experiences can impact students' ability to succeed and implement integrated STEM practices.

In this study, the Engineering Shoreline activities serve as the situated learning context, allowing students to engage in interdisciplinary STEM practices while addressing real-world environmental challenges in Galveston Bay. Together, I-STEM and situated learning provide a comprehensive lens for examining how students develop STEM competencies through collaborative, experiential learning. This intersection supports the study's focus on how authentic, place-based engineering experiences foster students' engagement, environmental awareness, and critical thinking.

Integrating STEM education equips students with a deeper understanding of how technologies function and are developed, while fostering authentic learning experiences centered around problem-solving, innovation, and design (Hernandez et al., 2014). Advocates of integrated STEM emphasize a cross-disciplinary approach to help learners and educators make meaningful connections between academic concepts and real-world challenges (NRC, 2014; Subramanian & Clark, 2016). Enhancing the EDP with mathematical concepts related to budget constraints helps students make connections to determining whether their design is cost-effective and scaled appropriately. This interdisciplinary model focuses on confronting real-life problems, critical thinking, content mastery, and creative problem-solving (Wang et al., 2011).

As awareness of STEM's value grows, educators increasingly recognize the importance of hands-on learning in building strong STEM foundations (Margot & Kettler, 2019). Schools are increasingly adopting the engineering design process (EDP) to make connections among STEM subjects, promoting iterative testing and improvement in solution creation (NRC, 2014). When integrated into math and science curricula, the EDP not only reinforces critical engineering principles but also nurtures adaptable problem-solving skills relevant across diverse STEM fields (English, 2019) and enhances students' STEM literacy across subjects (English, 2021). For EDP challenges to be truly effective, they must connect to real-world contexts. Teachers use common activities, such as the Marshmallow Challenge, to have students work through the EDP. Many times, however, these engineering activities do not align and often fail to provide authentic learning experiences (Maiorca & Mohr-Schroeder, 2020). Providing authentic engineering challenges should immerse students in experiences that teach the EDP, where students are engaged in critical thinking and provided opportunities to expand their STEM knowledge and increase their creativity. As such, engineering proves to be a powerful conduit for STEM integration (NASEM, 2020).

Instilling STEM and engineering design mindsets can help establish a shared vision and expectations for learning, which can contribute to a strong STEM-driven school culture (Waters & Orange, 2022). This culture fosters engineering habits and practices that are valuable to instill in students at an early age. Incorporating engineering education into elementary science classrooms reinforces essential habits of mind that extend beyond science and are transferable across STEM domains (Lippard et al., 2019). Implementing these processes can foster a STEM mindset among educators and students alike (Peters-Burton et al., 2019) and promote engineering habits of mind (i.e., systems thinking, creativity, optimism, collaboration, communication, and ethical awareness), which is crucial, as these align with essential 21st century skills (P21, 2015). The development of these habits and practices reflects the skills needed in an ever-changing world (Loveland & Dunn, 2014; NASEM, 2020). Thus, an interdisciplinary approach that emphasizes brainstorming, inquiry, and innovative thinking encourages students' creativity and imagination, much like professional engineers (Gormley & Boland, 2017; Marcos-Jorquera et al., 2017) and fosters a STEM-driven mindset.

Methodology

This study employed an exploratory case study design (Lichtman, 2010), which examined how the Engineering Shorelines activity, part of an Integrated STEM (I-STEM) program, impacted teacher perceptions of student engagement and students' understanding of environmental processes affecting Galveston Bay. The case was bounded by the implementation of the activity across 12 schools, including one university program, with students in grades 4-12. Additionally, this study investigated perceptions and experiences, which aligns with a case study design (Lichtman, 2010). This study explored the following research question: How do teachers perceive the impact of participating in engineering design and scientific inquiry on student engagement and understanding of environmental issues impacting Galveston Bay?

Participants were recruited to participate in the Bay to Schools program, an environmental education initiative designed to engage students in hands-on, inquiry-based learning focused on erosion and shoreline mitigation, during the 2024-2025 academic year. Fourteen teachers participated in the study, where environmental educators facilitated the Engineering Shorelines activity for their students. The study consisted of three classroom observations of students working through the Engineering Shorelines lesson and a teacher post-survey. Observations focused on student engagement during the Engineering Shorelines activity in fourth-grade, eighth-grade, and eleventh-grade science classrooms.

In addition, teachers completed a post-survey designed to gather feedback on their participation in the program, its impact on students, and its alignment with classroom instruction. The survey was initially created for the 2018-2019 *Get Hip to Habitat* program and was tailored to gather specific insights that help ensure the lesson remained relevant to classroom instruction, aligned with academic standards, and maintained the commitment to hands-on, inquiry-based STEM learning. Survey questions included (a) Why are you participating in a Bay to Schools program, (b)

How do you think this program affects participating students, and (c) How does this program align with what you are teaching in the classroom?

The researcher analyzed survey data from teachers, focusing on their participation in the program, its impact on their students, and how the program aligns with their curricula. Inductive coding was used to analyze survey responses and identify recurring trends, which were initially categorized by motivation, student impact, curriculum alignment, and benefits to teachers. Codes were cross-referenced with the researcher's observational field notes to triangulate findings and increase validity. Coded survey responses were organized into four categories: motivation, student impact, curriculum alignment, and benefits to teachers. In addition, the responses were overwhelmingly positive, with no dissenting voices from the participants.

Patterns and trends regarding how teachers perceive the impact of participating in engineering design and scientific inquiry through the use of the Engineering Shorelines activity from the I-STEM program were identified. The analysis revealed that student engagement, environmental awareness, and teacher empowerment are key factors in supporting experiential learning and helping students understand the role of engineering in mitigating natural processes such as erosion along Galveston Bay shorelines. This paper focuses on two emergent themes: (a) increased student engagement through experiential learning, and (b) enhanced understanding of erosion and mitigation processes within the Galveston Bay ecosystem.

Results and Discussion

Findings revealed that 1,403 students, spanning grades 4-12, participated in activities related to engineered shorelines. A key theme that emerged was increased student engagement. According to teachers' perceptions and observational data, students demonstrated heightened interest and engagement during the Engineering Shorelines activity, largely due to its interactive, hands-on approach. The findings indicated that students had an increased level of interest and engagement due to their active participation in the Engineering Shorelines activity. One high school senior teacher shared, "The students were really interested and had very high participation rates." Students designed and tested shoreline protection methods using different mitigation processes. High school students had to create a budget to determine the cost of materials and assess their cost-effectiveness before building their mitigation process. This connects to the students' hands-on participation in the activity the researcher observed, which helped them grasp the complex nature of erosion and its environmental impact on Galveston Bay (Figure 1).

Figure 1

High School Engineering Shorelines Activity

Intermediate and middle school teachers' observations also reinforced the engagement theme that hands-on, experiential learning helped students grasp complex environmental concepts, making abstract ideas like erosion more accessible and meaningful. A seventh-grade teacher stated, "The hands-on experience helped make an abstract concept very understandable." A fifth-grade teacher supported this notion and said, "It will give the students a hands-on opportunity" to engage in the engineering process. This active participation captured students' attention and helped them better understand complex environmental concepts through meaningful and experiential learning.

Participation in the engineering design activity deepened students' understanding of the Galveston Bay estuary system and highlighted the role of human impact and engineering in shaping coastal environments. Another finding indicated that the students improved their understanding of the Galveston Bay estuary system and its connection to how engineering can mitigate or hinder erosional processes. This greater awareness of the local ecosystem, erosion, and human impact allows the engineering activity to give students a deeper understanding of the area in which they live. A different seventh-grade teacher stated, "They learned about the erosion that occurs along the coastline." Her colleague at the same school and grade level shared that exposing students to multiple perspectives and expertise from GBF instructors made the content more engaging. She stated that the instructor "helps students connect their environment to their learning." This prompted students to discuss the connections between the engineering activity and their local environment. A high school senior teacher noted, "It allowed them to have dialogue about the activity and to be social."

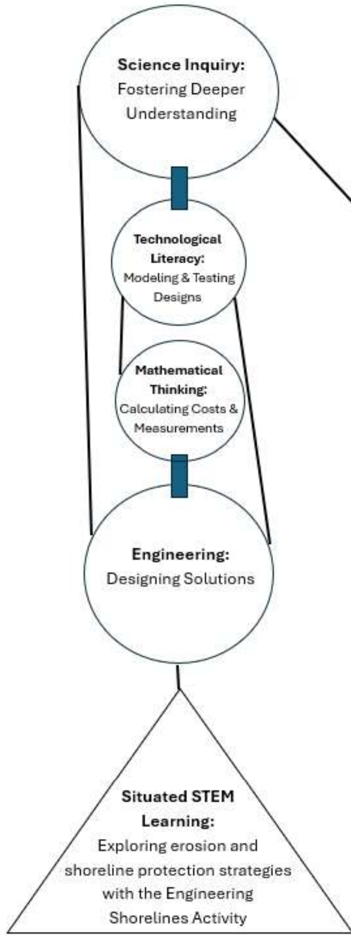
Furthermore, the engineering activity promoted critical thinking and began to shift some students' perspectives. Students appeared to be challenged to rethink initial assumptions and consider multiple solutions to environmental problems, such as erosion within Galveston Bay. A seventh-grade teacher recalled, "Most of them thought that bulkheads were the best, but they now understand that bulkheads have limitations." An aquatic high school teacher shared, "I think it was awesome and allowed them to think about how the things we do impact the structure and function of coastlines as well as the processes that impact them." Overall, the program and the Engineering Shorelines activity not only enhanced students' environmental awareness but also encouraged critical thinking, dialogue, and a more nuanced perspective on real-world ecological challenges.

The Engineering Shorelines activity exemplified I-STEM learning by immersing students in a real-world, interdisciplinary problem-solving experience rooted in environmental science (Kelley & Knowles, 2016). The situated STEM learning experience, Engineering Shorelines, allowed them to work through different authentic erosional scenarios and provided an opportunity to gain a deeper understanding (Kelley & Knowles, 2016). This I-STEM activity anchored students' learning within environmental science. It utilized the pulley system to integrate engineering design, mathematical thinking, and technology literacy, fostering literacy with a continuous flow of scientific inquiry. These experiences throughout the activity provided an interdisciplinary activity situated in STEM learning. By anchoring instruction in authentic challenges and integrating scientific inquiry with engineering design, the engineering shorelines activity fostered students' deeper understanding and meaningful engagement with complex environmental issues.

Situated STEM learning experiences foster essential workforce skills such as collaboration, communication, and problem-solving by engaging students in socially and geographically relevant contexts. Situated learning experiences foster collaboration and communication, two essential skills required in the STEM workforce. In addition, when providing students with a personal, geographic connection, it opens the door for learning to be relevant. Kelley and Knowles (2016) believe this is a key characteristic of situated learning. Finally, providing these experiences is essential for students to practice essential problem-solving, critical thinking, and creativity skills, all of which are essential for situated STEM learning (Kelley & Knowles, 2016). They enable students to navigate complex STEM problems, making meaningful contributions to their communities and future careers by grounding learning in real-world challenges and fostering teamwork and critical thinking.

Figure 2

Engineering Shorelines Situated STEM Learning



Implications

School districts should seek opportunities to partner with non-formal organizations, such as Galveston Bay, to provide authentic, place-based learning opportunities for students that situate learning and make it more meaningful and relevant. School administrators and academic coaches need to prioritize interdisciplinary STEM activities that engage students in the learning process and have them address real-world problems. Teachers should intentionally structure activities that require students to collaborate, share ideas, and reflect, which are necessary skills that are essential for both academic success and future STEM careers.

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IMPACT OF A MATHEMATICS REVIEW ON STUDENTS' CHEMISTRY SELF-EFFICACY: A QUALITATIVE EXPLORATION

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Abstract

The application of mathematics enhances students' understanding and use of chemistry concepts such as the mole. This paper presents results from a research study examining the impact of integrating brief mathematics reviews into undergraduate chemistry courses on students' chemistry self-efficacy. The participants were 40 undergraduate students in first-year general chemistry courses. Findings show an overall increase in chemistry self-efficacy, particularly cognitive abilities, with mastery experience as the main contributor. However, self-efficacy in everyday applications and psychomotor skills remained low. This paper explores the implications and challenges of embedding mathematics reviews into the chemistry curriculum to support student learning and self-efficacy in chemical problem-solving.

Keywords: self-efficacy, mathematics review, undergraduate chemistry

Introduction

The application of basic algebra is essential for solving calculation-based problems in chemistry (Ranga, 2018). Students may have learned these algebraic procedures in mathematics class, but struggle to apply them in solving chemistry problems (Ranga, 2018). Learners may also lack self-efficacy in applying the mathematics procedures while completing calculations in chemistry courses (Ramnarain & Ramaila, 2018). Self-efficacy is one's belief in their ability to carry out a task (Bandura, 1993) and is an indicator of success in undergraduate chemistry courses (Ramnarain & Ramaila, 2018). Success in general chemistry is key in retaining students within science, technology, engineering, and mathematics (STEM) programs, as early struggles often lead to attrition (Posey et al., 2019). To support persistence, students must be equipped with algebraic skills and confidence in applying them in chemistry problems—competencies shown to improve performance (Ranga, 2018).

Purpose and Research Questions

To be successful in chemistry, students need to have fluency with mathematical concepts and procedures such as division, numbers with exponents, and formulae transposition (Ranga, 2018). Students may know the mathematics required for use in chemistry but were never taught how to apply these procedures to other contexts (Ranga, 2018). A mathematics review provides instruction, exercises, and feedback to support students in revisiting previously learned mathematical procedures relevant to their chemistry course (Alivio et al., 2020). These foundational procedures are essential for supporting students' comprehension of chemistry and can improve student outcomes in chemistry courses. This study examined how a mathematics review—designed to reinforce procedures and promote flexible application in chemistry—affects students' self-efficacy in undergraduate chemistry. Research question: How does a focused mathematics review affect students' chemistry self-efficacy in an undergraduate chemistry course?

Theoretical Framework and Related Literature

Students often struggle with procedural fluency in chemistry due to a limited understanding of how to apply mathematical concepts and procedures in problem solving (Ranga, 2018). Facilitating students' ability to connect previously acquired mathematical knowledge with newly introduced concepts enhances their capacity to apply mathematical principles in chemistry-related problem-solving, thereby contributing to improved academic performance (Posey et al., 2019). A lack of self-efficacy may impact student outcomes in chemistry courses. According to Bandura (1993), self-efficacy plays a central role in students' motivation and achievement as individuals will modify their behavior based on what they believe they can accomplish. If a student does not believe that they can accomplish the task, they may not make the effort.

Bandura (1977) identified four key sources of self-efficacy: mastery experience, vicarious experiences, social persuasion, and emotional arousal. Mastery experiences—linked to prior success or failure—are the most influential (Bandura, 1977; Capa-Aydin et al., 2018). Observing others and receiving encouragement can shape beliefs in one's capabilities, especially for those lacking experience (Bandura, 1993). Emotional and physiological states also affect self-efficacy, with optimal performance occurring under moderate stress (Bandura, 1977, 1993). Ultimately, self-efficacy is shaped by both actual experiences and how their significance is perceived.

Self-efficacy is a major contributor to students' academic success and is a crucial determining factor of achievement in science courses. Ramnarain and Ramaila (2018) reported a positive correlation between students' chemistry self-efficacy and their outcomes in undergraduate chemistry, while Villafañe et al. (2016) identified a reciprocal causation between self-efficacy and academic performance in chemistry. Students' self-efficacy contributed to enhanced academic outcomes, which subsequently reinforced their self-efficacy and led to continued improvement on assessments over the course of a semester (Villafañe et al., 2016).

A mathematics review can successfully help students make the connections between mathematics procedures they learned in a formal mathematics class and the new chemistry concepts (Alivio et al., 2020; Ranga, 2018). This connection and fluency in applying mathematics in chemistry, including that provided through a mathematics review led to improved student academic outcomes in undergraduate chemistry courses (Alivio et al., 2020; Ranga, 2018).

The positive correlation between achievement and self-efficacy suggests that activities—such as a mathematics review—that improve students' outcomes will positively impact self-efficacy and result in improved performance as the reciprocal cycle continues (Villafañe et al., 2016). Measuring self-efficacy, designing learning activities to improve self-efficacy, and evaluating the impact of learning experiences on self-efficacy is important to help bridge the gap between mathematics and chemistry and improve achievements in undergraduate chemistry. Given the vital role of self-efficacy in academic achievement, interventions aimed at improving student outcomes should clearly identify the sources of self-efficacy being targeted and examine their influence on performance.

Methodology

Participants and Intervention

This paper presents qualitative findings from a larger mixed-methods action research study conducted over one semester in undergraduate general chemistry courses. The sample consisted of 40 male and female students, aged 16 to 44, enrolled at a small university college in the Caribbean with a total student population of fewer than 2,000. The institution offers degree programs up to the master's level. Two 45-minute review sessions were conducted in the chemistry classes utilizing the EBSCO PrepSTEP LearningExpress online instruction system. The system has instructional videos, guided tutorials, and practice problems (Lindsay, 2018). Review sessions were created using these instructional modules which aligned with the mathematics skills required in the chemistry courses.

Two 45-minute mathematics review sessions were conducted during weeks two and four of the semester. The first covered decimals, integers, and algebraic expressions using instructional videos and guided practice. The second addressed ratios, percentages, and proportions. Each was followed by a 10-minute practice activity linking math procedures to chemistry problems. Additional practice occurred during three subsequent classes, incorporating calculator use and topic reminders. Practice questions were delivered via the Kahoot platform without the leaderboard (Kahoot, 2024), followed by discussion to reinforce how mathematical procedures supported problem-solving in chemistry.

Data Collection

To evaluate the impact of the intervention on students' chemistry self-efficacy and its sources, all participants completed the College Chemistry Self-Efficacy Scale (CCSS) pre- and post-intervention, and eleven participants joined a post-intervention focus group. The validated 21-item CCSS uses a nine-point Likert scale to assess self-efficacy in tasks appropriate in first-year general chemistry across three skills domains: cognitive—mental processes students use to understand, analyze, and apply chemical concepts, psychomotor—required muscle skills, and everyday applications—use of chemistry concepts in daily situations (Uzuntiryaki & Çapa Aydın, 2009). Quantitative data from the full study showed a significant increase in chemistry self-efficacy, primarily in cognitive skills, while self-efficacy for everyday applications decreased (Gayle & Yee, 2024).

To better understand the results, the post-intervention questionnaire included five open-ended questions, based on the theoretical framework, to further explore the aspects of chemistry self-efficacy impacted by the intervention and the source of any change in self efficacy. The questions, which were also repeated in the focus group, were: (a) How did the review sessions make you feel about your abilities in the course, were you more confident in your abilities? (b) How did the review sessions affect your ability to complete calculations in the chemistry course? (c) How did the review sessions impact your ability to understand the chemistry content? (d) What were some challenges with the review sessions? and (e) Describe any ways in which the review sessions negatively impacted your performance in the course.

Data Analysis

Qualitative data were coded using a combination of a priori and in vivo coding strategies. A priori codes were derived from the self-efficacy framework and the CCSS instrument, while in vivo coding allowed for spontaneous exploration of student perspectives. Following an initial data review, the first coding cycle focused on how the mathematics review affected the three self-efficacy domains measured by the CCSS. In the second cycle, skills impacted were identified as: cognitive skills which included problem-solving and understanding of chemistry. Everyday applications were tasks relevant to coursework or future careers, and psychomotor skills reportedly included hands-on activities. A third cycle examined sources of self-efficacy identified by students: mastery experiences, physiological and affective states, and social persuasion. To ensure coding consistency, a summary of responses was reviewed with the interviewer, and discrepancies discussed until full agreement was reached, establishing 100% interrater reliability.

Results and Discussion

All aspects of students' self-efficacy—cognitive abilities, everyday applications, and psychomotor skills—were noted by students in their responses. However, there were overwhelming references to the review sessions having a positive impact on students' self-efficacy for cognitive abilities. A sample of the associated quotes from students obtained from the questionnaire and focus group arranged by aspects of self-efficacy is presented in Table 1.

Results suggest that the students perceived that the intervention positively impacted their cognitive abilities in the course. Overwhelmingly, students stated that the review content was applicable to tasks required in the chemistry course and aided in their understanding of the chemistry content. Students also noted that the content of the review intervention was applicable beyond their chemistry course and could be applied to everyday applications such as use in other courses and in future careers. On the other hand, participants reported the absence of psychomotor skills in the intervention.

Table 1

Sample Data Summary for Aspects of Self-Efficacy

Theme	Code (*N*)	Source	Evidence
Aspect of self-efficacy	**Cognitive**		
	• Contextual – review content was applicable to tasks/computations required in the chemistry course (43)	Focus Group	"The percentage review was able to apply to what we were doing in class."
		Questionnaire	"I now understand how to do mathematics, especially percentage yield."
		Focus Group	"It was helpful to see how math would relate into the actual chemistry especially in the word equations."
	• Relational - students could relate the review content to understanding various chemical principles (21)	Focus Group	

	• Mental mathematics and processing of mathematical procedures (5)		"The review sessions helped with the mental math ability and in checking my work."
	Everyday applications • Useful to other subject areas and careers (2)	Questionnaire	"Review was helpful and needed for me to excel in chemistry and will certainly aid my studies in the future. Even in a future career as well!"
	Psychomotor skills • Skills missing (1)	Questionnaire	"I liked the sessions, but we could do some hands-on work and games."

Students' desire for "hands-on work and games" reflects a need for psychomotor engagement. According to Bandura (1977), such activities offer mastery experiences that can strengthen self-efficacy by fostering confidence through physical task performance.

Of the questionnaire respondents, 24 students reported experiencing no challenges. However, several participants in both the questionnaire and focus group highlighted issues related to length and frequency of the review sessions. Regarding length, concerns centered around the brevity of the sessions. One student wrote, "I believe the time was too short." In the focus group, another student expressed, "The review could have been longer in order to grasp a concept." In terms of frequency, a focus group participant stated, "…. it could have been more frequent. I guess to really get those pathways going." One participant noted that the review prompted a reassessment of their strengths, revealing gaps in applying math to chemistry and a temporary drop in confidence. This led to reliance on instructor feedback to validate their problem-solving approach. The reflection underscores how review sessions can expose unrecognized weaknesses, encouraging students to seek clarification and reinforce foundational skills. These challenges highlight the need to carefully structure interventions to best support student participation and understanding.

Table 2

Sample Qualitative Data Summary for Sources of Self-Efficacy

Theme	Code (*N*)	Source	Evidence
Source of self-efficacy	Mastery experience (39)	Questionnaire	"I can complete calculations better because my math skills are improving."
		Focus Group	"It was covered in the review so with application and practice you would have been able to execute on the exam."
	Physiological and affective states (9)	Questionnaire	"I feel better about my work and about passing the course." "[one challenge with the review was] remaining calm and trying not to get frustrated."
	Social persuasion (2)	Questionnaire	"No one knew it was my answer, so I did not feel bad about mistakes. I got better at working out the stuff in my head and got the answer right sometimes."
		Focus Group	"[The review] affected my confidence levels in areas that I thought I was strong in and then realize this is a weakness and I need to work on it. I wasn't confident with my answers in a lot of questions. So, I had to keep checking with my teacher to ensure that what I did was in fact the right process."

Mastery experience was the main source of self-efficacy changes reported by students (Table 2). Learners reportedly experienced mastery as improved performance on tasks and assignments. Whereas mastery experience was referenced 39 times in the data, there were fewer mentions of physiological state (*N*=9), social persuasion (*N*=2), and vicarious experience (*N*=0).

Conclusions and Implications

Findings suggest that the mathematics review enhanced chemistry self-efficacy through mastery experiences, particularly in cognitive skills like algebraic manipulation. Students reported that contextualized problem-solving improved both confidence and performance. Consistent with Ramnarain and Ramaila (2018), findings suggest stronger self-efficacy in cognitive domains than in others, reflecting an instructional emphasis on conceptual understanding over hands-on practice. However, the lack of reported psychomotor skill development highlights the need to balance cognitive learning with experiential approaches. As Bandura (1977) notes, procedural competence is best developed through active, physical engagement—such as using lab tools or performing manual calculations—to support diverse learning styles. While some students saw relevance in other academic contexts, few recognized chemistry's everyday applications, echoing broader challenges in transferring STEM knowledge to real-life situations (Graham et al., 2019). These findings underscore the need for instructional strategies that promote cross-disciplinary and practical application of scientific concepts.

The mathematics review primarily enhanced students' chemistry self-efficacy by offering mastery experiences through targeted instruction and practice. This outcome aligns with Bandura's (1977) assertion that mastery is the most influential source of self-efficacy, fostering persistence and effort in the face of challenges. This claim is supported in studies by Capa-Aydin et al. (2018), which identified mastery as a key driver of self-efficacy gains in chemistry courses. Notably, they reported that mastery experiences accounted for 50% of the changes in students' cognitive chemistry self-efficacy. While less prominent, physiological and affective states and social persuasion, particularly through anonymous practice opportunities, also contributed to self-efficacy gains in this study. Capa-Aydin et al. (2018) similarly observed that these sources play a secondary role yet may influence how mastery experiences are perceived and internalized by students.

Student feedback highlights how review sessions shape self-efficacy, consistent with Bandura's (1977) view that perceived capability influences motivation and performance. One student, initially confident in applying math to chemistry, experienced a drop in self-efficacy after recognizing gaps in understanding, leading to increased reliance on teacher validation. This shift underscores the impact of review on perceived competence and the value of supportive feedback in promoting corrective learning, self-reflection, and resilience.

Overall, the findings underscore the significance of integrating review sessions with constructive feedback as a multifaceted intervention within educational settings. Such sessions can facilitate the recalibration of students' academic self-belief. The sessions can additionally function as both diagnostic and developmental tools, helping educators assess students' evolving academic self-efficacy and tailor support accordingly. As such, these pedagogical strategies hold considerable potential for enhancing students' success in learning environments.

This research offers practical insights for enhancing student self-efficacy through targeted, low-resource math interventions in undergraduate chemistry. By bridging the gap between mathematics and chemistry, the just-in-time approach builds on prior interdisciplinary work (Alivio et al., 2020; Ranga, 2018), requiring only instructor training while delivering significant learning gains. Though limited in scope and size, this scalable model holds promise for fostering interdisciplinary collaboration and improving STEM education across diverse settings.

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STRATEGIES FOR INTEGRATING MATHEMATICS IN CHEMISTRY COURSES: ENHANCING PROBLEM-SOLVING AND ANALYSIS

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Abstract

Applying mathematical concepts and procedures is essential in solving chemistry problems. This practitioner guide was developed to equip educators and instructional designers with tools to integrate mathematics into chemistry courses, to enhance students' problem-solving and analytical skills. This paper, based on results from an action research study on inclusion of math reviews in undergraduate chemistry, highlights effective methods to blend mathematics into chemistry lessons, bridge the gap between the disciplines, and promote inclusion and innovation in chemistry courses.

Keywords: chemistry; problem-solving; STEM integration; self-efficacy; mathematics review

Introduction

The mathematics required in undergraduate general chemistry is basic algebra which students would have been taught in secondary level mathematics. However, some students struggle to apply the procedures in solving chemistry problems especially in mole concepts, balancing equations, and gas-laws (Ranga, 2018). As general chemistry is a gateway course, strategies to help learners succeed in these courses may increase the retention of students in science, technology, engineering, and mathematics (STEM) fields (Posey et al., 2019). Research shows that helping students bring mathematics procedures to their working memory just before applying them in chemistry, leads to improved problem-solving abilities and outcomes in general chemistry (Nelson, 2018).

This guide was developed based on a mixed-methods research study which suggests that a just-in-time mathematics review in chemistry courses improves students' chemistry self-efficacy and their application of math when solving chemistry problems (Gayle, 2024; Gayle & Yee, 2024). The paper outlines strategies to incorporate readily available tools to bring previously learned mathematics principles into students' working memory and facilitate problem-solving in chemistry. The paper will also help educators assess the effectiveness of these strategies in their classes. The strategies included will promote increased innovation in science classes and foster inclusion so that all students are given the opportunity to succeed despite their previous mathematics experiences or successes.

Objectives

This paper aims to help instructors bridge the gap between mathematics and chemistry, demonstrating effective integration of mathematical concepts and procedures into chemistry classes to enhance students' analytical and problem-solving skills. The paper illustrates the importance of mathematics in understanding and solving chemical problems and provide strategies for incorporating needed mathematical into the chemistry curriculum.

Theoretical Framework and Related Literature

Challenges in developing procedural fluency in chemistry often arise when students struggle to connect mathematical reasoning with chemical problem-solving (Ranga, 2018). This disconnect can result in formula memorization without true conceptual understanding—an issue widely recognized by educators working across STEM disciplines. Students may have already been taught the necessary skills in a formal mathematics class but may not know how to apply the required concepts and procedures in chemistry (Kilner, 2018). Cognitivism provides a useful lens for understanding this challenge, as it enables an exploration of how students activate and use their prior knowledge. It emphasizes the role of prior learning, corrective guidance, and feedback in supporting the application of knowledge to new situations (Ertmer & Newby, 2013).

Recent studies emphasize the importance of embedding mathematics instruction directly into chemistry learning environments to address the struggles that students encounter with solving problems in chemistry courses (Alivio et al., 2020; Jackson, 2022; Williamson et al., 2020). For example, just-in-time teaching strategies—where math scaffolding is provided exactly when students encounter chemical calculations—have significantly improved engagement and understanding (Jackson, 2022). This approach allows instructors to identify and address concepts with which students struggle in real time, creating a more responsive and learner-centered experience.

Practitioners also benefit from understanding the impact of interdisciplinary teaching on student confidence. Research indicates that when students see math and science as connected rather than siloed subjects, their self-efficacy improves and they are more likely to persist in STEM pathways (Bain et al., 2018). Rooted in Social Cognitive Theory (SCT), the concept of self-efficacy emphasizes the belief individuals hold in their ability to succeed at a specific task (Bandura, 1999). Without this belief in one's capacity to succeed, motivation to persist in challenging tasks diminishes and highlights that self-efficacy is a crucial factor in motivation (Bandura, 1999). Bandura (1993) also distinguished between possessing knowledge and being able to use that knowledge under pressure, underscoring that performance can vary significantly between individuals with similar skill sets based on their level of self-efficacy.

Numerous studies identify self-efficacy as a key contributor to students' academic success and a critical predictor of achievement in science disciplines (Ramnarain & Ramaila, 2018; Villafañe et al., 2016; Boz et al., 2016). Ramnarain and Ramaila (2018) found a positive correlation between chemistry self-efficacy and undergraduate performance. Similarly, Villafañe et al. (2016) reported a reciprocal relationship between self-efficacy and exam performance in an organic chemistry course. Increased self-efficacy improved outcomes, further reinforcing students' confidence and subsequent achievement. Considering the impact that self-efficacy has on students' performance, Ramnarain and Ramaila (2018) recommended that learning experiences be designed to increase students' self-efficacy. Effective interventions often combine cognitive strategies, contextualized examples, and collaborative problem-solving to reinforce the links between chemistry and mathematics.

Bridging the math-chemistry divide isn't just an academic exercise, it's a pedagogical imperative. For educators, incorporating timely, context-specific math reinforcement into chemistry lessons fosters a more cohesive learning journey, better prepares students for future coursework, and supports long-term success in STEM programs. The mathematics review intervention outlined in this paper has been demonstrated to increase learner self-efficacy and problem-solving skills in undergraduate general chemistry courses (Gayle, 2024; Gayle & Yee, 2024).

Teaching and Instructional Practice

To better support students in undergraduate general chemistry, implementing a targeted mathematics review—featuring instruction, practice, and feedback—can reinforce prior math knowledge and prepare students for upcoming chemistry content. This approach is particularly effective for mid-performing students, enhancing their mathematical fluency and problem-solving abilities in chemistry (Alivio et al., 2020; Ranga, 2018). Timely reviews help shift math skills into working memory, improving their application during chemistry tasks (Nelson, 2018).

Improved math competency also contributes to greater confidence in chemistry, as research consistently links chemistry self-efficacy with academic success (Boz et al., 2016; Ramnarain & Ramaila, 2018; Villafañe et al., 2016). Strengthening math skills within chemistry instruction not only boosts performance but also enhances self-efficacy (Mack et al., 2019). The observed feedback loop between exam performance and self-efficacy (Villafañe et al., 2016) underscores the value of math reviews in improving outcomes. Whether delivered as brief refreshers or structured tutorials, these reviews are especially beneficial for at-risk students, supporting both skill development and confidence (Mack et al., 2019; Ranga, 2018).

This practical guide was developed based on the results of a mixed methods action research study which incorporated a targeted mathematics review into undergraduate general chemistry courses during the 2023 and 2024 spring semesters at a small university college in the Caribbean. The institution has an enrollment of just under 2000 students and offers degrees up to the Master level. Participants were 79 male and female students ages 16-44 years registered in the first-year undergraduate general chemistry courses. Data was collected using pre- and post-intervention Math-Up-Skills-Test (MUST) scores and Self-efficacy questionnaire (CCSS) data to collect quantitative and a post intervention questionnaire to capture participant perception of the intervention. The MUST is a validated 15-minute quiz that has been used to predict student success in undergraduate chemistry courses (Alivio et al., 2020; Williamson et al., 2020). The CCSS is a validated instrument that uses 21 Likert-type questions to measure students' chemistry self-efficacy in tasks specific to general chemistry courses (Ramnarain & Ramaila, 2018).

The intervention was designed as two 45-minute mathematics review sessions and subsequent 10-minute mathematics practice sessions conducted during the chemistry lessons. Topics covered included percentages, ratios, proportions, transposing formulae, calculations with scientific notations and number sense. Practice questions were chemistry specific and conducted as games on the Kahoot® platform, during five class sessions over six weeks. The review and practice session were conducted just before the chemistry content for which students would need to apply the material. For example, ratios and proportions practice session were conducted in the lesson just before balancing equation and stoichiometry were covered in the chemistry course.

Results

Table 1 shows the results of paired t-tests conducted on pre- and post-MUST and self-efficacy scores. There was a significant increase in MUST scores after the intervention (M = 12.0, SD = 3.7) when compared to the MUST scores before the intervention (M = 10.5, SD = 3.7, $t(78)$ = 5.32, $p < .001$). The pre- and post-CCSS test scores revealed a significant increase in scores after the intervention (M = 74.3, SD = 11.5) when compared to the pre-intervention scores (M = 76.5, SD = 13.0, $t(78)$ = 2.09, $p < .05$).

Table 1

MUST and Self-efficacy Score Descriptive statistics (N = 79)

MUST Score	**Pretest**	**Posttest**	**Score Difference**	***t*(stat)**	***p*-value**
Maximum	20	20			
Mean	10.5	12.0	1.6	5.32	<.001
Median	11.0	12.5	2.0		
Standard Deviation	3.4	3.7	0.2		
Self-efficacy Score	**Pretest**	**Posttest**	**Score Difference**	***t*(stat)**	***p*-value**
Maximum	105	105			
Mean	74.3	76.7	2.4	2.09	<.05
Median	73.5	77.0	2.0		
Standard Deviation	11.5	13.0	1.5		

The post-intervention questionnaire revealed several student insights about the review session and its impact on their chemistry learning:

- "It was helpful to see how math would relate into the actual chemistry especially in the word equations."
- "The review was helpful and needed for me to excel in chemistry and will certainly aid my studies in the future."
- "I can complete calculations better because my math skills are improving."

- "It was covered in the review so with application and practice you would have been able to execute on the exam."
- "The review session helped me be more confident in doing calculations in chemistry."
- "The review sessions could have been shorter and more frequent."

These quotes illustrate how the intervention supported students' use of mathematical procedures in chemistry and boosted their confidence in applying these skills.

The study demonstrated that the intervention significantly improved students' problem-solving in the chemistry courses as post-intervention MUST scores increased. These findings align with Alivio et al. (2020), who also reported positive outcomes from similar interventions. Additionally, students' self-efficacy increased by 3.5 points (3.3%), suggesting improved confidence in performing chemistry-related calculations which were confirmed by student statements on the post-intervention questionnaire. The practical guide below was developed based on the intervention conducted as described in this paper and reported by Gayle (2024) and, Gayle and Yee (2024).

Implementing Mathematics Reviews in Chemistry Classrooms: A Practical Guide

Evaluate Students' Need

Determine what mathematics skills need to be reinforced based on student need. This was done using a MUST pretest in this study and an evaluation of the data used to determine which topics to focus on. This assessment can also be done using ACT or SAT math component scores or an instructor created instrument (Ralph & Lewis, 2018).

Timing is Everything

Deliver math reviews just before relevant chemistry topics. This helps move essential skills into students' working memory (Nelson, 2018) and prepares them for immediate application. In this study, for example, ratios and proportions were reviewed before teaching balancing chemical equations or reaction yield calculations in chemistry.

Keep it Short and Focused

Brief sessions (5–20 minutes) on key skills—like exponents, ratios, or rearranging equations—can reinforce fluency without overwhelming students (Ranga, 2018). The session can be focused by using videos and video transcripts or targeted worksheets while incorporating short practice examples. In this study, student feedback indicated that the 45-minute review session were too long and that shorter sessions would have helped them better assimilate the material presented.

Use Real Chemistry Problems

Design math practice using real-world chemistry scenarios. This strengthens transfer and highlights relevance as noted by student reports on the post-intervention questionnaire. In this study, the procedures were reviewed with math problems followed by a demonstration on how to apply the same procedures using a chemistry problem like those that students would encounter in their coursework, everyday lives, or industry practice.

Incorporate Immediate Feedback

Use tools like Kahoot®, Plickers®, or worksheets to check understanding and clarify misconceptions in real time. Discussing the principles and having students explain their thinking, can help to identify areas of misconception. The immediate feedback received during this study allowed learners to ask clarifying questions and understand their abilities in applying the math procedures in chemistry to solving chemistry problems.

Reach At-Risk Students Early

Make sessions compulsory or embedded in regular instruction, especially for students with lower math confidence. Optional programs have low participation—even when effective (Jackson, 2022). In this study, the mathematics review was included as a part of the chemistry lessons so that all students had the chance to benefit.

Track and Reflect

Monitor progress through formative assessments (e.g., MUST scores, quiz scores, or hidden electronic leaderboards) and invite student feedback on the intervention. This helps reinforce gains in both performance and self-efficacy (Villafañe et al., 2016). Student feedback, reflections, and scores from the first semester's study were used to tailor the review sessions in the subsequent semester of this study and the ongoing intervention at the institution.

Implications for Instructional Design and Teaching

Evidence suggests that success in undergraduate chemistry is shaped not just by mathematical proficiency, but also by students' ability to apply math in chemistry contexts and their self-efficacy around problem-solving (Adkins & Noyes, 2018; Boz et al., 2016). Math difficulties consistently emerge as a barrier to performance (Kilner, 2018), but focused interventions—such as scaffolded math reviews—can enhance conceptual readiness and outcomes (Alivio et al., 2020; Jackson, 2022). This practitioner paper demonstrates the use of a targeted mathematics review to improve students' arithmetic fluency, algebraic skills, and chemistry self-efficacy in general chemistry. Integrating math support into chemistry courses improves student performance and confidence, highlighting the importance of embedding targeted modules or refreshers into general chemistry instruction. For teachers, cultivating an environment that supports math application and bolsters chemistry self-efficacy can boost persistence and achievement even among students with weaker math foundations (Vincent-Ruz et al., 2018).

Beyond skill development, the review helped shift students' perceptions of mathematics as a useful tool in chemistry, reinforcing the importance of self-efficacy in STEM learning. Incorporating conceptual learning, collaborative practice, and hands-on activities can further enrich engagement and promote long-term retention. To maximize impact, future iterations of the intervention should include everyday chemistry applications and draw on strategies that foster self-efficacy through mastery experiences and social interaction. Ultimately, interventions that strengthen fluency and confidence in applying math to chemistry tasks can yield greater impact than either alone. This calls for instructional designs and teaching approaches that intentionally foster both skill-building and self-belief (McAlinden & Noyes, 2019). Overall, embedding timely math interventions across chemistry curricula can support student success by bridging math and science, improving confidence, and reinforcing learning connections.

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DEVELOPING TEACHERS' KNOWLEDGE OF PRIMARY SOURCES TO ELEVATE STEM IDENTITIES IN RURAL COMMUNITIES

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Abstract

STEM Teaching with Embedded Primary Sources (STEPS) is a professional development program that introduces Mississippi K-12 STEM teachers to primary sources as an instructional aid and provides targeted training on embedding primary sources into STEM lessons. Training includes a two-day workshop during which participants engage in finding, selecting, and aligning primary sources to content standards. Teachers also develop STEM-focused lessons that utilize primary sources. Quantitative results show a statistically significant difference in pre- and post-survey results, with participants claiming a higher degree of confidence in locating and selecting primary sources, and more positive attitudes toward embedding primary sources in instruction.

Keywords: primary source, professional development, STEM, history of science, nature of science, mathematical modeling

Introduction

Embedding primary sources into mathematics and science instruction supports teachers' implementation of effective teaching practices in STEM classrooms, specifically instructional practices that support students' conceptual knowledge in mathematics and science content knowledge related to the history and nature of science (DeCraene et al., 2023; Nouri et al., 2019). A primary source is defined as "an account or record (such as a first-hand account, a contemporaneous news report, a photograph, or an audio or video recording) reflecting direct experience of a thing (such as a historical event) that is being researched or studied" (Merriam-Webster, 2024). The Library of Congress (n.d.) describes primary sources as "the raw materials of history" or the documents and artifacts that were created at the time the phenomena were under study.

The National Council of Teachers of Mathematics (NCTM) recommends eight teaching practices that are effective in supporting students' conceptual development and personal agency in learning mathematics (NCTM, 2014). Analyzing primary sources as part of mathematics curricula supports all eight practices (DeCraene et al., 2023) and especially supports recommendations that call for teachers to *facilitate meaningful mathematical discourse* in the classroom, *pose purposeful questions,* and *use and connect mathematical representations.* DeCraene and colleagues (2023) maintain that when teachers use primary sources to reach teaching goals, they encourage students' engagement in inquiry and support the development of positive mathematical identities. Furthermore, the authors claim that analyzing primary sources promotes students' agency and authority in mathematics. NCTM has called for mathematics teachers to examine their instructional strategies and look for ways to ensure that all students can find meaning in mathematics. Teachers should engage students in accessible yet challenging content and provide opportunities for rich classroom discourse so that all students have the opportunity to discover the great human endeavor of mathematics (NCTM, 2018). Primary sources provide teachers with unique opportunities to expose students to the history of mathematics and engage students in using mathematics to make sense of the world around them. *The Framework for K-12 Science Education* (National Research Council, 2012) recommends that science teachers specifically address the history and nature of science to support students' content development in science classrooms. Researchers have recommended using primary sources to anchor phenomena in K-12 science, engage students in scientific inquiry, and promote the Science and Engineering Practices (Nouri et al., 2019; Workosky, 2018).

Analyzing primary sources related to STEM fields can help provide relatable contexts to ideas, concepts, and skills that may seem abstract and not applicable to students' daily lives. When students analyze primary source artifacts and see evidence of how scientific phenomena have led to current tools and technology, they have an opportunity to gain a greater appreciation for the process of engineering and invention that led to our current conveniences. Making sense of mathematical models and analyzing history through a mathematics lens can help students make decisions about *who does mathematics* in the real world and *how the doing of mathematics* has contributed to the development of modern society.

Objectives of the Study

The purpose of this quantitative study was to determine the effect of the STEM Teaching with Embedded Primary Sources (STEPS) professional development (PD) program on confidence in and attitudes toward using primary sources to support instruction in STEM classrooms. The STEPS PD program highlights the importance of incorporating primary sources into Mississippi's rural education settings to help students recognize the history and value of their communities. This study aims to build teachers' knowledge of and confidence in using primary sources in STEM classrooms through PD opportunities that introduce teachers to the Library of Congress Teaching with Primary Sources program. The STEPS PD workshop is designed to guide and support teachers in finding and using primary sources in STEM classrooms to connect students with STEM histories, reflect on their own communities, and what it means to be a rural learner and innovator in America. We believe that this engagement is one way that educators can support community sustainability, challenge some common misconceptions related to rural America, and expand students' knowledge of STEM career opportunities in or near their home communities. Specifically in our home state of Mississippi, connecting STEM learning in K-12 classrooms to the state's rich history of agriculture, industry, national security, aerospace, and other STEM innovations is one move toward dispelling negative beliefs about opportunity in Mississippi that potentially contribute to the "brain drain" exodus the state has experienced in recent years (Miller & Collins, 2024; US Census Bureau, 2021).

Theoretical Framework

This study employed the Transformative Learning Framework (Loukes-Horsely et al., 2010) in which learners acquire new knowledge through a process of reflection and refinement of current knowledge. Within this framework, PD focused on teaching with primary sources was designed to create experiences that led learners to reflect on their current attitudes toward utilizing primary sources as instructional supports before being exposed to teaching with primary sources within these contexts. Then, learners were provided opportunities to refine their professional knowledge by incorporating the newly learned resources into practice through hands-on and collaborative activities.

Methodology

Program Design and Development

Science Teaching with Embedded Primary Sources, as the project was originally titled, began as a science-focused PD program that introduced K-12th-grade science teachers to using primary sources to support students' knowledge of the history and nature of science. The PD program was designed to include a low-cost, two-day PD workshop. In-person and asynchronous online options were offered across Mississippi in the first year (74 participants). In the second year, the project was expanded to provide more low-cost PD workshops and provide a richer continued learning experience for teachers who participate in the introductory (Phase I) workshop (19 participants in Year 2). Two follow-up experiences were added to the program, including an asynchronous online lesson-study component (Phase II) and an in-person, three-day collaborative lesson planning institute (Phase III). All 93 teachers who completed Phase I in Years 1-2 were invited to enroll in

Phase II when it launched. Thirty-four teachers enrolled in Phase II, with 19 completing the component and becoming eligible to advance to Phase III. Eleven of the 19 teachers who completed Phase II attended the Phase III lesson planning institute.

In Year 3 (26 participants), the PD program was revised to include teachers of all STEM subjects and rebranded as *STEM* Teaching with Embedded Primary Sources. The Phase I workshop was modified only slightly to include mathematics and technology-focused primary source examples, mathematics-focused activities, and connections across mathematics and science content. The format and focus of the workshop, as to introducing participants to Library of Congress resources, remained the same. Survey questions were adjusted to measure teachers' confidence and attitudes toward teaching STEM (replacing Science) with primary sources, and to determine attitudes toward using primary sources to help students engage in Modeling with Mathematics, one of the Standards for Mathematical Practice (National Governors Association Center for Best Practices & Council on State School Officers, 2010).

Participants

Participants were recruited to the STEPS project through direct and social media marketing campaigns. Direct marketing included newsletters, dedicated email blasts and mailings, and information booths at state-wide teacher conferences and other PD events. Years 1-2 targeted the recruitment of K-12th grade science teachers. Year 3 expanded recruitment to K-12 teachers of all STEM-related subjects, and the workshops were attended by science, mathematics, agriculture, computer technology, and gifted educators. In the current year, Year 4, recruitment has been expanded to all K-12th educators to support cross-curricular collaborations in STEM, and workshops have been attended by science, mathematics, gifted, special education, history, and English language arts teachers. While recruitment strategies targeted Mississippi teachers, registration was not limited to Mississippi teachers.

Data Collection

This study used a longitudinal survey design. Quasi-quantitative data was gathered through pre-workshop, post-workshop, and delayed-post-workshop surveys, which were managed by Qualtrics survey software. On each survey, participants were asked to report how confident they felt in finding, evaluating, and incorporating primary sources into their lessons, and how confident they felt in helping students evaluate primary sources. Confidence was measured across four areas on a

10-point scale. Participants were also asked to report their attitudes toward using primary sources in the classroom on a Likert-type five-point scale (see Table 2). The pre-workshop survey was distributed to registered participants one week before the workshop and was also made available during registration on the first day. Post-workshop surveys were distributed to participants at the end of the second day. Delayed-post surveys were distributed via email approximately six months after the workshop. In Years 1-2, survey questions addressed attitudes toward using primary sources in science content to support engagement in the history and nature of science (see tables in the next section). Beginning with Year 3, survey questions addressed teachers' attitudes toward using primary sources to teach STEM content (i.e., "science" was replaced with "STEM" in each question that did not specifically relate to science concepts, such as those related to the history and nature of science) and a question was added to examine attitudes toward using primary sources to help students engage in one of the Standards for Mathematical Practice (SMPs), Modeling with Mathematics.

Results and Discussion

In Years 1-2 of STEPS, 93 K-12 science teachers attended either an online or in-person workshop. Analysis of pre-, post-, and delayed-post survey data across the subgroup of participants who completed all three surveys (n = 47) indicates that participants reported gains in their confidence and perceived abilities in working with primary sources in the K-12 science classroom. A one-way repeated measures ANOVA was conducted on pre-workshop, post-workshop, and delayed-post survey confidence scores to determine the workshop's impact on the four confidence aspects before, directly following, and up to six months after attending the workshop. A statistically significant difference in confidence, $p < .001$, was found across all four aspects with large effect sizes, $\eta^2 > .138$, indicating a strong practical significance that participation in the workshop improved participants' confidence in accessing, evaluating, and using primary sources in science instruction (Table 1). Post-hoc analyses confirmed that confidence gains between pre- and post-surveys persisted four to six months post-workshop, as there were no significant differences found between post- and delayed-post scores, $p = 1.00$, when p-values were adjusted for multiple comparisons using the Bonferroni correction. Additionally, teachers were asked to rate their attitudes toward using primary sources in science classrooms on pre-, post-, and delayed post-surveys using a Likert-type 5-point scale. These scores were also analyzed using a one-way repeated measures ANOVA. Statistically significant differences were noted across all categories, with large effect sizes indicating a high degree of practical significance (Table 2).

Table 1

Science Teacher (Years 1-2) Participants' Confidence with Using Primary Sources (n = 47)

	Mean				
Confidence Category	**Pre**	**Post**	**Delayed**	***p***	***η*²**
Finding Primary Sources related to my science subject.	4.89	8.93	8.31	<.001	.59
Evaluating Primary Sources for use in my classroom.	4.36	8.91	8.36	<.001	.68
Incorporating Primary Sources as part of my science teaching.	4.99	8.94	8.53	<.001	.66
Helping students evaluate Primary Sources as part of a lesson.	4.32	8.93	8.42	<.001	.69

Note: Participants rated their confidence on a sliding 10-point scale, with 10 being most confident.

Table 2

Participants' Attitudes Toward Using Primary Sources (n = 47)

	Mean				
Statement	**Pre**	**Post**	**Delayed**	***p***	***η*²**
Using Primary Sources helps students:					
Better understand the history of science.	4.12	4.85	4.68	<.001	.29
Better understand the nature of science.	4.23	4.83	4.66	<.001	.30
Better understand science content.	4.21	4.79	4.60	<.001	.23
Make connections to other content areas.	4.04	4.79	4.75	<.001	.39
Understand current scientific discoveries.	4.17	4.72	4.66	<.001	.27
My students will struggle with reading and evaluating primary sources.	3.89	2.89	3.26	<.001	.32
My students will not find primary sources interesting enough for them to be a useful learning tool.	2.51	1.77	2.00	<.001	.20
Using Primary Sources helps me teach the science standards	3.79	4.49	4.36	<.001	.37

All my students can learn science through using Primary Sources.	3.72	4.23	4.19	.005	.11
Teaching with Primary Sources helps increase my own science content knowledge.	4.19	4.79	4.62	<.001	.24

Note: 5=Strongly agree, 4=Agree, 3=Neutral, 2=Disagree, 1=Strongly disagree.

Teachers who completed all three surveys during Year 3 (n = 24) showed significant growth, $p < .001$, across all four factors related to confidence in finding, evaluating, and incorporating Primary Sources into STEM instruction (Table 3). No significant differences were found in scores between post- and delayed-post surveys indicating that this reported growth was maintained after the workshop.

Table 3

STEM Teacher (Year 3) Participants' Confidence with Using Primary Sources (n=24)

	Mean			
Confidence Category	**Pre**	**Post**	p	η^2
Finding Primary Sources related to my STEM subject.	4.55	8.41	<.001	.67
Evaluating Primary Sources for use in my classroom.	4.37	8.30	<.001	.73
Incorporating Primary Sources as part of my STEM teaching.	4.07	8.21	<.001	.75
Helping students evaluate Primary Sources as part of a lesson.	3.82	7.96	<.001	.76

Note: Participants rated their confidence on a sliding 10-point scale, with 10 being most confident.

Due to an error on the post-survey, attitudes toward using primary sources to help students engage in Modeling with Mathematics were recorded on only the pre-survey and the delayed post-survey. A two-tailed paired samples T-test was conducted to determine if participants' attitudes in this area changed over time (n = 24). A statistically significant difference between pre-test (M = 3.62, SD = .59) and the delayed post-test (M = 4.06, SD = .56) scores was observed with teachers indicating a more positive attitude on the delayed post assessment, p = .008. A medium to large effect size was also noted, d = .74, indicating a strong degree of practical significance associated with STEPS training and attitudes toward using primary sources to support mathematical modeling. It is difficult to know if this change in attitude was a result of the workshop alone or if teachers became more positive toward using primary sources as phenomena in mathematical modeling after they engaged in these practices in the classroom. All but one mathematics teacher who responded to the delayed post survey (9 teachers) reported using primary sources in their instruction in the six-month interval between the workshop and the delayed post survey. Nonetheless, the teachers in this study did appear to find that implementing primary sources in mathematics instruction was a positive addition to their curricula.

Implications and Future Work

The findings in this study support our belief that STEM teachers will find primary sources to be a useful instructional resource once they are introduced to and engage in primary sources through targeted PD. Within the project, these findings have led to the refinement of the workshop experience for teachers. Following the success of past workshops, four classroom teachers who engaged in the STEPS project were selected to serve as STEPS Teacher Leaders in Mississippi. These teachers co-facilitated workshops and developed peer-reviewed lesson units that utilize primary sources. Future work is projected to include continued workshop offerings with STEPS Teacher-Leaders developing Mississippi-focused STEM lesson units and easily accessible primary source sets that include documents, photos, and other artifacts that highlight Mississippi's STEM history.

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