School Science and Mathematics Association
Founded in 1901

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SSMA Annual Convention
Knoxville, Tennessee
November 7 - 9, 2024

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School Science and Mathematics Association
Founded in 1901

SSMA's journey began over a century ago, guided by a profound belief in the transformative power of education. Since then, it has evolved into an inclusive and vibrant professional community, welcoming educators and researchers from diverse backgrounds. United by a shared passion for science and mathematics, they collaborate, innovate, and push the boundaries of knowledge in these disciplines. Established in 1901, SSMA has fostered a thriving community of educators and researchers dedicated to enhancing the STEM fields and empowering countless individuals to embrace the wonders of STEM subjects.

SSMA's primary focus lies in fostering research-based innovations within K-16 teacher preparation and continuous professional development in the realms of science and mathematics. By leveraging cutting-edge research, SSMA equips educators with the knowledge, skills, and strategies they need to captivate and inspire their students, fostering a love of learning and nurturing STEM curiosity. SSMA's reach extends far and wide, catering to an international and diverse audience that includes higher education faculty, school administrators, and classroom instructors from kindergarten through postsecondary education. Through its annual conventions, workshops, and publications, SSMA provides a platform for educators to share their expertise, engage in thought-provoking discussions, and stay abreast of the latest developments in science and mathematics education.

SSMA's mission can be summarized by four key goals:

- Cultivating a close-knit community of educators, researchers, scientists, and mathematicians.
- Advancing knowledge through rigorous research in science and mathematics education and their effective integration.
- Informing and enriching teaching practices by disseminating scholarly works within the fields of science and mathematics.
- Influencing education policies in science and mathematics at local, state, and national levels.

The proceedings of the 123rd Annual Convention encapsulate SSMA's rich traditions and its promising future. They serve as a testament to the organization's unwavering commitment to the advancement of science and mathematics education, ensuring that future generations continue to embrace the wonders of discovery and innovation.

SSMA President
2022 - 2024

Cory, B. & Ray, A. (Eds.). (2024). *Proceedings of the 123rd annual convention of the School Science and Mathematics Association* (Vol. 11). Knoxville, TN: SSMA

PREFACE

These proceedings are a written record of some of the research and instructional innovations presented at the 123rd Annual Meeting of the School Science and Mathematics Association held November 7 - 9, in Knoxville, TN. The blinded, peer reviewed proceedings include twelve papers regarding instructional innovations and research. The acceptance rate for the proceedings was 70.5%. We are pleased to present these Proceedings as an important resource for the mathematics, science, and STEM education community.

Beth Cory & Amy Ray
Editors

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TABLE OF CONTENTS
VOLUME 11

ENGAGEMENT IN PRAIRIE PHENOLOGY: UNDERGRADUATE STUDENT EFFICACY

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Abstract

Environmental socio-scientific topics are commonly taught in university courses as a way to engage students in relevant content. This study was conducted with undergraduate student participants (n = 34) enrolled in a common core course at a university in Texas. Within the course, a community (citizen) science intervention was utilized to engage students in local prairie biodiversity loss. Pre- and post-intervention assessments were administered to the students to measure efficacy for learning and doing science and environmental action. The findings indicate a significant increase in student efficacy for learning and doing science, following engagement with community science activities.

Keywords: science education, citizen science, self-efficacy, undergraduate students

Introduction

The desired outcomes for student participation in formal science education have been defined as learning science content knowledge, engaging in the practice of science and scientific discourse, understanding and working with data through scientific modeling, increasing interest and motivation in science, developing a scientific identity, and understanding scientific reasoning and the nature of science (NASEM, 2018). At the university level, courses have sought to address several of these desired outcomes by engaging students in socio-scientific topics. While environmental socio-scientific issues, such as climate change, are commonly taught in education, researchers who have utilized climate change as a topic found that the socio-scientific issue did not resonate with students as intended. Students' content knowledge of climate change increased following engagement with climate change activities; however, students could not view themselves as agents of change (Ballantyne et al., 2016; Shepardson et al., 2011; Stevenson et al., 2014). If students do not believe they possess the agency to address such issues, our current environmental problems may remain unresolved.

One tool undergraduate educators have utilized to introduce socio-scientific topics is community science (Golumbic & Motion, 2021; Hitchcock et al., 2021; Scott, 2016; Vance-Chalcraft et al., 2021). Involvement in community science projects provides students with an experiential learning opportunity through the engagement of "real science" projects. Miller-Rushing et al. (2012) defined community science as "the engagement of non-professionals in scientific investigations – asking questions, collecting data, or interpreting results" (p. 285). McKinley et al. (2017) advocated that engagement with community science prepares and empowers learners for community involvement beyond the initial project. Applying the notion that community science can be wielded as a tool of empowerment to the issue of lack of student environmental agency suggests that student agency for science and the environment may increase after engaging in community science activities.

Objectives of the Study

The goal of this study was to better understand undergraduate students' experiences with a socio-scientific environmental community science project. Our research question was: To what degree do undergraduate students' self-efficacy for learning and doing science and environmental action change after engaging in a community science intervention? It was hypothesized that university students' self-efficacy toward learning and doing and environmental action would increase following their involvement in community science activities.

Theoretical Framework and Related Literature

Dewey (1897) posed that the individual constructs meaning from social interactions that have been influenced by inherited cultural contexts. Further developing this notion, social learning theory (Bandura, 1977) and social cognitive theory (Bandura, 1981) press beyond the focus of the individual and acknowledge that social and cultural norms contribute to the humanly constructed reality (Gredler, 1997; Schunk, 2012). Through this social occurrence, learners develop their understandings from the process of shared discussions and experiences (Rannikmäe et al., 2020). An outside example of community knowledge building is visible in the greater scientific community. Science is built on former ideas and findings that have been tested and validated by members of this community.

When community science is utilized as an instructional learning method, a key component is learner participation in real scientific practices that contribute to the larger scientific community. Levy et al. (2021) proposed an expansion of the definition by incorporating the educational benefits that individuals experience from participating in community science projects. These benefits included greater topic awareness and appreciation, a sense of ownership for the topic, and community connectedness. Community science fosters opportunities for learners to engage with the practice of science, supports students' interests and motivations towards science, and can create opportunities to solve socio-scientific issues.

Several studies conducted with university students utilized community science as a tool to increase students' science content knowledge (Golumbic & Motion, 2021; Hitchcock et al., 2021; Scott, 2016; Vance-Chalcraft et al., 2021). When community science was introduced to pre-service teachers, student content knowledge and positive attitudes toward utilizing community science in their future classrooms increased (Scott, 2016). In a separate study, following engagement in a community science project, undergraduate students were found to have increased their knowledge of the process of conducting science (or the nature of science), motivation, and science agency (Borrell et al., 2016; Golumbic & Motion, 2021). In a higher-education science course that participated in a community science project, following engagement with the project undergraduate students' interest in science increased significantly (Smith et al., 2021).

Methodology

This study was conducted with undergraduate students at a Texas university enrolled in a course that utilized a community science intervention to engage students in local prairie biodiversity loss. Of the 34 (n=34) student participants in the study: 15 identified as female and 19 as male; two were classified as first-year students, seven as sophomores, six as juniors, and 19 as seniors; and 12 were science majors and 22 were non-science majors. The course was offered as a core curriculum course and available to all enrolled undergraduate students enrolled during the Fall 2022 and 2023 semesters. In both semesters, the course was taught utilizing the same curriculum by the same instructor from an agricultural program. Although student participation in the community science activities was a mandatory requirement of the course, the students self-selected to participate in the study. It was stressed to the students several times that participation in the study would not affect their class status or grade. Additionally, the students were informed that the course instructor did not know who was participating in the study.

Beef for Bees Project

The community science intervention utilized in this study was a piece of a larger project that emerged from a partnership between local ranchers, a botanical research institute, and university researchers. Through the project, students engaged directly with a local socio-environmental issue of the critical decline of a natural resource, the Blackland Prairies, due to anthropogenic impacts. With the assistance of the course instructor, the community science project was embedded into seven weeks of an existing course curriculum. The students were introduced to the Beef for Bees project by a local conservation botanist. Over the seven weeks, the students assisted in processing historical botanical uploaded images of preserved North Texas native plant specimens sourced from the Fort Worth Botanic Garden's herbarium. The students processed the images (ranging up to 100 years old) through Zooniverse, a community science web-based application. Processing involved recording the date that the specimen was collected, and identifying the plant specimen as having 'flowers,' 'fruit,' or 'both.' The students were placed in small groups and participated in the Zooniverse activities for approximately 20 minutes during five classes. The students scored 63 plant genuses in 1,200 scored entries. Directly following each Zooniverse session, students were prompted through reflective and observational group and class discussion questions to initiate abstract thinking. The prompts were questions related to the context of the community science project and students' lives. Such as, "How would a rancher use the data you are processing to inform their land management practices?" or "Last week during our project work, we talked about how climate changes are influencing phenological cycles and impacting pollinators. Thinking about your major/anticipated careers, discuss with your group ways the pollinator crisis will directly impact your career".

During the fifth week, the students participated in a class field collection event on the university's campus. Through the event, students collected approximately 50 samples of native plants utilizing iNaturalist. iNaturalist is a community science application platform commonly utilized by life scientists as a source of data. Later that week, the students processed and scored images collected from iNaturalist that were similar to their field collections.

Throughout the seven-week project, the students were provided various opportunities for reflection through discussion posts, reflection papers, and an opinion paper. In efforts to reduce infringement on the course and the Ranch Management instructor (the sole grader for the class), the writing assignment prompts were maintained from prior years' teachings. Rooted in a Socratic approach to learning, the instructor designed the discussion prompts to encourage students to share their original ideas and opinions. During the fifth week, the students took part in an in-class 'Ask the Rancher' activity to help scaffold abstract thinking. In the Fall of 2023, the ranching community was burdened with managing resources in extreme drought conditions. The course instructor, a local rancher, stepped into the role of 'Rancher.' During this activity, the students actively participated in the construction of a word map and informally and openly interviewed the rancher. The word map and interview scaffolded student thinking and resulted in the creation of a list of specific information about native plant species that would help support regenerative ranching techniques. Within groups, the students selected four of the 63 native plant genuses to find answers to the questions they had identified during the 'Ask the Rancher' activity. Following the last Zooniverse scoring activity, we exported, cleaned, and graphed the data the students generated in Zooniverse. During the seventh week, the students presented the information to the botanist, rancher, and university researchers about their four native genuses of plants. Following the student-led portion of the presentation, the students engaged in an open discussion with the botanist to analyze their phenological results. During this activity, the students were prompted to think deeply about their scientific results, the potential application of their results, and how their results could benefit stakeholders.

Data Collection and Analysis

The data sources utilized for this study included pre- and post-intervention self-efficacy assessments. The assessment comprised a 16-item 5-point Likert-scale survey from DEVISE survey inventories developed by the Cornell Lab of Ornithology (Porticella et al., 2017a, b). The assessment included items from the Self-Efficacy for Learning and Doing Science scale (SELDS) (Porticella et al., 2017b) and the Self-Efficacy for Environmental Action scale (SEEA) (Porticella et.al, 2017a). Within the SELDs scale, students were asked questions such as "Compared to other people my age, I think I can quickly understand new science topics". Within the SEEA scale, students were asked questions such as, "I believe that I personally, working with others, can help solve environmental issues." Statistical analyses were performed using IBM SPSS version 27 to address the research question. To assess if there were significant changes in efficacy following engagement with the community science project, the pre-and post-intervention self-efficacy assessment mean scores were compared using two repeated-measures t tests. The alpha level was set at .05 for both tests.

Results and Discussion

The paired t-tests indicated that student self-efficacy for learning and doing science increased significantly [$t(33) = -2.04$, $p = 0.05$] following the community science experiences. However, the results of the mean difference for SEEA were likely created by sampling error (chance) and the intervention did not have an effect on students' self-efficacy for environmental action [$t(33) = -0.694$, $p = 0.49$].

Discussion/Implications

Prior research has identified that student engagement in community science projects in formal college course settings can improve student STEM identities (Tillotson-Chavez & Weber, 2024) and interests in science (Smith et al., 2021). However, few studies have measured the effect of community science projects (or interventions) on undergraduate self-efficacy. In this study, undergraduate student self-efficacy for learning and doing science increased significantly following student engagement with the seven-week community science intervention. In contrast, the intervention did not have an effect on student self-efficacy for environmental action.

According to Bandura (1977), repeated experiences leading to increased mastery expectations with success can strengthen a student's self-motivated persistence/self-efficacy. Although the students in this study only engaged in science activities six times (five scoring events and one BioBlitz), formally writing reflections on their in-class experiences may have strengthened the students' self-motivated persistence/efficacy for learning and doing science. While the overarching goal of the community science project was intended to address an environmental issue through action (via the community science activities), participation in the activities was a course requirement. Prior research has indicated the importance of classroom autonomy in undergraduate self-efficacy for environmental action (Smith et al., 2021). In future reiterations of this community science curriculum, we plan to incorporate more options to address student autonomy and anticipate an increase in student self-efficacy for environmental action.

The results from this study also illustrate the need for qualitative research in undergraduate experiences with community science to better understand the relationship between community science and student self-efficacy. We suggest that future community science interventions incorporate time for student reflections and student autonomy to scaffold self-efficacy. It should be noted that a major limitation of this study is the small sample size. While the findings indicate a potential benefit of engaging undergraduate students in socio-scientific community science projects, it needs to be noted that this project would not have been possible without the support of our local partners. Through similar partnerships, community science projects can be developed as a learning and engagement tool for formal interdisciplinary classrooms.

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PROS AND CONS OF NATIONAL AND STATE DATABASES: LEARNING MODALITY RETURN TO SCHOOL FOR STEM TEACHERS DURING COVID-19 ERA

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Abstract

This paper is focused on utilizing a common language and is grounded in current research conducted through a Noyce track IV grant. The research project utilized large national and state data sets to select districts and determine impacts of modes of returning in Fall 2020 after the COVID-19 pandemic closure. During the process, the research team encountered unexpected barriers, including a lack of clear and operationalized terminology for defining high-need districts. Thus, this paper focuses on building a community of practice where the lack of clarity in the definition of high-need local educational agency (LEA) is addressed.

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

Introduction

The COVID-19 pandemic has had far-reaching effects on every aspect of society, including education. During the pandemic, nations worldwide developed lockdown measures to constrain the spread of the virus. As part of this national lockdown in the United States, schools shifted instruction online from traditional in-person learning in March 2020. According to the Centers for Disease Control and Prevention (CDC), during the school reopening in the Fall semester of 2020, there were three learning modalities used for instruction: online only, hybrid, and in-person only. As this event has had a profound impact on schools, classroom teachers, and students, it is important to understand how these different learning modalities have impacted STEM teachers' retention rates and STEM teachers' effectiveness as indicated by students' mathematics and science performance and graduation rates. This understanding can be used to inform policymakers and school leaders, preparing them for future emergencies and equipping them with adequate knowledge to manage similar situations effectively. We are interested in "high-need LEAs" in our study. NSF track IV grant focuses on research examining mathematics and science teachers working in high-need school districts serving diverse student populations. As recipients of a Track IV Noyce grant, we found that many terms used by educators and included in state and national policy documents do not have well-defined meanings. Additionally, other relevant data (e.g., teacher retention rates, student mathematics and science performance, graduation rates), although available to the public, are expressed in vague and varied language which is a challenge for those interested in education research or policy and advocacy.

Objectives of the Study

The study aims to understand how districts' decisions about school openings during COVID-19 impacted students, as well as science and mathematics teachers in high-need districts. The first goal of the project was to determine the learning modalities that were used by high-need LEAs beginning in fall 2020 through spring 2022. This will establish the experimental groups to examine the second goal of the project which is to determine how the utilization of different learning modalities within a COVID-19 dictated teaching environment contribute to STEM teachers' retention rates and STEM teachers' effectiveness indicated by student mathematics and science performances and graduation rates in high-need LEAs.

Related Literature

With the disruptive, entrenched, and ubiquitous impacts of COVID-19, there are aspects of teacher effectiveness and retention related to school district responses that need to be examined. The pandemic resulted in changes to the educational environment that were initially disruptive (e.g., internet access, loaner computers/tablets, parental communication, school/district communication, worsening digital divide) but, in the long-term, may be seen as enhancements (e.g., increased learning in a virtual environment, support to develop online modules/recorded lessons; Choate et al., 2021; de los Santos & Rosser, 2021; Kidd & Murray, 2020). STEM teachers who prepared and entered the profession before the 2020 pandemic were educated in practice-driven, face-to-face pedagogies. They were expected to use reform-based strategies (e.g., NGSS Lead States, 2013) when teaching in high-need schools which are known to impact teacher effectiveness and retention (e.g., Saka et al., 2013). However, by the end of March 2020, all public schools in the US had shut down in-person instruction and moved to various forms of remote instruction whereby teachers were required to move instruction to unfamiliar online platforms.

For this research, learning modality is defined according to the Centers for Disease Control and Prevention (CDC) HHS Public Data Hub and the National Center for Educational Statistics (NCES) as being in-person, remote, or hybrid (Department of Health & Human Services ArcGIS Online, 2022). School learning modality types are defined as follows:

- **In-Person:** All schools within the district offer face-to-face instruction five days per week to all students at all available grade levels.
- **Remote:** All schools within the district do not offer face-to-face instruction; all learning is conducted online/remotely to all students at all available grade levels.
- **Hybrid:** Schools within the district offer a combination of in-person and remote learning; face-to-face instruction is offered less than five days per week, or only to a subset of students.

In addition to learning modality, the research depends on selecting districts that meet the criteria set by the National Science Foundation (NSF) for Noyce projects which is based upon the Department of Education's definition of high-need local educational agencies (LEAs) by section 201 of the Higher Education Act of 1965 (20 U.S.C. 1021; 2000). This ability to verify the 'high-need' status of the districts was the necessary first step. There are national data sets with information about educational status as well as state and local data sets which were utilized as part of the selection process of high-need LEAs.

Methodology

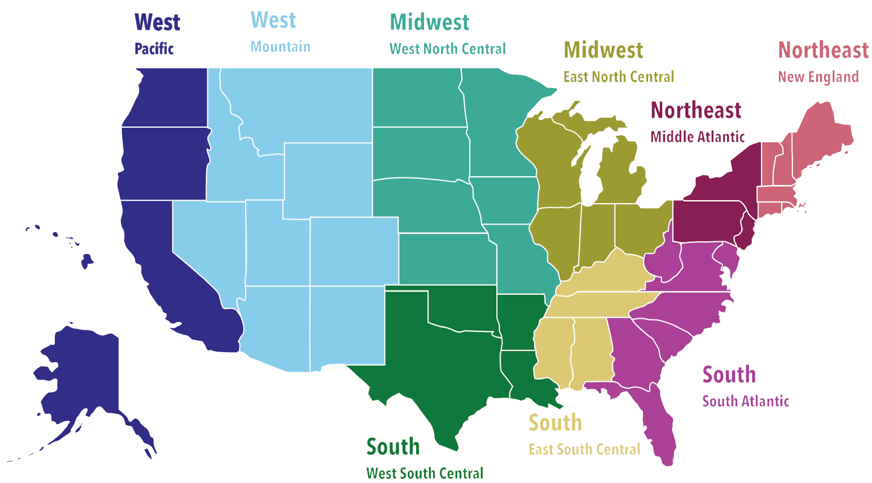
This paper addressed the first goal of the project through secondary analysis of publicly available national, state, and local data sets.

Sample Selection

Thirty-six (36) high-need LEAs were selected to answer the first research question (What learning modalities were used by high-need LEAs beginning in fall 2020 through Spring 2022). Exclusion criteria for LEAs in this project included: services agency listings, independent charter districts, districts that did not serve all grades K-12, and districts that did not report their learning modalities to the CDC during the COVID-19 pandemic. The sample includes 18 high-need LEAs from districts designated as being part of the Small, Rural School Achievement Program (SRSA; OESE, n.d.a) or the Rural or Low-Income School Program (RLIS; OESE, n.d.b) as identified on the US Department of Education Office of Elementary and Secondary Education website and 18 high-need LEAs from programs eligible for Title I funding from the US Department of Education ESEA Title I website (n.d.). Four districts within these programs were randomly selected from each of the nine US Census divisions (Figure 1).

Figure 1:

US Census Bureau Divisions from which districts were randomly selected



Identification of Learning Modality

The learning modalities used by these high-need LEAs was reported in the HHS Protect Public Data Hub (2023) website. This public data set was developed to ensure that COVID-19 data would be readily shared and available to researchers. The data set reports on the initial reopening learning modality utilized and how they were implemented over time.

Verification of High-Need Status

After the 36 LEAs were selected, they were verified as meeting criteria for being a high-need district as defined in section 201 of the Higher Education Act of 1965 (20 U.S.C. 1021). This definition is multi-faceted and for simplicity's sake will be discussed as having two primary components. Component A focuses on students living in circumstances of poverty or in rural areas. Component A states that at least one school within the agency must meet one of the following: (a) "greater than 20% of students from low-income families", or (b) "greater than 10,000 students from low-income families", or (c) "eligible for funding under the SRSA or the RLIS". Therefore, the 18 LEAs selected from the SRSA or RLIS programs, automatically meet criteria of Component A. However, it was more challenging to verify the 18 districts that were selected from the Title I program because there was no definition given of low income. For this project, low income was defined by a component of the Department of Education's Title 20 program which uses several measures of poverty including the one that we selected: "percentage of students eligible for a free or reduced-price lunch under RBR National

School Lunch Act." We selected this measure of poverty because it is directly related to education and because this data is readily available on the National Center for Education Statistics (NCES) website. The NCES site is publicly available and was used by the project to gather other educational data related to the LEAs. One LEA did not meet criteria under Component A and was replaced with another one randomly selected from within the same US Census division from which it had been selected. Component B focuses on teacher data and states that the LEA must also meet at least one of the following criteria: (a) "high percentage of teachers not teaching in the academic subject areas or grade levels in which they were trained to teach", (b) "high turnover rate or high percent of teachers with emergency, provisional, or temporary certification of licensure". This begs the question of how various states and districts define out-of-field and what percentage of turnover or challenges with certification or licensure constitutes a high percentage. Additionally, the type of turnover is not operationalized and may be related to turnover within a grade, a school, the districts or even the profession.

We used multiple approaches to attempt to define or calculate these numbers including the following: 1) asking other Track 4 grantees how they defined Component B; 2) exploring professional literature; 3) exploring NCES and similar websites; 4) exploring local (e.g., State Department of Education and districts) definitions; and 5) directly asking the districts. Tremendous variations in approach were revealed and responses that we received generally asked us what benchmarks we were using. There was minimal to no quantifiable data available, even at the local level, and no consistent data at the national level. Therefore, Component B was not utilized for the verification process. Thus, the methodology produced a sample representing different kinds of communities across the nation which were verified for inclusion by student economic circumstances.

Results and Discussion

For the 36 districts selected as meeting the inclusion criteria, learning modalities are listed (Table 1). Among the 36 selected LEAs, more than half returned with the hybrid learning mode, while the remaining LEAs were almost equally split between in-person and online-only modes (Figure 2). The predominance of the hybrid model suggests that most LEAs aimed to balance the benefits of face-to-face interaction with the safety offered by remote learning. Next steps include determining how these different learning modalities contribute to educational outcomes and teachers' effectiveness. Understanding the impact of each learning modality can provide valuable insights into best practices for future educational planning and crisis response.

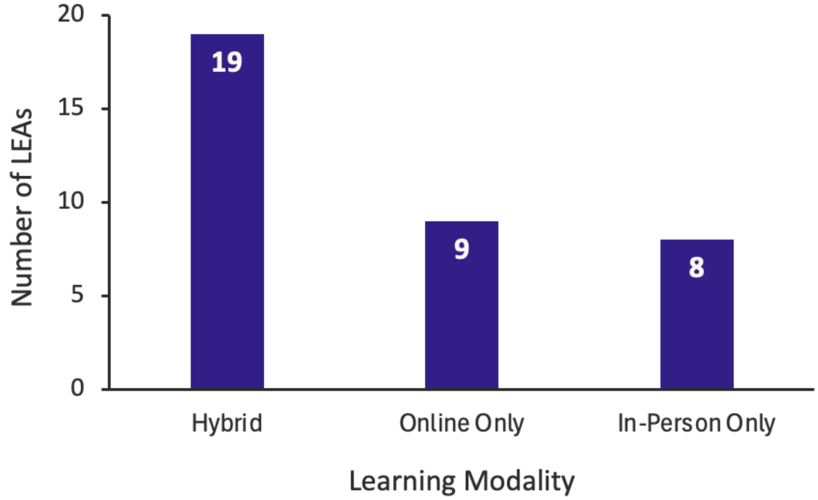
Table 1:

Learning Modality by LEA in the Fall of 2020

LEA #	State	Learning Modality		LEA #	State	Learning Modality
01	AL	Online Only		19	MO	Hybrid
02	AL	Hybrid		20	MS	Hybrid
03	AR	Hybrid		21	NC	Hybrid
04	CA	Online Only		22	NC	Online Only
05	CA	Online Only		23	NM	Online Only
06	CO	Online Only		24	NY	Hybrid
07	CO	In-Person Only		25	NY	In-Person Only
08	CO	Online Only		26	NY	Hybrid
09	FL	Hybrid		27	OH	Hybrid
10	GA	Hybrid		28	OH	In-Person Only
11	KY	Hybrid		29	OH	Hybrid
12	MA	Hybrid		30	OR	Hybrid
13	ME	In-Person Only		31	OR	Online Only
14	ME	Hybrid		32	PA	Online Only
15	ME	In-Person Only		33	SD	Hybrid
16	MI	Hybrid		34	TX	Hybrid
17	MO	Hybrid		35	TX	In-Person Only
18	MO	In-Person Only		36	TX	In-Person Only

Figure 2:

Learning Modalities by LEA in the Fall of 2020



Implications

There are several barriers to finding and using data from public sites to conduct research on high-need LEAs. First, the definition of 'high-need' has two components with terms that are not operationalized. Second, the definition mandated on many federally funded education research projects focuses on high-need LEAs and not high-need schools. In fact, the definition only requires that one school within the district meet the circumstances of poverty for the entire LEA to be defined as high-need even though for many districts there is a large disparity between schools. This becomes a challenge for understanding the research that might be better focused on high-need schools that are defined by their own circumstances and not by those of their districts. This also has implications for the placement of students who may either be interested in teaching in high-need schools or whose teacher preparation program has a commitment to placing students in high-need schools during their student teaching and other mentored teaching opportunities.

Furthermore, although many datasets are public, they are housed within different local and state agencies and under different classifications. Thus, finding both selection and outcome data can be time-consuming, and attempts at making the data uniform across districts and states are challenging to impossible. This is even more problematic for research being conducted within science teacher preparation since without a clear definition of these various terms and outcome measures, the ability to compare across teacher preparation programs is impossible. Since projects are forced to individually choose how to operationalize terms, there are inconsistencies across studies, making it impossible to compare findings, resulting in uncertainty about the methods used in published works. Additionally, these vaguely defined terms will generate barriers to conducting educational research as time and resources will be used to operationalize terms.

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CONVINCE, UNDERSTAND, TEACH: SECONDARY MATHEMATICS TEACHERS' CHOICES ABOUT USING PROOF

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Abstract

Proof is an essential part of mathematics. However, secondary and undergraduate students experience proofs as isolated exercises, or something to be memorized, and do not see the broader roles of proof. In this paper, we share results from a study examining how pre- and in-service secondary mathematics teachers participating in a mathematics research experience evaluated proofs with respect to whether the argument could be used to convince, understand, or teach.

Keywords: proof, views of proof, research experience for undergraduates, secondary mathematics teachers.

Introduction

Students at all grade levels should experience proof and proving as a fundamental part of doing mathematics, communicating mathematical ideas, and developing mathematical knowledge (Stylianides, 2007). Proofs should be taught across mathematical content domains, not only as a topic in high school geometry (National Council of Teachers of Mathematics [NCTM], 2000), and students should be able to construct viable arguments and critique others' reasoning by the end of their secondary school careers (National Governors Association Center for Best Practices & Council of Chief State School Officers [NGA & CCSSO], 2010). However, abundant research documents show that secondary school students struggle with proof (e.g., Köğce et al., 2010; McCrone & Martin 2004; Senk, 1985). A challenge secondary school students face with proof is that they seldom have opportunities to examine or experience different roles of proof, including verification, explanation, systematization, discovery, and communication (e.g., Knuth, 2002). More specifically, students' experiences with proof might be limited to proofs that verify the truth of frequently trivial statements, thus overemphasizing that a proof establishes the truth of a mathematical statement (Bleiler-Baxter & Pair, 2017; de Villiers, 1999; Knuth, 2002b) or that proof should follow a strict format (e.g., Bleiler et al., 2014; Boyle et al., 2015; Tabach et al., 2010). If secondary school mathematics teachers have a narrow perception of proof, their students might likely have similar difficulties with proof. By the time students are expected to write proofs, they have had limited experience in making arguments, formal or informal. In addition, teachers may provide excessive guidance to students, thus reducing the level of cognitive demand of proof-related tasks (Sears & Chávez, 2014).

According to Usiskin (1980), "We seem to have failed in our teaching of proof because we too often ignore when and why mathematicians do proofs, the variety of possible types of proof, and how mathematicians write down proofs" (p. 419). Knuth (2002a) further stated that "the greatest challenge facing secondary school mathematics teachers is changing both their conceptions about the appropriateness of proof for all students and their engagement of corresponding proving practices in their classroom instruction" (p. 83). Taken together, these contentions point to a need to provide more insight into how pre- and in-service secondary mathematics teachers select proofs for convincing, understanding, or teaching. Consequently, we examined how secondary mathematics teachers who had an authentic mathematics research experience choose proofs for these different purposes.

Objectives of the Study

The purpose of our study was to examine pre- and in-service secondary mathematics teachers' views on proof. We have reported other results from the same study (Chávez et al., 2023), in which we examined the criteria pre-service and in-service teachers used to evaluate proofs. In this part of the study, we focused on the specific proofs that teachers would use to convince, understand, and teach. By specifying three different purposes, we seek to explore differences in proof selection and criteria based on purpose. Reid and Knipping (2010) noted, teachers' understanding of proof is not much different from students'. However, a teacher must use proof for multiple purposes. Has their understanding of proof progressed to a point to bring out the nuances among the different purposes? Do they select different proofs for different purposes, or do they use the same criteria for all?

Related Literature

Knuth (2002b) examined 16 in-service high school teachers' views on what constituted proof and found that valid methods (i.e., particular proving methods), mathematically sound (i.e., an argument explained the truth of a statement for all cases or uses accepted facts), sufficient detail (i.e., an argument showed all of the steps), and knowledge dependent (i.e., a teacher's conceptual understanding of the mathematics presented in an argument) were the four major features of proofs. Dickerson and Doerr (2014) reached a similar conclusion, reporting that several of 17 in-service high school mathematics teachers thought that a proof should include "details, step-wise justifications, precise vocabulary, diagrams, and appeals to common sense" (p. 723). Similarly, Lesseig et al. (2019) indicated that most of 32 pre-service secondary mathematics teachers believed that a proof should be based on accepted statements, follow logical steps, and show that a statement is always true.

When asked to determine the conviction of a given argument, Knuth (2002b) found that many teachers judged if a given argument was convincing based on both valid methods and being mathematically sound. Knuth (2002b) also found that concrete features (i.e., an argument used specific examples or diagrams), familiarity (i.e., a teacher relied on his/her past learning and current teaching experiences), generality (i.e., an argument established the truth of a statement for all cases), and showing why (i.e., an argument provided insight into the underlying mathematics) were other characteristics of convincing arguments used by the teachers.

Building on these previous studies (Dickerson and Doerr, 2014; Knuth, 2002b; Lesseig et al., 2019), we examined what criteria pre- and in-service secondary mathematics teachers used to evaluate whether an argument was convincing. We found results similar to those stated above (Chávez et al., 2023). However, Healy & Hoyles (2000) found that "students simultaneously held two different conceptions of proof: those about arguments they considered would receive the best mark and those about arguments they would adopt for themselves" (p. 426). The students held two different views of proof based upon the purpose of the proof. We pondered whether a similar result would be found among teachers and subsequently asked them about which proofs they would use if the purpose was to convince, understand, and teach.

Methodology

There were 27 teachers in our study, 7 in-service and 20 pre-service, who participated in an NSF-funded Research Experience for Undergraduates (REU). As described elsewhere (Chávez et al., 2023), the goal of the REU was to provide participants an opportunity to conduct research in mathematics. Although there was an education component, participants spent most of their time doing mathematics research.

A survey was given during the fourth week of the REU that included different proofs of three statements. For the statement "complements of congruent angles are congruent," participants were given two proofs: a paragraph proof [GEO-paragraph] and a two-column proof [GEO 2-column]. For the statement, "the sum of the first n positive integers is equal to $n(n+1)/2$," participants were given four proofs: a visual generalization based on forming triangular arrangement of squares and combining them to form a rectangle [SUM-visual], Gauss's well-known proof using equal addends [SUM-Gauss], a proof by induction [SUM-induction], and a generalization from a table of partial sums [SUM-table]. For the statement, "if $x > 0$, then $x + 1/x \geq 2$," participants were given two proofs: a two-column algebraic proof *of the converse* [ALG-2-column] and a proof using a right triangle with legs of length $x - 1/x$ and 2 [ALG-geometric]. For reasons of space, we are not including the proofs here, but they will be shared during the presentation.

In the questions used for this part of the study, we asked participants to indicate what proofs (a) were most convincing, (b) were helpful to understand the mathematics involved, and (c) they would use in their classroom. For each of the three questions above, we identified the proof or proofs selected by each participant, according to the following criteria: if a participant directly mentioned the name of the proof, provided a direct quote or common name for the proof, or described characteristics that could only apply to one proof, we coded the proof as the one selected by the participant. The researchers coded all responses independently. Afterwards, the research team met as a group and the coding was revised collectively, until a consensus was reached for each response.

Results and Discussion

Convince, Understand, Teach

Our results indicate that teachers prefer different types of proof for the different scenarios of convincing, understanding, and teaching. Table 1 records the number of participants who selected each proof for these three purposes. Some participants gave one or more reasons for their choice, while others did not identify explicitly a criterion for their selection.

Table 1

Number of teachers who selected each proof for the purpose to convince understand, and teach

	Convince	Understand	Teach
GEO-paragraph	0	3	4
GEO-2-column	9	4	9
SUM-visual	1	8	7
SUM-Gauss	4	4	4
SUM-induction	3	3	2
SUM-table	0	0	0

ALG-2-column	2	1	0
ALG-geometric	3	2	3

The proofs selected as *most* convincing were GEO-2-column (9), followed by SUM-Gauss (4), and then SUM-induction and ALG-geometric (3 each). The participants who chose GEO-2-column as the most convincing did so primarily because of the formal structure and the reasoning it provided for each step (7), two participants alluded to the idea that it was easier to comprehend. One participant said, "I found [GEO-2-column] proof to be one of the most convincing because I am the most used to it. This seems to happen a lot in education because we get convinced simply because it is the norm, and we have noticed it before." Of the four that selected SUM-Gauss, three thought it was easy to follow, and two mentioned the visual nature of the proof as the reason it was most convincing. Two of the participants selected ALG-geometric proof as the most convincing because of how it made connections between ideas. One participant found SUM-induction as most convincing because "it would work in all cases."

The proofs selected as most helpful to understanding were SUM-visual (8), followed by GEO-2-column and SUM-Gauss (4 each). All eight of the participants who selected SUM-visual mentioned the visual nature of the proof as illustrated by the following quote, "This is helpful so that I can visualize the specific case before generalizing that approach to all numbers/cases." The participant went on to say, "The proofs with base cases worked out showed me how the mathematician was thinking before trying to prove it for all cases." Three of the four who chose GEO-2-column did so because each step was justified, similar to the arguments for why GEO-2-column helped to convince them.

The proofs selected as ones they would use to teach were GEO-2-column (9), followed by SUM-visual (7), and then GEO-paragraph and SUM-Gauss (4 each). Of those that selected GEO-2-column, five participants discussed the standard structure or familiarity with one mentioning, "it was like the 2 column proofs that I remember from my geometry class." Four referred to the clear line of reasoning. One participant commented that they would use GEO-2-column because "it made a bit more sense and was easier to comprehend, *as well as teach*," hinting that two-column proofs would be easier to implement from the teacher's perspective. Four of the participants who chose proof SUM-visual talked about the visual nature of the proof with one participant commenting, "the visual approach... shows [students] that the numbers actually represent something." In addition, for SUM-visual, one participant commented, "they provide insight into the mathematics but do not obscure it behind symbols and formalism" and another, "I would most likely use the cases that show how the mathematician is thinking through base cases/finding simple patterns and then how those patterns are applied for larger cases."

Discussion and Implications

GEO-2-column and SUM-visual illustrate two big themes in the participants comments—structure and visualization. When the purpose of proof is to convince there was a larger emphasis on structure. When the purpose of proof that is to understand, the emphasis shifted to visualization. Both structure and visualization were emphasized for selecting proofs for teaching in mathematics classrooms. As the aforementioned evidence doesn't tell the entire story, we pondered whether certain participants had an affinity for a particular type of proof regardless of purpose. There were two participants who selected GEO-2-column and commented on structure for all three purposes, and one participant who selected SUM-visual and commented on visualization for all three purposes. Although there were three participants who stuck with a single proof for all three purposes, most participants switched proof types depending on the purpose. Current literature documents the prevalence of students' preference for structure, but broadening the use of different types of proofs might be a possible way to make explicit the different roles and purposes of proof. Five of our participants specifically mentioned the importance of multiple perspectives or multiple proof types when discussing which proofs they would use to understand or teach, but no one mentioned multiple perspectives for the purpose of convincing. One participant commented,

> "I feel like looking at all the proofs together helped me to understand the mathematics to the fullest because I was seeing multiple people explain why a problem makes sense and how it can be completed in a different way while all still coming back to the same answer. This is a great way to gain an understanding into the thought processes of different students since they will be thinking of the same problem in a different context."

Our results are consistent with previous studies on teachers' and undergraduate students' conceptions of proof (e.g., Knuth, 2002a, Lesseig et al., 2019). As in other studies, participants in our study emphasized the form or appearance of a proof over its substance and prioritized verification among the roles of proof. This pervasive emphasis on the verification role of proof seems to hinder teachers', and future teachers', appreciation of other roles, in particular the role of proof as a tool for teaching and understanding important mathematical ideas and methods.

Although more work is needed in this area, our findings suggest that teachers should experience more opportunities to engage in tasks that emphasize the argument of a proof, rather than the structure of its presentation. It seems significant that the format of a proof, and the familiarity that teachers have with a particular format, has so much influence on teachers' choices. In the United States, two-column proofs continue to be the standard, and the participants in our study expressed a clear preference for them. GEO-paragraph and GEO-2-column were essentially the same proof, and yet more participants found the latter more convincing. Moreover, ALG-2-column was incorrect, and yet only one participant noticed it. It seems that the familiar two-column format, together with correct algebraic steps, made an incorrect proof seem persuasive.

Previous studies have shown how secondary mathematics teachers teach proof is greatly influenced by their own views on proof (e.g., Bieda, 2010; Buchbinder & McCrone, 2020). Our work suggests that teachers should have richer experiences with proof, as part of their teacher preparation program and in professional development.

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DON'T TELL ME WHAT I NEED: EXPLORING SCIENCE TEACHER PROFESSIONAL DEVELOPMENT WITH NARRATIVE RESEARCH

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Abstract

Little research exists to document science teacher perspectives on professional development (PD). Qualitative research methods such as interviews, focus groups, and field observations can illuminate the unique views of science teachers with varied lived experiences, and narrative research can be used to understand the perspectives of individuals through direct quotes and relevant life stories. This case study explores how an engineer turned honors physics teacher negotiated professional development in a large suburban high school space. This particular teacher was frustrated by PD experiences that were irrelevant for his position and wanted support to streamline his teaching practices.

Keywords: science teacher, professional development, case study

Introduction

Teaching science presents challenges that may not be the same for other disciplines such as mathematics or language arts (Luft et al., 2003). Like other teaching professions, professional development (PD) is a tool to help science teachers improve in all areas including classroom management, delivering instruction, or increasing student test scores. There is research in science education about PD including the best ways to deliver PD for teachers, what PD is most effective for teachers, and using PD to introduce new teaching strategies or new curriculum. A small number of researchers have also suggested taking science teachers' needs and preferences into account when designing PD experiences. However, there is little research to document what science teachers want or need from PD, and science teachers are almost always told what PD they need or what PD they are required to attend.

There is immense value in analyzing complex and interrelated structures within school settings to reveal nuances that would otherwise remain hidden from public view (Brandt et al., 2010). Retelling stories and reflections from a science teacher's perspective situates the narrative in an authentic lived experience. Viewing teachers as individuals acknowledges their unique understandings and honors their voices as educators. A novel perspective from classroom science teachers is needed to address the status of science teacher PD in the 21st Century. The voices of science teachers could generate innovative methods for science teachers to learn, develop, grow, and change as educators. While narrative research does not lend itself to generalizations or assumptions about other teachers' experiences, sharing the stories of science teachers' personal journeys may provide insights into how some science teachers negotiate their professional responsibilities.

Objectives of the Study

The objectives of this study were to explore high school science teacher experiences with PD and ways teachers describe their priorities for teaching and learning in relation to their PD needs. This target group of teachers 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 scant research about PD from the perspective of high school science teachers. This case study analyzes one physics teacher's experiences with PD in a large suburban high school. Considering science teachers as individuals with unique opinions and ideas about their learning and development as educators could impact the practices of science educators and designers of PD. Giving voice to science teachers' experiences with PD and advocating for the field of science teaching gives this research both purpose and potential to make a lasting contribution to the field of science education (Brandt et al., 2010; Madison, 2020; Rosaldo, 1993).

Theoretical Framework

Educational research paradigms investigate the complex human processes that occur within the institution of schooling and can lend themselves to a variety of research methods (Mertens, 2020). The primary focus of this research was to explore how individuals remember, describe, and explain their experiences with PD as high school science teachers. The methodology for this research study was based upon a constructivist worldview placing science teachers as social actors, and qualitative research methods were used to examine a group of high school science teachers' experiences with PD. Each teacher develops thoughts, ideas, and memories as a result of a PD experience; therefore, this qualitative research study attempted to interpret individual teacher understandings from PD. Teacher PD experiences contain specific rituals and customs that intertwine with other social actors, events, and activities in both the personal and work life of the individual (Erickson, 1984; Geertz, 1973; Madison, 2020). Acting as a participant-observer gave me the opportunity to observe the content, delivery, timing, and intended outcomes of some beginning-of-the-year PD, while noticing teacher interactions and participation with peers and the expectations placed on teachers with different teaching backgrounds and years of experience (Desimone & Le Floch, 2004).

Methodology

For this study, I followed seven science teachers during their back-to-school week of PD. Narrative research was used to understand the various discourses present when teachers begin the school year and participate in both district and campus-level PD. Conducting research with a small group of science teachers with different career histories at a single site afforded the opportunity to observe parallels and divergence among the narratives of science teachers (Rahm, 2012). Grounded theory methods avoid predetermined rules when collecting and analyzing observations and instead allow the data to determine the direction of the research (Charmaz, 2006; Mertens, 2020). This research method situated and immersed me as the researcher within the research context while I simultaneously collected data, considered observations, and proposed hypotheses as they appeared during the research process (Mertens, 2020).

The study site was a suburban school district, referred to as Poleville Independent School District (PISD) and Poleville High School (PHS) pseudonyms, in North Texas where I worked for nine years as a teacher and administrator. Concentrating the study with high school science teachers from a single school district ensured the teachers have shared in some of the same PD experiences and allowed the teachers to explain nuances in their perceptions of the same PD events. I conducted individual interviews before the PD week to understand their careers in education and the types of PD experiences they've had. I observed the teachers during mandatory PD sessions, science department meetings, and other district and campus activities. I had a focus group with the teachers at the end of the week, and I conducted follow-up interviews with the teachers after the school year began.

Incident by incident coding was used to review qualitative data from individual participants along with my field observations (Charmaz, 2006). At the conclusion of the initial coding phase, *in vivo* codes reflected the teachers' words and terms understood within the campus and school district that situated the research in a specific time and place (Charmaz, 2006). The qualitative data were synthesized into narratives about teaching, learning, and PD with the teachers' voices through direct quotes and my field observations. Each teacher's narrative was unique in its flow, content, and organization, reflecting the individual personalities and dispositions of the individuals who participated in the research process. Analysis of the seven narratives revealed two major themes: the teachers' perspectives on the teaching profession and their thoughts about PD.

Eddie the Engineer

Eddie was beginning his second year at Poleville High School (PHS), after almost 30 years as an engineer and nine years of physics teaching. As a former engineer, Eddie had a unique outlook on science teaching, how schools operate, and professional development (PD). He described himself as "an introvert, engineer-type person" who initially struggled with classroom management, while "the classroom content has never been an issue for me" (post-interview, September 18, 2023). When Eddie was asked for feedback and input about how PHS operates or how the district designs PD, he was open and honest about recommendations to improve efficiencies. He said, "I guess that's one thing I picked up on from being an engineer, I want everything to be applicable. Don't waste time teaching things that have no relevance" (post-interview, September 18, 2023). Eddie's previous career experiences made him an outlier in the science department at PHS, and he had his own ideas about teaching and PD.

As a physics teacher, Eddie was confident in his ability to know and understand the science content for an Advanced Placement (AP) Physics course, even though the district was not able to send him to the AP Summer Institute workshop for the course. He said, "Content I know because what we teach in physics doesn't really change year after year. It's pretty static other than the minor tweak changes that they make every year" (post-interview, September 18, 2023). Eddie was more focused on *how* he taught the course, rather than *what* he taught in the course. Eddie looks for strategies to make labs more experiential and less prescribed for students, and he tries to find ways to make class fun for the students. Eddie said he would like to have some "ways to make my job easier" (post-interview, September 18, 2023), although he did not elaborate specifically what he wants to be easier.

Perhaps it's his engineering background, but Eddie wants to simplify the time it takes to complete PD assignments and not waste time doing activities that take away from classroom instruction. Because Eddie takes teaching responsibilities seriously, he does whatever he is told to do for PD activities. Some PD assignments are cumbersome for Eddie if they require technology modules because he admits that technology is frustrating for him at times. Eddie explained his frustration with the online training modules saying, "I'm typically screaming at my computer … the system is not set up to make it easy. There's a lot of clicking here, clicking there" (pre-interview, August 9, 2023). He wants PD experiences to be immediately applicable to his current teaching assignment. He described a technology PD assignment saying:

> Talking about the [technology] training we need to be doing … I'm not going to be using that. That's a high barrier to usefulness. Yes, I can see it might be kind of useful, but I'm not seeing the payback. I want ROI. I want return on investment. (pre-interview, August 9, 2023)

Several other teachers disliked the technology PD modules assigned during the back-to-school PD week, but Eddie's reasoning for dismissing the training was articulated in a distinctive way. Eddie is willing to complete PD assignments, but he prefers that they are worth his time and energy.

Eddie was the only teacher in the PHS science department who had spent the majority of his career outside the education profession. Eddie shared that he had been an engineer for almost 30 years. His role was in production engineering, helping to take ideas for electronics and put them into production. When he explained engineering professional learning, he said there were some annual compliance-type trainings, but "there weren't any new tools training unless you specifically asked for it" (post-interview, September 18, 2023). When he began his engineering career, many of the training sessions were held in person because online training was not yet an option. He said required training included topics such as sexual harassment, handling money, and in some cases not taking financial bribes at work. When asked how engineering "professional development" compared to teacher PD, Eddie was quick to share that all of the engineering training had an immediate application or use on the job, he said, "there wasn't much fluff" (post-interview, September 18, 2023).

To clarify, "fluff" in education for Eddie was all of the training he sat through for back-to-school, and while some sessions were needed, in Eddie's opinion, most of the PD time was not used wisely. In engineering, for example, a company would never make everyone sit through a meeting or a training session unless every single person in the room needed that information for their job. He recalled "new teacher PD week" from the year before when he was new to PHS. He said the new hire PD was all a waste of time because none of it prepared him for what he would need to know to work at PHS. He described the introduction to the campus as a new employee:

> The training didn't have anything to do with learning the systems [at PHS]. When you're starting it in a new place it'd be nice to actually spend a lot of time just going over the new systems that are there. Instead, they went through the system so quickly that you never had actually time to sit down there and actually start getting some things done. (post-interview, September 18, 2023)

The campus had policies, procedures, rules, and nuances that Eddie felt were more important to understand, and all of the information was all thrown at him in a very rushed and confusing manner.

Eddie also disliked the annual compliance courses that are mandatory for all instructional staff because they were repetitive and unengaging.

When asked what Eddie would like to do for PD this year if he could choose a PD experience, he smiled and said, "That's a darn good question. One thing that I've been wanting to do is actually have more fun activities" (post-interview, September 18, 2023). Eddie said, "I want to have fun, and I know that if I'm having fun, the kids will be having fun too" (post-interview, September 18, 2023). Eddie wants PD to help him improve the experience students have in the classroom. He explained:

> If I could see something I can actually use in my classroom, then yes, I'm much more excited about it … life is far too short to be bored all the time. I want to have fun doing things. Even when I'm learning, I want to have fun doing things. (pre-interview, August 9, 2023)

Eddie wants to make his content fun and applicable so students enjoy learning physics (post-interview, September 18, 2023). He dislikes lecturing and prefers to set up situations where students can learn through exploration in his AP Physics classes. Eddie prefers using a modeling method because it allows for hands-on learning and student-led experimentation. He said, "I don't like lecturing because kids typically don't learn by lecturing ... I love setting up situations where the kids learn" (pre-interview, August 9, 2023). Eddie also wanted to learn things that will save him time. He wants to be more efficient at grading because "I just spent 7-8 hours rating the free response to our first test" (post-interview, September 18, 2023).

Eddie views teaching high school physics as an engineering design problem that needs to be understood, streamlined, and constantly improved. While other teachers mentioned the word "time" as something they could balance their time between work and home, Eddie saw *time* as an area for personal improvement. He does not want a shortcut that might decrease the learning outcomes of students, but he is looking for the best and most efficient ways to teach content. As a former engineer, Eddie had a simple and efficient approach to teaching and learning, but he yearned to cut through some of the "fluff" in education that complicated his role as a science teacher.

Implications

Eddie's case study is a reminder that when PD is relevant to teachers' classroom practices, teachers are more likely to focus on student learning (Penuel et al., 2007). PD could be more effective if teachers are given choice in what they learn. PD has the potential to enhance Eddie's instructional methods with learning technologies such as online simulations, electronic probe ware, modeling software, and virtual learning (Krajcik & Mun, 2014). Eddie wants to learn a variety of new content, concepts, and skills to stay current in his field of science teaching, and Eun and Lim (2009) suggested those learning opportunities should be interesting, meaningful, and relevant.

The information gained from asking teachers about their perspectives on PD is of value to science teacher educators and school administrators. PD providers should value science teachers' needs, preferences, and prior experiences when designing PD. Science teacher educators need more research to understand science teachers' PD preferences to improve science teacher PD experiences. This research has the potential to go beyond analyzing science teacher PD and could promote positive change by improving PD at the school level for the teachers. There is an opportunity to encourage administrators and teacher educators to value science teachers' needs, preferences, and prior experiences when designing PD. PD designers need to plan with teacher input and feedback in mind and consider providing differentiated PD options for teachers. Teachers are often not asked what they want or need to learn, instead they are told what they need to learn.

Learning about the identities and lived experiences of science teachers as they interact with PD may allow others in science education to open spaces (Barton, 2001) for conversations about the profession of teaching and how PD is defined within the profession. Science teachers deserve to have opportunities to reflect on their own professional learning needs and should be encouraged to advocate for choice and differentiation in PD. Future research could investigate survey instruments to gather input from science teachers about their preferences and needs for PD. Science teacher educators could provide workshops for classroom science teachers to explore their professional strengths, weaknesses, and learning needs. Facilitating partnerships between science education researchers and school district administrators could increase the flow of information between research scholars and school practitioners. If science teachers are truly education *professionals*, then perhaps the phrase *professional development* is an outdated concept in need of revision to meet the needs of today's science teachers.

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YEAR-LONG TEACHING RESIDENCY PILOT:
REFLECTIONS FROM SECONDARY MATH AND SCIENCE CLINICAL TEACHERS

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Abstract

This study examined the experiences of secondary mathematics and science clinical teachers during their year-long teaching residency. Participants completed anonymous questionnaires during their clinical teaching experience. The qualitative analysis revealed clinical teachers valued mentor support, became more confident in interacting with students throughout the year, and struggled with the heavy workload of being a student and clinical teacher. The findings provide insights into the challenges and priorities of new teachers in these critical subject areas during their residency year.

Keywords: teacher candidates, year-long clinical teaching, teacher workload

Introduction

In an effort to better prepare new teachers to be Day 1 ready while also addressing the continued teacher shortage, the Texas Education Agency (TEA) has begun partnering with local education agencies (LEAs) and educator preparation programs (EPPs) to develop paid teacher residency programs. These programs are designed to be mutually beneficial by providing teacher candidates with a full academic school year of compensated clinical teaching under the guidance of a mentor while the district benefits from the candidates fulfilling various instructional duties on days not committed to their program and certification requirements. With paid teaching residency programs still in their infancy in the state of Texas, research into the benefits and challenges for all stakeholders, as well as the long-term outcomes, has just begun. At our institution, secondary level clinical teaching has historically been completed in one semester. However, with the opportunities for compensation and potential benefits of an extended experience, we piloted a year-long teaching residency for clinical teachers seeking secondary mathematics and/or science certification.

Purpose of Study

The purpose of this study was to investigate the experiences of secondary mathematics and science clinical teachers in their year-long teaching residency. This research study was guided by the following research questions:

1. What are the benefits of year-long teaching residencies?

2. What are the challenges faced by clinical teachers during a year-long residency?

Related Literature

Hollins and Warner (2021) defined the clinical experience as the "application of academic knowledge to practice in classrooms, schools, and communities where candidates learn to contextualize the curriculum, learning experiences, and other teaching practices for specific individuals and groups of students" (p.2). Clinical teaching for undergraduates seeking secondary certification has traditionally consisted of one semester. Yet, secondary teachers and teacher educators have explicitly noted the need for more time in authentic clinical experiences, earlier experiences in their preparation, and multiple placements to offer a varied experience (Beck et al., 2020; Fields & Williams Mills, 2023; Windschitl, et. al., 2021). An intentional year-long clinical experience can provide opportunities for teacher candidates to gain agency and self-advocacy, while supported by both a teacher mentor and university faculty supervisor prior to taking the next steps into their permanent role as the classroom teacher (Fields & Williams Mills, 2023; Greenberg, et.al., 2014; Windschitl, et. al., 2021).

Graduates of year-long clinical experiences are more likely to continue teaching in the school where they completed their clinical experience and more likely to remain in the teaching profession (Bland et al., 2023; Guha et al., 2017). Teacher candidates benefit from year-long clinical experience because they receive strong pedagogical training while being placed with a mentor teacher (Bland et al., 2023). The year-long experience also gives them an opportunity to build relationships with students and school personnel, causing them to become a part of the school community (Henning, 2018). To alleviate some of the financial burden participating in a year-long clinical teaching experience can bring, some districts are implementing programs that allow year-long clinical teachers to receive financial support (Bland et al., 2023; Guha et al., 2017; Henning 2018). Teacher candidates are able to participate in an immersive, high quality teacher preparation program while not having to stress as much about finances (Henning 2018).

Methodology

This study was conducted at a regional university in Texas. Clinical teachers were asked to complete anonymous online questionnaires of several open-ended questions regarding their roles and responsibilities of their placements, challenges they faced during clinical teaching, as well as successes they had and future plans for teaching. For the purpose of this study, only clinical teachers enrolled in the program's pilot year-long clinical teaching program and seeking secondary certification were used during analysis. Clinical teachers were asked to complete the survey at the end of their first semester of clinical teaching and again in the final weeks of their second semester of clinical teaching. The first and second questionnaire included similar questions but were phrased slightly differently to address experiences from the particular semester and/or entire clinical teaching. Both questionnaires administered asked participants to share about a typical school day, reflect on their feelings about their placement and teaching, and discuss what they enjoyed most and what struggles they faced during that semester's clinical teaching placement. Participants were also asked both to share their hopes and concerns for the future and had a space to share about anything they wished we would have asked about. In the second semester questionnaire, participants were also asked about how their experiences changed from the first to second semester of clinical teaching.

The pilot program had a total of four secondary mathematics and science clinical teachers. Three participants responded to the questionnaire at the end of their first semester of clinical teaching, and three also responded at the end of their year-long placement. Due to the anonymity of the survey it is unclear if the same three clinical teachers responded both times, so the number of total participants is either three or four. During this pilot program, all four clinical teachers were compensated for their teaching residency. This required them to serve their secondary school campus for an entire school year, beginning with teacher-inservice. While the purpose of this paper is not focused on compensation, it should be noted that because they were paid by the school district, they committed to working the same calendar as classroom teachers, while unpaid clinical teachers at the university completed significantly fewer hours of clinical teaching.

Two members of the research team used open coding (Glaser & Strauss, 1967) to qualitatively analyze the questionnaire responses of the participants. During the analysis, we reviewed each response together. If we disagreed on a code, we discussed and reviewed the context of the response and came to a consensus. During the qualitative analysis process we refined our codes into four themes.

Results and Discussion

Four themes emerged during the coding of the questionnaire responses - workload, mentor support, student, and other. The "other" category included comments that did not pertain to their field experience and were not related to the study and therefore will not be discussed in this paper.

This results section is organized by the themes identified during the coding process and includes relevant quotes from the participants.

Workload

Participants in the study frequently mentioned their coursework, typical daily schedule in the classroom, mental load of being a teacher, and finding a healthy work-life balance. A couple of participants mentioned the heavy coursework, especially during their first semester of clinical teaching. The participants were taking up to two courses in their major, as well as the field-based education courses. One clinical teacher explained their workload during internship,

> I am really stressed out and struggling compared to where I normally am during this point in the semester…I am a full-time student and a full-time teacher. I am at my district more than some of the actual teachers because of the time I arrive in the morning and leave in the afternoon. My college classes have me pushing 20 or more hours a week in homework not counting class time. Trying to balance the workload hasn't been the worst, but I haven't had a day to myself in weeks and I struggle to stay awake during some of the classes I am not teaching.

When describing their typical school day, participants described completing activities like lesson preparation, observations of cooperating teachers, leading lessons, attending meetings, and grading student work. One clinical teacher highlighted the benefits of the year-long residency, "The pacing was much slower so I was able to gain confidence as I went and [took] things day by day as I picked up more responsibility. Now, I am completely in charge…My mentor has trusted me enough to be able to see all of the teaching experience and time management."

Participants frequently mentioned the heavy mental load of being a teacher, like overthinking, handling challenging student and parent situations, burnout, student testing success, and dealing with stress. After one semester of clinical teaching, one participant described these difficulties, "the constant mental struggles with feeling overwhelmed and unsure if all the effort is worth it at the end of the day." However, the participant did mention, "As things have moved forward, I am feeling better and more comfortable and have started to enjoy it more." At the end of the year-long residency, participants still mentioned the heavy mental load, but seemed more hopeful, "I am excited to be a teacher and hope I can adjust to some of the mentally draining aspects." Another clinical teacher described their transformation, "As the year goes on I have been able to be more myself and settle into my teaching style. It's been great overall and I feel like I am more prepared as I go into my classroom in the fall."

Participants also described the challenges they faced in maintaining a healthy work-life balance. At the end of the first semester, one clinical teacher said, "Some struggles I face have been being able to separate work and my personal life," and "being a teacher is something I want to do, but I don't think I could deal with it long term. It is a difficult lifestyle and finding a balance is necessary. I am still excited to continue with my career even though there are many things I wish would be better."

Mentor Support

Participants described the positive relationships they had with their mentor teacher. Some shared that they were scared and fearful of starting their residency but were relieved when their mentor teacher and other school personnel made them feel welcome and created an inviting environment. One clinical teacher appreciated her mentor, "ensured that her classroom was mine as well. This gave me more confidence to ask questions and ask to alter certain lessons." Another clinical teacher said, "The school I was placed in is supportive of my teaching career. I have had other teachers invite me into their classrooms." Other participants shared their excitement as they finished their first semester and looked forward to their second semester. One clinical teacher responded, "I feel excited to keep learning from my mentor and get more freedom over the classroom next semester."

Participants described the ways their mentor demonstrated support throughout the year. Mentors not only spent time planning and explaining lessons with their clinical teachers, but they also provided a realistic perspective into teaching. One clinical teacher reported, "She tells me how I will feel and how to beat being burned out. I think she has helped me greatly with understanding that I will not be perfect, and to not sweat over the small stuff." Participants also shared their experience with substituting and the support they had in those experiences. For example, "If I am subbing there is always someone asking if I need anything." Other clinical teachers shared their hopes and concerns related to support in their future teaching positions. One clinical teacher said, "I think I am most concerned about the supports I am going to receive as a teacher." Another clinical teacher commented, "I have some concerns about situations where I'm not sure what I need to do will come up but I hope everything works out fine."

Students

Participants shared their fears and successes when working with students in their classroom. Clinical teachers described how they saw relationships develop throughout the year. One clinical teacher said, "My biggest struggle this semester has been making myself be seen as a teacher to all of the kids." Another participant discussed, "My biggest struggle with student teaching would be the substituting dynamic…I think students saw me as a substitute instead of a teacher." A clinical teacher also recognized progress, "I noticed a shift from not trusting me to actually interacting with me a few weeks into the semester and now even more have started being involved and are excited to be around me." Again, seeing personal growth, a participant shared, "Throughout the year I was getting my footing, I think that I grew into a teacher role, and students recognized this."

Participants discussed how their level of comfort with the students grew through the year. One clinical teacher stated they were, "getting more comfortable with teaching and being in front of a group of students." Another clinical teacher said, "It took a long time for me to be comfortable with talking to the students normally…I was pounded with all the don'ts when it comes to being around students and it really made me scared to talk to anyone." Participants shared what they learned through the experience of having a varying range of abilities in a classroom and the classroom management skills they learned. Reflecting on the year of student teaching, one clinical teacher mentioned, "I think that the first semester of my internship was for me to work on student relationships and classroom management. I think the second semester is where I have been able to grow as an actual teacher."

The purpose of this study was to identify the benefits and challenges of math and science clinical teachers in a year-long residency. The participants identified several benefits to the year-long clinical teaching experience. Participants became more confident in working with peers, students, and leading the classroom as the school year progressed. Some expressed gratitude in the year-long experience, allowing for scaffolding and more opportunities to act and be treated like a teacher. The clinical residents also appreciated the wisdom and guidance of their mentor teachers, who seemed to play a strong role in helping them manage the heavy work and mental load of teaching.

The participants found the workload, especially in the first semester, very challenging due to taking college classes and working full time as a clinical teacher. They also expressed concerns of the high levels of stress and the difficulties of managing a healthy work-life balance. This seemed to somewhat improve in their second semester of clinical teaching, but they still shared concerns of the high demands teachers face.

Implications

Due to the qualitative nature of this study, the findings are not generalizable; however teacher education faculty may find similarities among their programs. Participants in this study expressed challenges of the heavy workload in their first semester of clinical teaching due to working full time as a clinical teacher and completing content specific university coursework. EPPs should consider degree plans that allow secondary mathematics and science clinical teachers to complete all content specific coursework prior to their senior year. Field-based and/or coursework related to pedagogy would allow for a more manageable load during their clinical teaching experience.

Another major implication of this study is the challenge clinical teachers face in managing stress and heavy teaching workloads. The cooperating teachers seem to play a strong role in helping prepare clinical teachers for this challenge in the profession. When selecting cooperating teachers (mentors), EPPs and principals should consider pairing clinical teachers with mentors who model a strong work-life balance and use appropriate coping techniques when dealing with stress. A welcoming climate among all campus teachers also seemed to encourage teacher candidates to continue in the profession. In addition, clinical teachers seemed to feel more prepared to handle the stress at the end of a year of clinical teaching than they did at the end of the first semester, so further research should explore if clinical teachers feel better prepared to handle stress in extended clinical teaching placements when compared to one semester placements. EPPs and teacher education faculty should also emphasize stress management techniques and strategies for promoting healthy work-life balance during their clinical experiences.

Finally, the participants in this study seemed to grow more confident in teaching, planning, and building relationships with students throughout the school year. Although the workload was especially heavy in their first semester, they appreciated the slower scaffold of responsibility and extended opportunities they had because of their year-long placement. EPPs should consider these extended clinical teaching opportunities for those seeking secondary certification but create support and balance in the university and field-based workloads to avoid burnout or failure.

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CLIMATE CHANGE: EXAMINING PERSPECTIVE OF THE CLIMATE FOR WOMEN STEM FACULTY

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Abstract

A 'chilly climate', introduced in 1982 describing working conditions for women STEM faculty, may still exist. This research sought to identify systemic factors obstructing equity and inclusion of females in STEM at a R2 university. Quantitative and qualitative data were collected and analyzed though an intersectionality lens. Data included university documents, interviews, focus groups, and job satisfaction survey. Preliminary results indicate that women and men view support at the department, college and university level differently. The most man/woman variation was at the department level and differed greatly between departments. Variation was found between tenure-track and non-tenure track women faculty.

Keywords: STEM; female faculty, equity, intersectionality

Introduction

Science, technology, engineering, and mathematics (STEM) education faculty are aware of the importance of having women, people of color, and LGBTQ+ as role models for attracting youth into STEM. Thus, having individuals from diverse groups as instructors and researchers at the university level is imperative. However, as made evident by a substantial corpus of research, barriers for women exist in STEM fields within institutions of higher education that do not exist for men. Studies report that women, particularly given their intersectional identities of ethnicity, LGBTQ+, race, and caregiver, are less likely to be recruited, hired, promoted, and retained in STEM departments (Cech & Waidzunas, 2021; Liu et al., 2019; National Academies of Science, 2010). While being multifaceted, several issues have been cited for further consideration. Current data suggests that retention and promotion rates in tenure-track lines may be lower due to the service assigned to (or taken on by) women faculty. Many of these activities tend to be heavily assigned to women and are often of the kind that hold little value for evaluation and promotion decisions (Babcock et al., 2017; Hanasono et al., 2019). In addition, women faculty are less likely to say "*no*" to service assignments or negotiate alternatives (Hanasono et al., 2019). Additionally, women (Misra et al., 2021; O'Meara et al., 2017) and people of color (Domingo et al., 2020; Misra et al., 2021; Trejo, 2020) often are assignments workloads that are disproportionately high. Paradoxically, even as these inequities are enacted and help account for the underrepresentation of women and people of color in STEM, the importance and value of having both is well documented (Obiomon et al., 2007; Smith, et al., 2018). Research concerned with the "leaky pipeline" report that having a women and/or person of color for an instructor increases by 20%-50% the retention of underrepresented minority students (Ghazzawi et al., 2021). Thus, examining the climate, including recruitment, hiring, promotion, and retention, within STEM fields on university campuses is warranted. Beyond identification and documentation of barriers, as well as bridges, is the added benefit of the creation of strategies that mitigate the barrier and enhance the bridges on individual campuses and that may be reproduced on other campuses.

Objectives of the Study

The goal of this study was to conduct a self-study to identify systemic factors that impede equity and inclusion of women in STEM, paying particular attention to the ways intersectional analyses informs understandings of women's experiences on campus given their diverse identities and embodiments. The research question for this study was: What are barriers and bridges for recruiting, hiring, promoting, and retaining women faculty in STEM?

Theoretical Framework and Related Literature

Scholarship from two communities served as the theoretical foundation for this study: intersectionality and institutional self-study. These frameworks provided a theoretical lens and an analytical framework for approaching the research questions, selecting data types, analyzing data, and submitting data to interpretation.

Intersectionality

While Crenshaw (1989) is not the first to highlight the complexity of humans, her work did bring it to the forefront and gave it a name – intersectionality. In its origin, intersectionality emphasized Black women's multidimensionality of experience as she critiques the inclination to treat race and gender as mutually exclusive (Crenshaw, 1989). More recently, many researchers agree with intersectionality's general principles that interrogates the structures that affect multiple forms of discrimination. The intersection of race, class, gender, sexuality, ethnicity, nation, ability, and age are reciprocally constructing phenomena that in turn shape complex social inequalities. Thus, inequities do not result from one, distinct factor but from the overlap of many (Hankivsky, 2014). The strength of Crenshaw's work is demonstrated by the continuing scholarship that adds complexity to the ways we think about formations of identity. One example includes the work of Puar (2007), who offers a variation on the concept of assemblage (Deleuze & Guattari, 1987) as a way to capture the contextual and contingent nature of identity. Applying a postcolonial, critical theoretical frame to a data set from a study of women of color, Jackson and Mazzei (2011) demonstrate that an institution's diversity does not guarantee a change in culture that is more inclusive. If anything, diversity can obscure the ways in which the normative practices and policies of an institution remain centered on dominant hegemonic structures such as whiteness and patriarchy. In this sense, the work of the current study relies on intersectionality to uncover the ways in which our institution's practices and policies are inherently discriminatory.

Institutional self-study

Accrediting agencies (MSCHE, nd) and NSF-funded projects (Griffin et al., 2020) provided guides developed from reviews of research on conducting institutional self-studies. The overarching goal of a self-study is to improve the institution by developing and implementing a strategic plan aligned with the institutional mission. This requires a conscious and self-reflective analysis of strengths and weaknesses of the institution. The process should include (a) organizing a team that includes individuals with decision-making abilities, (b) reviewing previous efforts, (c) listing data types needed and how to collect each type, (d) defining intended outcomes, (e) establishing a timeline, (f) providing a communication plan within the institution during and after the process, and (g) writing a strategic plan. While some data should be quantitative, relying only on a quantitative approach may not sufficiently identify the university social capital or promote sustained academic cohesion and connectedness (Rosa & Amaral, 2007). However, if the self-study model incorporates both the quantitative and the qualitative approaches suggested elsewhere (Rosa et al., 2005), it may indeed contribute to enhance "the networks by which academic cohesion and professional control are achieved" (Dill 1995, p. 106).

Methodology

Data Collection

As suggested for intersectional work (Metcalf et al., 2018), we utilized mixed methodologies of quantitative and qualitative research approaches. The quantitative data were requested from existing databases and a campuswide survey. Qualitative data were secured through new data collection in order to delve more deeply into the lived experiences of women faculty. Esposito and

Evans-Wingers (2022) reminded researchers of the four most common forms of data for qualitative work – interviews, focus groups, observations, and document analysis. We used three of these (documents, interview, focus groups). Project design:

- *Collect faculty quantitative data*. The Office of Institutional Research (OIR), Office of Human Resources (OHR), and Office of the Provost (OP) responded to a request for information from 2012 to present on (a) faculty searches, (b) harassment allegations, and (c) exit data sorted by different identities (gender, race, etc.). Also, a Job Satisfaction Survey was sent to all faculty using Qualtrics.
- *Collect faculty qualitative data*. OIR provided the names of all women faculty in STEM departments. Three collection points were used. First, tenure track and non-tenure track women faculty in all STEM departments at the university were invited to participate in a one-hour interview resulting in 40 interviews from the list of 63 women faculty. The interviews were followed by two women faculty focus groups and a men-faculty focus group. Faculty were randomly selected.
- *Review existing documents that establish current policy*. Current written documents at the university, college, and department level were analyzed. Faculty Handbooks from 2015, 2020, and 2024 were examined.

Results and Discussion

Quantitative data

Having quantitative data from several sources helped provide a more reliable picture of the climate at the university. Data provided by OIR included five years of salary, position by rank by college (promotion), and retention by gender. The original Job Satisfaction survey was developed using items from published surveys found in the literature. It was sent to 678 faculty with 248 responding (after cleaning there were 194 for a response rate of 28.6%). Demographics indicate that 54% women and 39% men; 83% heterosexual and 4% bi/queer/gay; and 74% white. A factor analysis resulted in the items clustering in four groups (*Culture, Workload, Policies and procedures, Support from university)* and overall *Satisfaction.* Confirmatory factor analyses (CFA) was conducted to validate the four-factor structure of the adapted job satisfaction survey with a total of 32 items. Model-data fit indices for the four-factor model were as follows: CFI=0.952, TLI=0.948, RMSEA=0.066, and SRMR=0.072. At the university level, women faculty had slightly higher scores than males for

Satisfaction, Culture, Support, and Workload but lower for *Policies and Procedures*. When sorted by college, men had higher scores than women on the total satisfaction and the four subscales in the College of Science & Engineering. However, women had higher scores than men in the College of Communication. In the College of Liberal Arts, women had higher scores overall and on three subscales but lower than men on *Policy & Procedures*. When sorted by non-STEM and STEM, the non-STEM women had higher scores than men on all scales. However, for STEM faculty, Women had higher scores for overall *Satisfaction, Workload*, and *Support* but lower scores on *Culture* and *Policies & Procedures*.

Qualitative Data

Interviews were uploaded into *Nvivo*, where they were systematically coded by identifying passages relevant to the research. The transcripts revealed three intersectional themes (gender and professional rank, family structure and nationality, and emotional labor and advocacy) within the experiences of women in STEM. These require further unpacking. Non-tenure line and tenure line women expressed different experience with non-tenure more satisfied (supported by Job Survey Survey). Tenure line women STEM faculty varied in their experience toward tenure. Positive experience for women tended to be non-specific to the university (e.g., enjoying time with students, proximity to family) and highlighted the intersection of gender, rank, family, and emotional labor. Negative experience tended to be specific to the university (e.g., tenure policy, promised lab space, mentoring). A theme across departs involved having promises made during the interview process not fulfilled. Leadership issues were cited as barriers and bridges. Barriers included negative work environments exacerbated by male faculty actively opposing promotion of women. Service that was time intensive but carried little prestige or leadership advancement was cited in all departments. Bridges were department chair who played a significant role in culture an opportunity. Female-dominated departments experience fewer workplace and isolation concerns but unequal service loads were still cited.

Implications

Mathematics and science education faculty who are SSMA members are included in the NSF definition of STEM faculty. Being STEM faculty working in Colleges of Education or departments of mathematics or science, SSMA members have a vested interest in the university climate for women in STEM. Having new data that indicates that the climate for women in STEM is still less positive that the climate encountered by men is a call for advocacy. Being aware of the bridges and barriers faced by women in STEM in this study may help other universities institute change. As a research team, we seek to be more than simply a call for more diversity in our STEM units on campus, but a reckoning with the policies and norms that perpetuate discrimination. Opportunities for improvement include implementing faculty mentorship programs, establishing clear policies on family care and non-university duties, examining service assignments, and increasing teaching support. We suggest that with more role models in STEM faculty, more students will enter STEM and STEM education majors.

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A SYSTEMATIC LITERATURE REVIEW OF THE INSTRUMENTATION USED IN MATHEMATICS SPECIALIST RESEARCH

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Abstract

With a growing body of research involving mathematics specialists, we know that they are important players in the professional learning and support of teachers and do make a difference in improving student learning. However, there are limitations within the research due to the nuanced roles and responsibilities of these positions within the diverse contexts in which they work. Further instrument design and development are needed to capture this nuanced work to answer questions about policy and practice. This systematic literature review identifies methodologies and the lack of adequate instruments and highlights the need for the development of rigorous, quantitative measures.

Keywords: instrumentation, mathematics specialists, synthesis

Introduction

As research regarding mathematics specialists continues to increase (Rigelman & Lewis, 2023), it is imperative to identify and develop valid instruments to study the nuanced roles and responsibilities of mathematics specialists. Mathematics specialists are uniquely positioned as pivotal influences in teacher professional learning (e.g., Association of Mathematics Teacher Educators [AMTE] 2013, 2024; Campbell & Malkus, 2011). Mathematics specialists often have a seat at the table when curriculum and instructional decisions are made (National Council of Teachers of Mathematics [NCTM], 2020), thus positioning them as change agents (AMTE, 2024). The current instrumentation has produced fragmented results to draw from about the impact and work of mathematics specialists. Without measures that accurately capture specific information, there is a lack of empirical research about mathematics specialists' work.

Objectives of the Study

The objectives of this study include identifying the methods and instrumentation used in the research regarding mathematics specialists. We seek to answer the following research questions: (1) What methodologies are used to study mathematics specialists? and (2) What are the common instruments used to study mathematics specialists?

Theoretical Framework and Related Literature

We frame this study by defining mathematics specialists as "dedicated professionals, possessing the necessary knowledge and skill to create opportunities that maximize the learning of mathematics" (NCTM, 2014, p. 112). Mathematics specialists provide job-embedded professional development to advance the teaching and learning of mathematics (McGatha & Rigelman, 2017). Mathematics specialists are incorporated into a variety of models of professional development with the responsibility of supporting teachers or students or a combination of supporting both teachers and students with ongoing, focused, and interactive learning experiences (Gibbons & Cobb, 2017). Additionally, mathematics specialists are situated and work within varied spaces and levels, including schools, districts, regions, and/ or states. At the simplest level, a specialist can be a strong math teacher whose primary responsibility is to the classroom (Swars Auslander et al., 2023; Webel et al., 2017); a specialist can serve as an interventionist who provides individualized student support (Baker et al., 2021; McGatha & Rigelman, 2017); and a specialist can take on a coaching role working along-side teachers and administrators to enhance and support mathematical teaching and learning (Baker et al., 2021; Saclarides & Lubienski, 2020).

Research points to the positive influence mathematics specialists have on teachers (Gibbons et al., 2017; Polly, 2012) and students (Campbell & Malkus, 2011; Author, 2021). Mathematics specialists are not only positioned to "significantly influence curriculum, assessment and PD decisions" (NCTM, 2020, p. 125), but also to support, inform, and model a culture of equitable mathematics so that each student can access effective teaching practices with high-quality curriculum and challenging instruction (AMTE, 2024; NCTM, 2014).

Methodology

To achieve a high-quality literature synthesis (Sandelowski & Barroso, 2007), we drew on Cooper et al.'s (2019) recommendations. This study is part of a larger systematic literature review which initially yielded 16,669 articles using search terms related to mathematics specialists across six databases. After analyzing the titles and abstracts, as well as the use of mathematics we were left with 441 articles. Next, we determined if the mathematics specialist was a primary part of the research (n=135). We then evaluated the study quality using the appraisal criteria of Risko et al. (2008) that has seven quality criteria (109). For this exploratory study related to instrumentation, we focused on specific subcodes related to mathematics specialists as seen in Table 1. The data set for this study was 81 articles. After identifying the subcodes, we read the methodology sections of the papers to identify the research type, and the instrumentation used within the studies.

Table 1

Inclusion and Exclusion Criteria

Application of Inclusion and Exclusion Criteria	**# of Articles**
Coded as "MS" Articles coded Mathematics Specialist, or "MS" after examination of the article title and abstract.	135
Quality Coding Using Scoring Framework Articles remaining after scoring for clear research questions, supporting literature, participant description, research methods, and coherent findings (Risko et al., 2008)	109
Specific Subcodes Examined in Analysis Articles in which the mathematics specialist was central to the research focus and were coded: 'MTL as Learner', 'MTL as Math Coach: District-level', 'MTL as Math Coach: School-level', 'MTL as Teacher Leader', 'MTL as Instructional Coach: School-level', 'MTL as Instructional Coach: District-level'	81

Results and Discussion

The results from the methodology analysis identified that most studies regarding mathematics specialists were qualitative (58%), with the remainder of the studies being classified as 1.2% tool development, 13.6% quantitative, and 27.2% being mixed methods. We were surprised with the number of mixed methods studies, as we anticipated a strong prevalence for qualitative cases around the study of mathematics specialists since this was higher than the mixed methods studies found in the mathematics teacher leader body of research (Livers et al., Accepted).

The most prevalent data collection instruments were surveys, rubrics, and reflections developed for that specific study (48%). We coded them as "no named surveys" (n=12; 36%) and "no named rubrics" which were developed to quantify qualitative data (n=3; 0.09%), and reflection instruments (n=1; 0.03%). Some of these studies provided sample questions or shared the rubrics, but there was not enough detail for these instruments to be used in other studies. The most used validated instrument used was the Mathematical Knowledge for Teaching (MKT; Hill et al., 2008) instrument (n=5; 15%). Additionally, the Standards-based Learning Environment Observation Protocol was used in three studies (Tarr et al. 2008; n=3; 0.09%). Three instruments were used in two different studies; they are the Reformed Teaching Observation Protocol [RTOP] (Sawada et al., 2002; n=2; 0.06%), Fennema–Sherman Mathematics Attitudes Scales for Teachers [FSMAS] (Fennema, & Sherman, 1976; n=2; 0.06%), and Mathematics Beliefs Scales [MBS] (Capraro, 2001; Fennema et al., 1990; Ren & Smith, 2013; n=2; 0.06%). Most of the instruments in the quantitative and mixed methods studies analyzed were within only one study. Some of those instruments include: the CLASS observation instrument (Pianta et al. 2008), Instructional Quality Assessment (IQA; Boston & Wolf, 2006) and Learning Mathematics for Teaching (LMT; Hill et al. 2004).

Implications

With most research regarding mathematics specialists being qualitative and most studies that use mixed methods or quantitative methods using measures that are developed specific to that study, we urge the development of validated instruments. The most popular validated instruments used as noted above were not specially designed for mathematics specialist research, but mathematics teaching in general. Specifically, results of this systemic literature review highlighted study specific instrumentation with many studies creating their own surveys and rubrics. Because instruments are not being used across research, we are left to make decisions around policies and practices of mathematics specialists without substantial evidence. We are unable to generalize or substantiate important quantitative findings and are limiting the impact of the research around mathematics specialists. We urge the development of validated instruments, so we can collectively move the field of mathematics specialists research forward. Validated instruments would result in stronger methodological practices for mathematics specialist research, in addition to supporting mathematics specialists within their practice.

Disclaimer

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ENHANCING CULTURALLY RELEVANT MATH TASKS THROUGH COGNITIVE DEMAND AND CULTURAL CONNECTIONS FRAMEWORK

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Abstract

This paper introduces the Cognitive Demand and Cultural Connections (CDCC) framework to examine how preservice teachers' tasks integrate cognitive demand and cultural connection. Analyzing 11 tasks created by preservice teachers over two semesters at two universities, the study employs a priori coding via the CDCC framework. Results show most tasks are categorized at Level 2, indicating an imbalance between cognitive demand and cultural connections. Level 3 tasks mainly focused on kindergarten content, highlighting that increasing content complexity makes maintaining cultural connections difficult. Implications suggest scaffolding tasks with low cognitive demand or cultural connections to enhance mathematical thinking and meaningful engagement.

Keywords: mathematics education, teacher education, cognitive demand, cultural connections

Introduction

Integrating culturally relevant teaching necessitates that teacher education equips elementary preservice teachers (PSTs) with the skills to understand and leverage students' prior experiences, cultural backgrounds, and interests, fostering meaningful teaching and learning (Association of Mathematics Teacher Educators, 2017; Ladson-Billings, 1995; National Council of Teachers of Mathematics, 2020). Culturally responsive teaching, as defined by Gay (2010), involves "using the cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant to and effective for them" (p. 31). This pedagogical instruction has students reflect on their own culture and identity, learn about others, and invite students to participate in cultural practices that can humanize mathematics (Bishop, 1990).

Objective of the Study

Culturally relevant instruction can offer "mirrors," "windows," and "sliding glass doors" (Bishop, 1990; Gutiérrez, 2007). These metaphors describe teaching practices that help students reflect on their culture, learn about others, and engage in cultural practices while learning academic content. Understanding culture as shared experiences through beliefs, language, and practices, socially constructed through intersectional factors like ethnicity, class, gender, race, and ability, allows students to appreciate cultural complexity and their positions within cultural groups (Gutstein et al., 1997). This research aims to examine PSTs' culturally relevant mathematics tasks using the

Cognitive Demand and Cultural Connections (CDCC) framework (Gupta & Moldavan, under review). The research seeks to identify areas where tasks can be improved to provide higher cognitive demand alongside deeper cultural connections. The guiding research question is: How are PSTs' culturally relevant mathematics tasks examined using the CDCC framework to assess the integrated levels of cognitive demand and cultural connections?

Theoretical Framework

Culturally relevant teaching is vital in mathematics education. Matthews and colleagues (2022) identified three tenets for culturally relevant mathematics teaching: "(1) fostering critical mathematics thinking as well as critical consciousness, (2) building on students' informal mathematics knowledge and their cultural knowledge, and (3) prompting empowerment orientations to students' cultural and experience rather than their deficit orientations" (p. 10). This approach invites students to actively participate in mathematics (e.g., Anhalt et al., 2018; Leonard & Guha, 2002; Matthews et al., 2013; Tate, 1995). Culturally relevant mathematics tasks leverage students' prior experiences through cultural and community inquiry, promoting students' funds of knowledge, agency, and empowerment (Gallivan, 2020; Riling et al., 2022). This approach helps students cultivate positive mathematical identities and enhance learning experiences (Aguirre et al., 2013).

Another crucial aspect is ensuring the rigor of tasks and balancing cognitive demands with cultural connections (Matthews et al., 2022). While tasks should facilitate student reflection on mathematical identity, maintaining cognitive demand is essential. Designing tasks that balance both fosters appreciation for mathematics and cultural diversity, but navigating this balance presents a challenge, especially for PSTs (Moldavan & Gupta, 2021; 2022; 2024). By supporting PSTs in considering cultural and societal issues in their task designs, PSTs can develop their professional practice and guide their future students in becoming informed citizens, recognizing mathematics as a tool for understanding themselves and the world (Gutstein, 2006).

The Cognitive Demand and Cultural Connections Framework

The effectiveness of integrating cognitive demand with cultural connections has yet to be widely explored. Considering this research, along with Stein and Smith's (1998) framework for creating high-cognitive demand mathematics tasks, the CDCC framework presents a way to conceptualize various levels where cognitive demand (low or high) is mapped onto cultural connections (low or high). While Matthew et al. (2013) adapted the Stein et al. (2009) framework similarly to the CDCC framework, addressing ways to relate procedures with connections and doing mathematics to cultural connections, this framework includes all levels of cognitive demand. This paper uses the CDCC framework (see Figure 1) to assess where the tasks are characterized within the framework and discusses suggestions for enriching the task.

Figure 1

Cognitive Demand and Cultural Connections (CDCC) Framework

	Cultural Connection (Low) - (LCC)	**Cultural Connection (High) - (HCC)**
Cognitive Demand (Low) - (LCD)	LEVEL 1- LCD-LCC (Beginning) Low-level cognitively demanding task with low-level connections to culture	LEVEL 2a- LCD-HCC (Developing) Low-level cognitively demanding task with high-level connections to culture
Cognitive Demand (High) - (HCD)	LEVEL 2b- HCD-LCC (Developing) High-level cognitively demanding task with low-level connections to culture	LEVEL 3- HCD-HCC (Applying Connections) High-level cognitively demanding task with high-level connections to culture

The CDCC framework is divided into four indicators examining the integration of cognitive demand and cultural connections in a culturally relevant task. Stein and Smith (1998) differentiate cognitive demand into high-level and low-level categories. High cognitive demand tasks require students to apply concepts through reasoning and connections to elicit conceptual understanding, encouraging evaluation, analysis, synthesis, reflection, and applying knowledge to new situations. In contrast, low cognitive demand tasks focus on basic recall, procedural practice without explanation, and repetitive skill practice.

Cultural connection levels (high and low) evaluate how tasks reflect students' diverse cultural backgrounds regarding relevance, representation, inclusivity, and empowerment (Gay, 2002; Ladson-Billings, 1995). High cultural connection tasks engage students in meaningful cultural connections, reflect classroom diversity, provide multiple entry points for cultural comparison, and encourage pride in cultural identities. Low cultural connection tasks offer limited cultural connections, often reducing culture to settings without exploring it deeply or making relevant comparisons, potentially marginalizing students. For a more detailed analysis of the CDCC framework, see Gupta and Moldavan (under review).

Methodology

A qualitative case study (Yin, 2014) was conducted across two elementary mathematics methods courses at two universities in the United States. These courses, the only mathematics methods courses in their programs, precede the PSTs' field experiences in elementary schools. Although the programs emphasize creating culturally relevant lessons, the PSTs have yet to design mathematics tasks that reflect this approach.

After reading foundational texts and observing sample tasks co-taught by the researchers, the PSTs designed culturally relevant mathematics tasks in small groups, micro-taught them to peers, and submitted plans for feedback. PSTs were provided a list of books from different resources however they were also provided the freedom to explore and make connections through their own discovered multicultural books. The tasks leveraged diverse children's literature, acknowledging contributions from individuals beyond white, Western, and colonized perspectives, and informed the design of the PSTs' tasks to humanize mathematics. These tasks aimed to foster critical consciousness and mathematical thinking, build on students' mathematics and cultural knowledge, and position students' cultures as instructional assets (Matthews et al., 2022).

Data Sources and Analysis

Data sources included 11 tasks from consenting PSTs, with three tasks from one university and six from the other. Using the CDCC framework indicators, we evaluated each task. Each task was independently categorized into a specific level, and justifications for the classifications were documented. The data were coded using a priori coding with indicators from the CDCC framework to identify emerging themes associated with each level (Saldaña, 2016). To ensure the trustworthiness of the findings, we cross-checked our noted codes and themes (Grbich, 2013).

Results and Discussion

The task analysis indicated a range across the three levels in the CDCC framework. Three tasks were categorized as Level 1. In Level 2, there were five tasks, one representing high cognitive demand and low cultural connections and four representing the reverse. Three tasks were categorized as Level 3. An example from each level is shared to justify the level's indicators.

Level 1

Analysis categorized three tasks, one for kindergarten and two for third grade. One kindergarten task with reference to counting forward and backward to at least 20, with and without objects (Common Core State Standards Initiative [CCSSI], 2010) used Blackstone's (1995) *My Granny Went to Market: A Round-the-World Counting Rhyme*, where students listed items collected by Granny during her travels. Students copied the number of each item Granny collected without discussing each item's significance or cultural connections, resulting in low cognitive demand and missed opportunities to explore different counting strategies and extend counting to 20. Additionally, the task lacked cultural connections, as it did not encourage students to further inquire about the items in their cultural context or compare them to their own cultures. This approach led to a task focused on basic recall with limited cultural connections, missing opportunities to explore cultural settings, compare varied cultures, and reflect on students' cultures. Analyzing the task on the CDCC framework provides opportunities for PSTs to revise the task for high cultural connections, such as situating the cultural connections in students' own travel and sharing about their culture. The cognitive demand can be increased to stimulate critical thinking and deepen the understanding of the mathematical content by sorting and combining items that different groups bring together thus making bigger sets and extending learning by discussing various counting strategies.

Level 2

In a Level 2a task, PSTs used Feelings' (1992) *Mojo Means One*, which introduces numbers from one to ten in Swahili. For instance, tano (five) depicted animals on the savannah, and sita (six) described East African traditional clothing. The task aimed to help first-grade students solve addition and subtraction problems (CCSSI, 2010). After reading, students converted Swahili words into numbers and solved basic arithmetic problems, offering insights into East African culture and fostering discussions about language differences. However, the task's cognitive demand was low, as it only referenced numbers up to ten and lacked higher-order thinking or word problems. To enhance the task's cognitive demand, problems could be contextualized with cultural elements, involve two-digit operations, or ask students to create their own problems. This approach would promote deeper mathematical understanding and higher-level thinking.

Most tasks were categorized at Level 2, indicating either high cognitive demand with low cultural connections or vice versa. This suggests that PSTs, with their limited experience, often prioritize either cognitive demand or cultural connections when planning their tasks. Although the tasks ranged across various grade levels, four out of five tasks presented strong cultural connections enriching students' learning experiences by relating to their personal lives and helping them understand their peers. However, the cognitive demand of the four tasks was insufficient failing to challenge the students adequately to promote critical thinking and application of learned concepts. This imbalance suggests PSTs need opportunities to develop culturally relevant pedagogy effectively and use the CDCC framework to guide their task analysis.

Level 3

In a Level 3 task, PSTs used Thong's (2000) *Round is a Tortilla* to address the kindergarten mathematics standard of identifying, describing, comparing, creating, and composing shapes (CCSSI, 2010). The book features rhyming text, illustrations, and Spanish words describing shapes. After reading, the PSTs introduced masa, a staple in Mexican and Latin American cuisine, and discussed Hispanic culture and the shapes of cultural foods mentioned in the story. Students then used masa to create shapes resembling their cultural foods and shared their models with peers. The task immersed students in cultural learning, fostering community and high cultural connections by discussing traditions in diverse cultures and comparing them with Hispanic culture. Creating and describing shapes in formal and informal language led to high cognitive demand. The activity facilitated rich exchanges about cultural similarities and differences, serving as a "window" into other cultures and a "mirror" for self-reflection. Although the task reflects the highest level of the CDCC framework, it can be enhanced by having students further describe their shapes or create additional shapes representing more cultural items.

The Level 3 tasks predominantly focused on kindergarten content. Maintaining cognitive demand for upper elementary content proved challenging for the PSTs. The three Level 3 tasks (two on counting and cardinality, one on geometry) made rich cultural connections, offering contextualized learning opportunities. However, increasing cultural connections without sacrificing cognitive demand became harder as content complexity increased. This trend may result from PSTs gravitating toward lower grade levels while developing their pedagogical methods.

Implications

PSTs need experience designing culturally relevant mathematics tasks. To best support PSTs in this pedagogical approach, the CDCC framework can be utilized to identify indicators of cognitive demand and cultural connections, thus leading to valuable insight and self-assessment opportunities when designing tasks. A well-balanced, rich task can provide critical thinking of the mathematical concepts and engagement in the culture for meaningful learning. Teacher educators can facilitate this process through prompts that scaffold learning and support students to think deeper and critically. Prompts, such as "Can you modify the task to ask students to solve problems in multiple ways" or "Ask students to share a related mathematical connection from their culture with the class," can guide PSTs in refining their tasks, thereby enhancing mathematical thinking, making connections, and application. Though the sample size for the study was small which poses a limitation to the study, using the CDCC framework to examine the intersection between high cognitive demand and high cultural connection can offer teacher educators insights into how they might scaffold PSTs' practice in designing culturally relevant mathematics tasks and extend such ideas to other applicable content areas like science. This approach aligns with the work of Matthew et al. (2013), "a framework for culturally relevant, cognitively demanding mathematics tasks does not provide a magic bullet but instead provides a tool to guide teachers in the selection of tasks" (p. 133). Through this framework, we hope teachers can enhance their design of culturally relevant tasks to foster an inclusive environment that leverages students' cultural and mathematics strengths, empowering them as active participants in understanding the world through mathematics.

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INFUSING MATHEMATICS INTO COLLEGIATE CHEMISTRY: IMPACT ON SELF-EFFICACY AND PROBLEM-SOLVING

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Abstract

Applying mathematical concepts is important for solving calculation-based chemistry problems in undergraduate courses. Utilizing a sequential mixed methodology, this action research study evaluated the impact of in-class mathematics interventions on students' chemistry self-efficacy and problem-solving abilities. The study was completed with 40 first-year undergraduate general chemistry students. Results indicate a statistically significant increase in students' Math-Up Skills Test scores and their reported chemistry self-efficacy after the intervention. The implications for just-in-time mathematics interventions in undergraduate chemistry courses will be explored in the paper.

Keywords: undergraduate chemistry, mathematics, self efficacy, problem-solving

Introduction

The application of mathematical concepts and procedures is important while solving calculation-based problems in chemistry (Ranga, 2018). Numerous studies have reported a direct correlation between students' achievement in mathematics and their performance in undergraduate chemistry (Williamson et al., 2020). Albaladejo et al. (2018) noted, however, that the mathematics needed in the chemistry classroom is basic algebra, and students with weak mathematics skills struggle with numbers and the application of mathematics in integral areas of chemistry, such as mole concept and reaction stoichiometry. The undergraduate general chemistry courses are considered gateway courses because students who are unsuccessful in general chemistry are likely to withdraw from STEM degree programs (Posey et al., 2019). As such, competency in areas of mathematics, such as algebra, will give students the foundation necessary for problem-solving, allowing them to acquire a more in-depth understanding of chemistry concepts, thus being able to continue in STEM degree programs (Ranga, 2018).

Purpose and Research Questions

Undergraduate general chemistry students may have been taught mathematical concepts in a formal mathematics class but struggle to apply the concepts in chemistry areas, including mole concepts and reaction stoichiometry (Ranga, 2018). Focused teaching strategies, such as a mathematics review, can result in improved students' skills in solving calculation-based problems in general chemistry and help students better understand the material in higher-level chemistry courses, thus increasing their chances of success at the undergraduate level (Alivio et al., 2020). A mathematics review includes instruction, questions, and feedback to guide students through the mathematical concepts they would have already covered in a formal mathematics class and will encounter in their chemistry course (Alivio et al., 2020). The aim of this research study was to examine how a mathematics review impacts students' chemistry self-efficacy and problem-solving in first-year undergraduate chemistry courses. Research questions include: (RQ1) What is the change, if any, in test scores after a focused mathematics review in an undergraduate chemistry course? (RQ2) How does a focused mathematics review affect students' chemistry self-efficacy in an undergraduate chemistry course?

Theoretical Framework and Related Literature

Students' difficulties with procedural fluency in chemistry calculations can result from a lack of knowledge about applying mathematical concepts and procedures to chemistry principles and computations (Posey et al., 2019). Cognitivism is a viable frame to encapsulate this difficulty because it will allow us to examine how students apply prior knowledge. Cognitivist learning theories encompass a focused approach to understanding how individuals process information and are considered appropriate for explaining more complex learning activities, including reasoning, solving problems, and processing information (Pritchard, 2014), such as those involved in learning chemistry. Cognitivism can apply to mathematical principles necessary for chemistry calculations and emphasizes helping learners relate new information to the knowledge they already possess, including the application of mathematics in chemistry (Pritchard, 2014).

Based on students' comments about a mathematics review Ranga (2018) suggested that some students' difficulties with chemistry calculations can result from a lack of knowledge about applying mathematical concepts to chemistry principles. Helping students make the connection between the mathematics they have already learned and the chemistry they are being taught will help them flexibly apply the mathematical principles to problem-solving in chemistry and improve their academic outcomes (Posey et al., 2019).

Some students may lack self-efficacy around carrying out required tasks in a chemistry class (Ramnarain & Ramaila, 2018; Villafañe et al., 2016). If individuals do not believe that they can succeed at a particular task, there is no incentive for them to persevere (Bandura, 1999). Self-efficacy is necessary for acquiring new competencies and has been reported as one of the major contributors to the academic achievement of students, as a learner's self-efficacy will determine how they apply what they have learned (Ramnarain & Ramaila, 2018). Ramnarain and Ramaila (2018) reported that students' chemistry self-efficacy accurately predicted their outcomes in a first-year chemistry course, reported a positive correlation between self-efficacy and achievement, and recommended designing learning activities that increase students' self-efficacy.

This suggests that activities that improve students' self-efficacy will positively impact performance immediately and in future courses as this reciprocal cycle continues (Villafañe et al., 2016). Indeed, Villafañe et al. (2016) showed that positive self-efficacy in science disciplines, including chemistry, is strongly correlated with students' persistence in STEM fields. Therefore, learning activities that facilitate growth through self-efficacy (e.g., a mathematics review) are required to effectively train the next generation of chemists. Measuring students' self-efficacy and the impact of any intervention on self-efficacy and performance (e.g., including a mathematics review) is an important undertaking, and the theories of self-efficacy and cognitivism support the intervention and measures proposed.

Methodology

Participants and Intervention

As part of a larger explanatory sequential mixed-methods doctoral study, this paper focuses on quantitative analysis from the mathematical intervention done over eight lessons during one semester. Participants were 40 students (16 – 44 years old) enrolled in two first-year undergraduate general chemistry courses at a small university college in the Caribbean. The institution has an enrolment of approximately 2000 students and grants degrees up to the master's level. Two 45-minute mathematics review sessions were conducted *during* chemistry classes using the EBSCO PrepSTEP LearningExpress online instruction system (Lindsay, 2018). The review involved multiple short lessons and eight 10-minute practice sessions on developmental mathematics skills. The LearningExpress Library provided tutorials that included short videos, guided learning tutorials, practice questions, and solutions broken down into units to help students reinforce the concepts (Lindsay, 2018). The content of the chosen modules aligns with the skills required for the chemistry courses.

The review sessions included the instructor playing the instructional videos, providing reminders, and guiding students through the online examples for applying mathematics concepts such as decimals, integers, algebraic expressions, percentages, ratios, and proportions. Review sessions were followed by practice sessions to help students apply mathematical concepts to the chemistry content. The practice sessions were conducted using Kahoot games (an online formative assessment given in class) without the leaderboards (Kahoot, 2024). Just before each Kahoot game, students were briefly reminded of the concepts and calculator use pertinent to the topic covered in the questions. After each game question, a discussion of the answer and additional reminders of the concepts ensued.

Data Collection

Students completed the Math-Up Skills Test (MUST) and the College Chemistry Self-Efficacy instrument (CCSS) before and after the intervention to determine changes in their problem-solving ability and chemistry self-efficacy, respectively (Albaladejo et al., 2018; Uzuntiryaki & Çapa Aydın, 2009). The MUST is a validated 15-minute quiz that has been used effectively to predict whether students will be successful in undergraduate chemistry courses (Alivio et al., 2020; Williamson et al., 2020). There are two versions of the MUST, each with 20 questions related to multiplication, computations with powers of ten, changing fractions to decimal notation, rearranging algebraic equations, logarithms, determining the base-10 logarithm functions, scientific notation, and balancing simple chemical equations (Albaladejo et al., 2018; Alivio et al., 2020). In studies carried out by Williamson et al. (2020), the MUST was correct in 79 - 83% of its predictions of student success in general chemistry. Therefore, a low MUST score can indicate a deficiency in basic arithmetic skills, which may result in lower scores in general chemistry courses (Alivio et al., 2020; Williamson et al., 2020). Different versions of the MUST were used for the pre- and post-tests to eliminate increased scores due to participant familiarity with the test items. To answer RQ1, this study will determine if the MUST score measured the impact of a mathematics review within a chemistry course.

The CCSS is a validated instrument created by Uzuntiryaki and Çapa Aydın (2009), and used by researchers to measure students' chemistry self-efficacy and assess the effectiveness of interventions on students' self-efficacy (Ramnarain & Ramaila, 2018). As self-efficacy is context-specific, this tool is appropriate because it allows for the measurement of self-efficacy related to tasks that first-year chemistry students should be able to successfully complete (Uzuntiryaki & Çapa Aydın, 2009). The questionnaire has 21 items rated on a nine-point Likert scale and asks students to indicate how well they believe they can accomplish the tasks related to cognitive skills—the capacity to handle intellectual operations in chemistry, psychomotor skills—ability to deal with required muscle skills, and everyday applications—ability to use chemistry concepts in daily situations. To answer RQ2, the CCSS was the metric used for students' chemistry self-efficacy to determine what changes, if any, occurred in their self-efficacy during the study period.

Data Analysis

To answer RQ1, a paired samples *t*-test was used as the statistical tool to ascertain whether two paired groups differ significantly (Privitera, 2024). The MUST data was evaluated and found to have met the assumptions for use of the paired *t*-test which include a minimum of five continuous, paired data sets that are normally distributed, representative of the population, and have a similar spread (Privitera, 2024). A Pearson correlation analysis determined the strength of any relationship between the two variables (Privitera, 2024). Pearson correlation analysis requires independent, paired data sets that are continuous and normally distributed. The MUST scores collected are normally distributed, continuous, paired data sets. Results from the MUST scores were numerical, and the participants completed the two assessments independently of each other with assessment questions on each instrument, not contingent on each other.

Student responses to the CCSS questionnaire were collected in an online survey form with the Likert scale modified to 5 points. The 5-point scale was converted to numerical scores as follows: very poorly = 1, poorly = 2, average = 3, well = 4, and very well = 5. As the CCSS included four or more Likert-type items for which the scores were tallied to give self-efficacy in various categories and then total self-efficacy, the data was considered ordinal (Privitera, 2024). The CCSS results were evaluated and determined to have met the previously outlined requirements for a paired samples *t*-test. The conditions for a *t*-test (continuous data, normal distribution, random sampling from population, and similar variance) were found to have been met, validating the use of the *t*-test scores for both the MUST scores (RQ1) and the CCSS survey values (RQ2).

Results and Discussions

Table 1 shows the results of a paired *t*-test conducted on pre- and post-MUST test scores for each student, which revealed a significant increase in scores after the intervention ($M = 13.0$, $SD = 4.4$) when compared to the MUST scores before the intervention ($M = 11.4$, $SD = 3.9$, $t(39) = 3.72$, $p < .01$).

Table 1

MUST Score Descriptive statistics (N = 40)

Score	Pretest	Posttest	Score Difference	*t*(stat)	*p*-value

Maximum	20	20			
Mean	11.4	13.0	1.6	3.72	<.01
Median	11.0	12.5	1.5		
Standard Deviation	3.9	4.4	0.5		

Using a further breakdown of the frequency of changes by 2 points (e.g., 1-3, 4-6, 7-9, etc.), it was found that 67.5% of the participants had an increase of 1-3 points in their MUST score after the intervention, aligning with the mean score difference.

The increase in MUST scores suggests that the intervention resulted in a positive change in students' mathematics abilities. A Pearson analysis revealed a strong positive correlation between students' pre-intervention and post-intervention MUST scores, r(38) = .77, p < .001. This indicates that participants' posttest scores can be accurately predicted by their pretest scores. Notably, the coefficient of determination, $R^2 = 0.59$, highlights that 59% of the posttest scores can be explained or predicted by the student's pretest scores.

Results of a paired *t*-test conducted on the pre- and post-self-efficacy responses (see Table 2 below) revealed significant differences in all three dimensions. Whereas self-efficacy for cognitive skills increased significantly ($t(39) = 3.50$, $p < .01$), the increase for self-efficacy associated with psychomotor skills ($t(39) = -1.69$, $p = .05$) was less significant. Students self-efficacy for everyday applications showed a significant decrease ($t(39) = -3.6$, $p < .01$) after the intervention. This suggests that the intervention positively impacted students' self-efficacy for cognitive skills and their ability to solve chemistry problems. Ultimately, there was a significant increase in students' total self-efficacy ($t(39) = 2.85$, $p <.01$) after the intervention ($M = 79.5$ $SD = 11.3$) when compared to self-efficacy before the intervention ($M = 75.8$ $SD = 11.8$).

Table 2

Descriptive Statistics for Self-efficacy Dimensions (N = 40)

Dimension	Central Tendency	Pretest	Posttests	Change	*t* (stat)	*p* value
Self-efficacy for cognitive skills	Mean	3.51	3.72	0.21	*t* = 3.50	*p* < .01
(57% of Survey)	Median	3.42	3.83	0.41		
Maximum per question	St. Dev	0.57	0.52	-0.05		
		5	5			
Self-efficacy for psychomotor	Mean	4.01	4.15	0.14	*t* = 1.69	*p* = .05
skills	Median	4.00	4.22	0.22		
(24% of Survey)	St. Dev	0.64	0.70	0.06		
Maximum per question		5	5			

Self-efficacy for everyday applications (19% of Survey)	Mean	3.62	3.54	-0.08	$t = -3.60$	$p < .01$
	Median	3.63	3.50	-0.13		
	St. Dev	0.68	0.66	-0.02		
Maximum per question		5	5			
Total self-efficacy (100% of Survey)	Mean	75.8	79.5	3.7	$t = 2.85$	$p < .01$
	Median	74.0	81.5	7.5		
	St. Dev	11.8	11.3	-0.5		
Maximum per survey		105	105			

Conclusions and Implications

To answer the research questions, the significant increases between the pre- and post-CCSS and MUST scores suggest that the intervention increased both students' chemistry self-efficacy and their test scores. With 67.5% of the participants increasing their MUST score by 1 – 9 points, the study results show an improvement in students' mathematics performance after the intervention. We can conclude that the MUST accurately measured the impact of the mathematics review within the first-year chemistry courses. The results of this study support those obtained by Alivio et al. (2020) which reported positive outcomes for students when a mathematics review was included in undergraduate chemistry courses and increased students' MUST scores. Additionally, the intervention resulted in significant increases (3.7 points or 3.5%) in student's total self self-efficacy. This increase was most significant in students' self-efficacy for cognitive skills (0.21 points or 4.2%) and suggests that the mathematics intervention resulted in positive changes in students' self-efficacy for carrying out calculations in the chemistry course. This supports results by Ramnarain & Ramaila (2018) which showed marked improvements in students' self-efficacy for cognitive skills over psychomotor skills and everyday applications in a chemistry course. They also concluded that students' self-efficacy for cognitive skills predicted students' performance, as seen in the current study. The increase in MUST scores can be explained by the reciprocal causation reported by Villafañe et al. (2016) which indicates that higher self-efficacy results in higher test scores for chemistry students.

The uniqueness of this study lies in the successful use of just-in-time mathematics intervention, expanding on prior interdisciplinary literature that highlights the benefits of including mathematics skills and applications in chemistry lessons at the undergraduate level (e.g., Alivio et al., 2020; Ranga, 2018). This study presents a tangible, practical way to integrate mathematics into chemistry courses. The intervention requires no additional resources (beyond instructor Professional Development on instruments) and results in great improvements in student outcomes without too much time and effort on the instructor's part. Significantly, the intervention does not require much instructional time across the semester. Implications for research include a method to synchronize STEM topics (Mathematics and Chemistry) so that students can see the critical connections to build self-efficacy. It paves the way for collaboration across disciplines and curricula and can help to build tangible inroads to interdisciplinary STEM in higher educational institutions.

Further ongoing analyses suggest that prior mathematics experience at the undergraduate level has a positive impact on students' self-efficacy during the study. Results from a paired *t*-test revealed significant difference between the reported changes in self-efficacy for students who had completed any undergraduate level mathematics course ($p < .01$) but none for those who had completed only secondary level mathematics ($p = .28$) prior to the intervention. Interestingly, the pre-intervention self-efficacy score was almost identical for students who completed only secondary level mathematics and those who completed any undergraduate level mathematics course. This could indicate that there is no correlation between prior mathematics preparation and reported chemistry self-efficacy of the participants but that the prior mathematics preparation may have helped students to better access the content of the review sessions and better understand the chemistry content, and so resulted in improved self-efficacy over those with lower-level mathematics experience.

The limitations of this study include the small study size and the action research methodology, which limited the study to only one institution. The study can be repeated in other institutions across more chemistry courses, with more instructors to inform instructional practice and expand the use of mathematics interventions to improve student outcomes in undergraduate chemistry courses and increase retention in STEM degree programs.

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EFFECTS OF A CLASSROOM COGNITIVE APPRENTICESHIP ON STUDENT AGENCY AND BIOLOGY SELF-EFFICACY ON STUDENTS IN HIGH SCHOOL BIOLOGY

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Abstract

Students entering high school often believe they are not "science kids" and cannot be successful in Biology, leading to a lack of Biology self-efficacy (BSE) and student agency. Exposure to research experiences has been shown to increase BSE, student agency. To determine if exposure to authentic research could increase BSE and/or student agency, a cognitive apprenticeship classroom (CAC) was tested. All students showed an increase in BSE and qualitative data showed an increase in depth of student responses. The data indicate that a CAC can increase biology self-efficacy.

Key words: science education, research experience, biology education, secondary education

Introduction

One student says, "Do I have to know this?", and another wants to know if one sentence is enough of an answer while a third student shrugs and says, "I can't do this; I'm just not a science person" and gives up before really getting started. These statements have become far more common over the past several years. Students came into class expecting to memorize facts and definitions to recite for a test. When doing laboratory exercises, they expected there to be a single set of correct steps that lead to a predetermined answer and when confronted with the ambiguity natural to research, many students had no idea how to proceed.

Two issues seem to drive this problem. First is the lack of academic and science self-efficacy many students entering a high school science classroom. Academic self-efficacy refers to students' beliefs in their own ability to be successful at school (Hayat et al., 2020) while science self-efficacy refers to "students' belief in their ability to succeed in science tasks, courses, or activities" (Britner & Pajares, 2006, p. 486). Second is the lack of student agency: students' opportunity and ability to make choices about what and how to learn (Renaissance, 2022). Whether from a lack of practice or secondary to a lack of academic self-efficacy, students entering 9th grade are not comfortable making choices related to their education.

Objectives of the Study

The problem of practice addressed by this study is to determine the effectiveness of a curriculum based in a cognitive apprenticeship in the classroom that is specifically designed to increase student agency, academic self-efficacy, and biology self-efficacy while maintaining the depth of knowledge. A cognitive apprenticeship places the students in the position of a scientific researcher but provides for individualized scaffolding as students learn the necessary skills (Charney et al., 2007; Collins et al., 1991). Additionally, it provides a supportive environment where students and the teacher work together to answer questions generated by the students (Collins et al., 1991). Since both self-efficacy and agency are associated with increased academic success, a program designed to improve both measures should increase student success in the remainder of high school and into college (Bandura et al., 1996; Eymur, 2018; Pastorelli et al., 2001).

Theoretical Framework and Related Literature

This study is situated within a framework of situated cognition (Brown et al., 1989) with the goal of providing a cognitive apprenticeship (Collins et al., 1991) experience for the students. Situated cognition assumes that the acquisition of knowledge is fundamentally linked to the context in which that knowledge will be used (Brown et al., 1989) and, therefore, can link both individual and social learning. In a classroom, the students become a part of a community of scientists using the science practices (*NGSS Lead States*, 2013) in the same way that working scientists use the practices. In this environment, students are required to explain and then defend conclusions to peers and instructors using data developed in experiments and other research in the same way that scientists submit papers for peer review. Collins et al. (1987) proposed a pedagogy that applied the strengths of the apprenticeship to the development of conceptual knowledge which they termed 'cognitive apprenticeship.' Instructors using a cognitive apprenticeship model must externalize the underlying cognitive skills that make up most academic tasks so that students can clearly see how the expert moves through the process being taught. As the student practices, the expert provides guidance and gradually releases control of the process to the student as skill improves (Brown et al., 1989; Collins et al., 1987). While Collins et al. (1987) focused on reading and writing, others have expanded the concept into physics (Kapon, 2016), chemistry (Putica & Trivic, 2016), mathematics (Hennessy, 1993), and medicine (Charney et al., 2007; Stalmeijer, 2015; Woolley & Jarvis, 2007). In general, these studies show an increase in student engagement, ability to apply knowledge to real-world problems, and increases in content knowledge over traditional, lecture-based classrooms.

Self-Efficacy

A person's belief in their own abilities to carry out particular actions in specific environments has been termed self-efficacy (Bandura, 1977, 2012). Personal experiences of success, seeing peers experience success, encouragement from peers and instructors, and reductions in fear and/or anxiety have all been shown to increase self-efficacy (Ainscough et al., 2016; Bandura et al., 1996). Academic self-efficacy can influence performance on tests, presentations, or other required assessments. The effect is particularly marked when the ability level is low, with the percent of correct answers increasing from just below 20% for students with low self-efficacy to over 40% for students with high self-efficacy (Bandura, 1993).

Science Self-Efficacy

The confusion caused when students encounter the complexity and ambiguity of scientific knowledge as they move into high school and the increasing importance of standardized tests may influence the reduced level of science self-efficacy. Lin (2021) explored the interplay between science self-efficacy and engagement. The author states "in order to deeply engage learners in science learning, promoting their science learning self-efficacy from various aspects is of great importance" (Lin, 2021, p. 1201). Ainscough et al., (2016) showed that science self-efficacy can be increased over the length of an introductory biology course by 26% by designing the course to include personal successes, termed mastery experiences (Ainscough et al., 2016).

Student Agency

Opportunities for agency (making choices) increase from middle school to high school and on into college. Without the belief that academic success is possible, the choice to spend time going to class or on homework becomes more difficult. At school, most classes are completely planned by teachers and there are few, if any, choices for the student to make. Thus, when confronted with a teacher asking them to pick a topic they want to study for a long-term research project, the students simply sit and stare. Even choosing the order in which to complete a series of tasks can seem overwhelming (Tringali, 2020). With more schools offering synchronous and asynchronous online coursework, agency is becoming more critical for students.

Cavagnetto et al. (2020) describe agency in science as "active participation in knowledge generation as a function of learning" (p. 128) and use the term authorship. Whether consciously or unconsciously, students balance the potential costs of agency/authorship against the benefits (Cavagnetto et al., 2020). To support this type of student agency, classrooms must adhere to social norms that allow students to feel safe enough to share ideas and critique the ideas of others without critiquing the person sharing the idea.

Methodology

This study was intended to test the effectiveness of a classroom-based cognitive apprenticeship (CAC) program for teaching biology to ninth-grade students. The research questions under investigation during this study were:

1. How, if at all, does a CAC affect student agency?
2. How, if at all, does a CAC affect student academic and Biology self-efficacy?

Study Participants

The study took place at a small private independent school in the suburban Southeast. The school enrolls students from preschool through twelfth grade and has approximately 500 students, of whom 150 are in high school. All ninth-grade students are enrolled in one of three sections of Biology/Honors Biology which are all taught in a mixed-level classroom by the same instructor. In the 2022-2023 school year, there were 42 students enrolled in CAC Biology/Honors Biology.

Data Collection

All instruments chosen for quantitative data collection have been previously published and validated and were administered at the beginning of the year, at the semester break, and at the end of the year. Instruments were presented as electronic forms and the students completed each on a different day. Agency was measured using a subset of the questions embedded within the surveys for Academic self-efficacy (Pastorelli et al., 2001) and Biology self-efficacy (Baldwin et al., 1999). Academic self-efficacy was measured using a subset of the Children's Perceived Academic self-efficacy instrument originally developed by Bandura (1993). Biology self-efficacy was assessed using the Non-majors Self-efficacy in Biology survey developed by Baldwin et al. (1999). Qualitative data was obtained from student reflections completed at the end of each unit and coded separately for self-efficacy and student agency.

Results and Discussion

At the beginning of the 2022-2023 year, students entering the CAC performed significantly lower on Biology self-efficacy than students in the 2021-2022 school year (71.45 ± 1.83 vs 77.44 ± 2.20). By the end of the year, there was no longer a significant difference. Biology self-efficacy showed a significant increase for students in the CAC (See Table 1). Honors Biology students (10.32 ± 2.19) made significantly greater gains in Biology self-efficacy than Non-honors students (2.83 ± 2.49) in the CAC (See Table 2) even though all students were enrolled in mixed-level CAC sections.

Table 1

Change in Biology self-efficacy from August to May

	Biology Self-efficacy	
	Fall	Spring
2021-2022 (non-CAC)	77.44±2.20*	82.37±2.94
2022-2023 (CAC)	71.45±1.83	77.67±2.09**

*p < 0.05 – compared to Fall 2022-2023)

**p < 0.01 – compared to Fall 2022-2023

Table 2

Average change in Biology self-efficacy between Honors and Non-honors students

School Year	Change in Honors Score	Change in Non-honors Score
2021-2022 (non-CAC)	3.79 ± 4.57	6.15 ± 2.55
2022-2023 (CAC)	10.32 ± 2.19*	2.83 ± 2.49

*p < 0.05 – compared to Change in Non-honors Score

Implications

Given the lack of change in agency for Honors students, providing different, higher-level practice and a greater emphasis on data analysis along with explicit instruction on group interactions might provide the intellectual stimulation needed to build student agency. Another possible issue is self-regulation. Many Honors students have been able to complete assignments with little effort or time expenditure during middle school and carry those habits into 9th grade. When suddenly faced with the need to do more work or to work differently, they may struggle to change long-standing patterns of behavior. Previous work showed that Honors students tend to be less open to changes in typical classroom operation, possibly because they had been successful in a traditional class (Byford, 2013). Non-honors students, on the other hand, have typically been less successful in traditional classrooms and may be more willing to try a new format. However, those students may need additional scaffolding, particularly early in the school year, to build foundational skills, including executive function, and to reduce the perceived risk of failure.

It is unclear which aspects of the CAC led to these effects, but several aspects could be implemented in the context of a more traditional inquiry-based classroom. These aspects are concisely stated by Roth and Bowen (1995, p.75):

1. Participants learn in contexts constituted in part by ill-defined problems.
2. Participants experience uncertainties, ambiguities, and the social nature of scientific work and knowledge.
3. Participants' learning (curriculum) is predicated on and driven by current knowledge state (whatever that might be).
4. Participants experience themselves as part of communities of inquiry in which knowledge, practices, resources, and discourse are shared.
5. In these communities, members can draw on the expertise of more knowledgeable others, whether they are peers or advisors (Roth & Bowen, 1995).

Since Biology self-efficacy did increase in the CAC, the practices associated with strengthening self-efficacy (Bandura, 1977) should be maintained. These practices included providing early successes, particularly for students in Non-honors Biology and those with LPs. Vicarious experiences and verbal persuasion exist naturally in a mixed level classroom but should be deliberately fostered. Finally, agency should be supported by explicitly teaching groupwork.

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TEACHING THE AGE OF THE EARTH: SCIENCE TEACHERS NEGOTIATING INTERNAL CONFLICTS

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Abstract

In this study, we examine the worldviews of pre-service science teachers who are negotiating scientific theories that may conflict with their religious ideology. Data are drawn from a survey of 96 pre-service secondary science teachers in which they express their beliefs about the Earth. Quantitative results indicate that 53% of participants have conflicts between Old-Earth and Young-Earth beliefs. Qualitative data suggest that either religion or science classes construct their worldviews. While plate tectonics was mostly agreed upon, the geologic time scale was challenged. This research will inform educators of the scientific evidence and religious ideology influencing views of pre-service science teachers.
Keywords: Young Earth, Teacher perceptions, Religion, Teacher education

Introduction

A scientific theory is a well-supported explanation of a natural phenomenon. For example, germ theory explains why we have communicable diseases, cell theory explains what all living organisms are composed of, and atomic theory explains what matter is made from. Science teachers teach these theories to meet state standards, but most U.S. state science standards include some scientific theories which some teachers may find challenging to teach, as the theories conflict with some Jewish or Christian interpretations of ancient religious texts (e.g. Big Bang, evolution, geologic time scale). Teaching these theories in K12 science classrooms is important because they help students understand Earth's history and interpret current issues in the context of what has happened in the past (Teed & Slattery, 2011). Additionally, understanding these theories is positively correlated with general attitudes towards science (Allum et al., 2008). Surveys of U.S. adults indicate that 52% do not think that humans evolved from simpler organisms, and 61% reject the Big Bang theory (Besley & Hill, 2020). The results of a Gallup poll in 2017 indicate that 38% of U.S. adults think that the Earth is less than 10,000 years old (Swift, 2017). Since 70% of the American population considers themselves religious (Pew Research Center, 2022), interpretations of ancient, religious texts can impact how and what science is taught in schools (Mansour, 2008).

Purpose of the Study

The purpose of this study is to determine what impacts science teachers' beliefs about Earth's natural history. To improve scientific literacy, university science teacher educators need to know the views K-12 science teachers might hold so they can design appropriate instruction. The research questions are: 1. What are pre-service secondary science teachers' beliefs about Earth's natural history? 2. What influences pre-service secondary science teachers' beliefs about Earth's natural history? 3. How do secondary science teachers negotiate teaching scientific theories related to Earth's natural history when their interpretations of ancient religious texts are in conflict?

Related Literature

Young-Earth creationism as espoused by *some* Judeo-Christian adherents (Rupke, 2002) is a belief that the Earth was created by a "theistic Being who has causally acted both during and after its initial formation" about 6,000 years ago (Ross, 2005, p. 322). Pre-service science teachers' Young-Earth beliefs prevent them from accepting the theories supported by the scientific consensus (Govender, 2017). Teachers with strong Young-Earth views are less willing to teach the Big Bang in their classroom (Christonasis et al., 2023). Newall and Reiss (2023) interviewed pre-service teachers about their acceptance of evolution in relation to their religious beliefs and found that they found it difficult to accept the time that evolution requires. Rutledge and Mitchell (2002) surveyed biology teachers in Indiana to examine their knowledge, acceptance, and teaching of evolution, and found that religious views and prior classroom experiences could be attributed to low teacher participation in standards that address evolution. A considerable amount of literature exists of studies that investigate undergraduate student perspectives regarding the intersection of science and religion. (Artez et al., 2016; Mantelas and Mavrikaki, 2020; Manwaring et al., 2015). This study adds to the current literature since it teases apart which topics some preservice science teachers may not agree with in light of their interpretation of religious texts.

Methodology

In this qualitative study, pre-service teachers, university students enrolled in a science methods class, took an anonymous survey on the first day of the semester so that their professor could determine their beliefs about Earth's natural history and teach with sensitivity according to the findings, being careful not to drive a wedge between herself and any students holding Young-Earth opinions. See Figure 1 for a copy of the instrument. The university where participants were enrolled is a state university in the southeast region of the United States and participants were a variety of undergraduate and graduate students enrolled in a secondary science teacher preparation program. Institutional Review Board permission to analyze anonymous, extant data, was secured. The survey had been distributed seven times between 2014 and 2024, with a total of 96 participants. The survey was developed by the first author, and items in the survey were based on existing surveys of science literacy (Cotner et al., 2010; Dunlop, 2000; Mant, 2006). The survey items pertained to common scientific conceptions about the geologic time scale, evolution, and the formation of the universe as well as viewpoints expressed by some Young-Earth creationists (Answers in Genesis, 2024).

Figure 1

The survey, Opinions about Earth and Time.

Check the statement you agree with.

	Column A	Column B	
☐	☐ The Earth is about 6000 years old.	☐ The Earth is about 4.5 billion years old.	☐
☐	☐ Life on Earth began with multicellular organisms.	☐ Life on Earth began with single celled organisms.	☐
☐	☐ Dinosaurs and humans co-existed at one point in time.	☐ Dinosaurs went extinct millions of years before humans existed.	☐
☐	☐ The Grand Canyon was formed during a flash flood or some other catastrophic event.	☐ The Grand Canyon was formed slowly over 4 million years as the Colorado Plateau rose and water eroded away the land.	☐
☐	☐ The continents remain almost in the same positions that they were when they formed.	☐ The continents have shifted significantly since they were first formed.	☐
☐	☐ Heavy metals such as lead, cadmium and mercury have always existed since the beginning of the universe.	☐ Heavy metals such as lead, cadmium and mercury form when stars become supernovae.	☐
☐	☐ Coal and oil deposits formed about 4000 years ago when superheated water came up out of the Earth.	☐ Coal and oil formed over millions of years as plant matter decayed and was subject to pressure and heat.	☐

Optional: Explain how you decided between choosing mostly Column A options and/or mostly Column B options.

In Column A of the survey, Young-Earth viewpoints are expressed, and in Column B, Old-Earth viewpoints are expressed. Participants were asked to check the viewpoints that they espoused and leave a comment explaining how they made their choices. The comment portion was optional since the responses were handwritten, and students might not want to be identified by their penmanship. Results were tabulated on a spreadsheet and analyzed by looking at frequency as well as the ratio of Young- to Old-Earth viewpoints. Comments were open coded in NVivo.

Data were analyzed by computing the frequency with which certain statements were chosen as well as computing the ratio between Young- and Old-Earth viewpoints. The textual explanations written on the surveys were transcribed and examined. This qualitative study involved an analysis of written and selected data (Braun & Clark, 2006). Textual data were open coded using NVivo. Coding is a qualitative research activity whereby text is classified with labels, and similar codes are then grouped into themes. Themes were examined in light of the research questions.

Results and Discussion

Question 1: What are pre-service secondary science teachers' beliefs about Earth's natural history?

Thirty nine percent of participants held completely Old-Earth viewpoints, selecting all the statements in Column B on Figure 1. Eight percent of participants held completely Young-Earth viewpoints, selecting all the viewpoints in Column A. The remaining 53% held a mixture of the two. Twenty percent selected the statement, "The Earth is about 6000 years old," while 36% indicated that humans and dinosaurs coexisted, and 30% indicated that life on Earth began with multicellular organisms. Table 1 displays the percentage of participants who chose each statement. Percentages of opposing statements do not always sum to 100% since some participants did not select either one.

Table 1

Percentage of participants who chose each item.

Statement	Percent
The continents remain almost in the same positions as when they were formed.	5%
Coal and oil deposits formed about 4000 years ago when superheated…	18%
The Earth is about 6000 years old.	20%
The Grand Canyon was formed during a flash flood or some other….	24%
Life on Earth began with multicellular organisms.	30%
Heavy metals such as lead, cadmium and mercury have always existed.	31%
Dinosaurs and humans co-existed at one point in time.	36%
Heavy metals such as lead, cadmium and mercury form when stars…	49%
Dinosaurs went extinct millions of years before humans existed.	64%
Life on Earth began with single celled organisms.	67%
The Grand Canyon was formed slowly over 4 million years as the…	76%
The Earth is about 4.5 billion years old.	78%
Coal and oil formed over millions of years as plant matter decayed…	79%
The continents have shifted significantly since they were first formed.	79%

The average scientific view score (SVS) was computed for each participant, where an average of 1 indicates that all Old-Earth views were chosen, and a 0 indicates that all Young-Earth views were chosen. While 39% of participants had an average SVS of 1, 30% of the participants had an average SVS beneath 0.60.

Table 2

Distribution of average scores

Range of scientific view scores	Frequency	%
0 (totally non-scientific)	8	8%
between 0 and .2	8	8%
between .21 and .4	2	2%
between .41 and 6	11	11%
between .61 and 8	18	19%
between .81 and .99	12	13%
1 (totally scientific)	37	39%

Question 2: What influences pre-service secondary science teachers' beliefs about Earth's natural history?

Sixty-one (64%) of participants left comments on their surveys. Open coding of these comments revealed that the primary influence on participants' beliefs is science classes, particularly geology classes, followed by a scientific mindset, with 26% of participants stating that the Bible, their church, religion, faith, or belief in a divine creator influenced their opinions. The most common of these religious statements was that the Bible influenced them.

Table 3

Primary influences of opinions

	Frequency	Percentage
Personal belief	1	2%
Reading Science Texts	3	6%
General knowledge	6	11%
Religion	14	26%
Science Mindset	14	26%
Science Classes	16	30%

Examples from statements related to science classes or a scientific mindset include:

"I have taken enough geology and other science classes to have learned these things and I trust my teachers' knowledge." Participant 1701, SVS=0.78

"I chose column B because I was taught these "things" in my geology courses and growing up in grade school." Participant 1709, SVS=1.0

Participants with a SVS less than 0.5, with Young-Earth viewpoints made statements such as:

"Because I believe in the Bible and what the Bible tells me." Participant 1801, SVS=0.0

"I believe in the Bible and not everything science says." Participant 1601, SVS= 0.33

"I chose those answers based on my faith in God and best interpretation of the Bible." Participant 1414, SVS = 0.29

"These are simply my beliefs. I am a Christian and believe that the Bible is God's word and I can trust it." Participant 1801, SVS = 0.0

"Truthfully, I believe in the story of creation so whatever I thought best aligned with that." Participant 2403, SVS 0.14

It is interesting to see where science and religion seem to be in conflict, as if some participants believe some things from their science and geology classes, but not others. Of the 19 participants who selected, "The Earth is about 6000 years old", 10 (53%) also selected "The continents have shifted significantly since they were first formed." This seems to indicate that many participants with Young-Earth views cannot dismiss plate tectonics or think that continents shifted much quicker than what is stated in the current scientific literature (Palin & Santosh, 2021). For example, Participant 2403, quoted above, selected all Young-Earth statements *except* for the one about plate tectonics. Only 5% of all participants overall selected, "The continents remain almost in the same positions that they were when they formed."

Question 3: How do secondary science teachers negotiate teaching scientific theories related to Earth's natural history when t**heir interpretations of ancient religious texts are in conflict?**

Some of the participants with Young-Earth views stated that they would still teach the scientific facts and opinions even though they are in opposition to their own beliefs. The following quotes illustrate this.

"Even though I personally believe one way does not necessarily influence what I present to students." Participant 1701, SVS = 0.77

"I will never infringe on anyone's beliefs or thoughts and I will teach the curriculum I am provided."

Participant 1902, SVS = 0.0

Some participants found a way to justify both a scientific and a non-scientific worldview by combining them. For example, "*Life began with both multicellular and single celled organisms at the same time*." Participant 1402, SVS = 0.29, or "*I ride the fence a lot for example: I think that the world was created ~6000 years ago but was made already old*." Participant 1601, SVS = 0.33. The survey, as constructed, does not allow for the selection of nuances such as this one.

A particularly interesting finding was that 35 (36%) of participants stated that they thought dinosaurs and humans co-existed. Half of these (N=17) stated that the Earth is about 6000 years old and the other half had mixed beliefs. Given this, while half of the "dinosaur cohabitants" held Young-Earth beliefs, some participants with mostly Old-Earth viewpoints also stated that dinosaurs co-existed with humans.

It is not clear how participants negotiate holding both Young- and Old-Earth viewpoints at the same time, and we plan to uncover this dichotomy by conducting interviews with teachers who ascribe to a mostly Young-Earth worldview.

Implications

Preservice science teachers in this study overwhelmingly believed that the continents have shifted since time on Earth began. Participants who held three or more Young-Earth opinions, never chose the "Life began with single celled organisms" statement, but 67% of them chose the "The continents have shifted significantly since they were first formed" statement. Since more than half of the strongly young Earth participants also agreed that the continents have shifted, it could be productive for faculty who prepare science teachers to lean into the science of tectonic plates to convey scientific knowledge pertaining to the age of the Earth.

Additionally, there seems to be some confusion about when dinosaurs existed versus when humans came onto the scene. While most of the believers in a dino/human world were also Young-Earth believers, half were not, indicating the need to further educate pre-service science teachers about the geologic time scale.

While 8% of participants were strictly on the Young-Earth side of the spectrum, 53% fell somewhere in the middle and 39% were completely in line with current, Old-Earth scientific viewpoints (as described in Palin & Santosh, 2021). Science education faculty could use the science supporting plate tectonics in discussions about the geologic time scale to help pre-service science teachers with mixed views understand the scientific consensus.

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EXPLORING THE IMPACT OF TEACHER CURIOSITY ON JOB SATISFACTION AND SELF-EFFICACY

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Abstract

This study investigated the relationship between teacher curiosity, job satisfaction, and teacher self-efficacy among teachers of STEM subjects. The findings indicate a correlation between teacher curiosity and job satisfaction, suggesting that educators with higher curiosity experience greater job satisfaction. A low correlation was identified between teacher curiosity and teacher self-efficacy.

Keywords: teacher curiosity, teacher self-efficacy, job satisfaction, sources of self-efficacy

Introduction

Curiosity has been defined as "the desire to know, to use, to see, or to experience that motivates exploratory behavior directed towards the acquisition of new information" (Litman, 2005, p. 793). Curiosity has been researched both in education in general and in STEM education (Binue et al., 2020; Cohen, 2019; Ford, 2018; Healy, 2004; Knuth, 2002; Lamnina & Chase, 2021; Pace, 2012; Peterson & Vigeant et al., 2018). Each study investigated some aspect of the importance of curiosity on learning whether it be motivation/engagement or retention. There has also been ample research on the benefits of curiosity in the workplace (Gino, 2018; Hamilton, 2019; Kashdan et al., 2020; Mussel, 2013; Reio & Callahan, 2004; Reio & Wiswell, 2000). These studies have identified the critical benefits of curiosity to work production, job satisfaction, innovation, and its role in healthy work relationships.

While there has been significant research in the study of curiosity of students and employees in the business sector, there exists an opportunity to explore the potential importance of curiosity among STEM educators. Prior research has identified a relationship between teacher self-efficacy and job satisfaction (Karabatak & Alanoglu, 2019; Skaalvik & Skaalvik, 2004; Toropova et al., 2021). Research has also shown a connection between teachers with low self-efficacy having increased teacher burnout (Hurley, 2021). This study seeks to connect the research on workplace curiosity and educational curiosity by exploring the relationship between STEM teacher curiosity, teacher self-efficacy, and job satisfaction.

Objectives of the Study

The purpose of this study was to provide a research-based foundation for the importance of curiosity of STEM teachers. The research questions were: (1) What relationships exist, if any, between the curiosity of teachers of STEM subjects and teacher self-efficacy? (2) What relationships exist, if any, between the curiosity of teachers of STEM subjects and teacher job satisfaction? And (3) What relationships exist, if any, among teacher curiosity, teacher self-efficacy, and sources of self-efficacy for teachers of STEM subjects?

The first research question aimed to fill the research gap about the relationship between teacher curiosity and teacher self-efficacy. Many of the positive outcomes associated with teacher self-efficacy are also related to the benefits of curiosity in the workplace. The second question looked specifically at the relationship between teacher curiosity and job satisfaction. While there are already studies confirming the relationship between teacher self-efficacy and teacher job satisfaction, no available research existed on the link between teacher curiosity and job satisfaction. The third question sought to further explore the relationship between teacher curiosity and teacher self-efficacy by looking deeper at the potential relationship between sources of teacher self-efficacy and teacher curiosity. Understanding the association between a teacher's curiosity and their source of self-efficacy may provide valuable information that could help educational leaders with professional development and teacher training and hiring processes.

Related Literature

Workplace curiosity has been researched for the last thirty years in the business sector. Curiosity has been shown to be deeply related to creativity and innovation, job satisfaction and performance, and collaboration and social benefits in the workplace. In a study that created a tool for measuring curiosity, Hamilton said, "We can correlate curiosity with engagement, emotional intelligence, innovation, and productivity" (2019, p. 2). Another workplace curiosity study used an assessment to measure four dimensions of workplace curiosity including joyous exploration, deprivation sensitivity, stress tolerance, and openness to people's ideas (Kashdan et al., 2020b). These dimensions predicted outcomes including job satisfaction, work engagement, healthy work relationships, and innovation. In an article in the Harvard Business Review, Gino (2018) conducted a study of more than 3,000 employees from different industries. Gino reported that employees with higher curiosity make fewer decision-making errors, are more innovative and creative, and reduce group conflict.

There is significant research on the important role of curiosity in schools. Research examining what makes students successful in school looks at different factors. While there is research on the importance of intelligence and conscientiousness, von Stumm et al. (2011) proposed evidence to support that curiosity is the third pillar of predicting academic achievement. In their meta-analysis, they showed that curiosity plays a significant role in student achievement. Additionally, researchers looked at the role of curiosity in the development of memories and retention of learning (Gruber & Fandakova, 2021). The research showed that as the brain develops further in childhood, adolescents' curiosity both elicits and enhances memory. Another benefit of curiosity in the classroom is the effect it has on the relationship between students and teachers. In a study of 518 public school teachers across the United States, curiosity and demographics were analyzed to look for barriers to building positive student relationships (Neto et al., 2022). The results showed that more curious teachers also appear more interested in connecting with students and getting to know them.

Teacher self-efficacy is defined as a "teacher's judgment of his or her capability to bring about desired outcomes of student engagement and learning, even among those students who may be difficult or unmotivated" (Tschannen-Moran & Hoy, 2001). Teacher self-efficacy has been linked to many positive outcomes for teaching and learning. It has been linked to lower stress and higher job satisfaction (Karabatak & Alanoglu, 2019). Furthermore, it is a predictor to counteract teacher burnout (Dexter & Wall, 2021), and it has been linked to higher student achievement (Mojavezi & Tamiz, 2012).

Where does a teacher's self-efficacy originate from? Bandura (1999) identified four sources of self-efficacy including mastery experience, vicarious experience, social persuasion, and physiological/affective states. Mastery experience involves direct personal action as the means to achieve one's goals (Morris et al., 2017). Vicarious experiences are when learning occurs by observing an influential person performing the targeted behavior (Bandura, 1999) Social or verbal persuasion is based on comments that a person receives about their performance (Bandura, 1999). Physiological and affective states, also called emotional and physical arousal, refer to the way a person feels while performing a task whether the person directly relates that feeling to the task or not (Bandura, 1999).

Methodology

This action research study took place in an urban school district. The study was a nonexperimental quantitative study which was descriptive as the data was used to look for correlations and relationships among variables without any interventions. The participants in this study were preK-5 teachers and 6-12 science, math, and technology teachers. All teachers of STEM subjects in the district were invited to complete the survey and 96 ended up completing the survey.

The survey was sent to 303 teachers within the targeted district. The requirement to be included in the survey was that the teachers taught at least one STEM subject, including science, technology/digital literacy, engineering, and mathematics. In total there were 96 research participants. 53 participants or 55.2% identified themselves as PreK-5 or elementary teachers and 43 participants or 44.8% identified themselves as 6-12 or secondary teachers.

The participants were given a four-part survey, consisting of items from research validated studies. The tool used to measure curiosity was the five-dimensional curiosity scale (5DCR) which has been used in other studies of employees in noneducational settings (Kashdan et al., 2018). To measure teacher self-efficacy, the teacher self-efficacy scale (TSES) was used, developed by Tschannen-Moran and Hoy (2001). Teachers were asked to consider their practice of teaching STEM subjects while answering the survey. The tool used to measure teacher job satisfaction was created by Troeger (2021) called the Teacher Job Satisfaction Survey or TJSS. This survey includes factors like supervision, colleagues, working conditions, pay, responsibility, work itself, advancement, security, and recognition. The section about job satisfaction as it relates to teaching was the only section used. The tool used to identify the sources of self-efficacy is the Sources of Teacher Efficacy Questionnaire (STEQ) created by Hoi et al. (2017) to measure sources of self-efficacy for Chinese teachers. This tool was developed and validated to identify the four sources of self-efficacy specifically for teachers.

Results and Discussion

A Pearson Correlation Analysis was to measure the strength of the relationship between the variables. The results are included in Table 1 listed below.

Table 1

Pearson correlation analysis for Job Satisfaction

______ vs. Job Satisfaction	N	Pearson r	r^2	p	Correlation
Average Curiosity	96	0.57	0.33	<0.001	Moderate, positive
Average Self-Efficacy	96	0.34	0.11	0.001	Low, positive

Prior research has examined the relationship between teacher self-efficacy and job satisfaction (Karabatak & Alanoglu, 2019; Skaalvik & Skaalvik, 2004; Toropova et al., 2021). These results confirm that there is a correlation between job satisfaction and teacher self-efficacy. The results also show that for the sample population there is a higher correlation between curiosity and job satisfaction with a moderate positive correlation than teacher self-efficacy. The correlation between curiosity and self-efficacy was $r=0.51, p>0.001$ which is a moderate positive correlation.

Table 2 and Table 3 show the results of a Pearson Correlation Analysis when looking at curiosity and each source of self-efficacy, teacher self-efficacy, and the source of self-efficacy.

Table 2

Curiosity and Sources of Self-Efficacy

	n	r	r^2	p.	Correlation
Mastery Exp	96	0.21	0.05	0.038	Little, positive
Vicarious Exp	96	0.22	0.05	0.034	Little, positive
Social Persuasion	96	0.23	0.05	0.026	Little, positive
Physiological and Affective States	96	0.34	0.11	0.001	Low, positive

Table 3

Sources of Self-Efficacy and Average Self-Efficacy

Source of Self-Efficacy vs. Teacher Self-Efficacy	n	r	r^2	p	Correlation
Mastery Experience	96	0.43	0.18	<0.001	Low, positive
Vicarious Experience	96	0.3	0.09	0.003	Low, positive
Social Persuasion	96	0.47	0.22	<0.001	Low, positive
Physiological and Affective States	96	0.28	0.08	0.006	Little, positive

The relationship between sources of self-efficacy and curiosity showed for all sources there is a low or little correlation with curiosity. The results also indicate that social persuasion had the highest correlation with teacher-self-efficacy followed by mastery experience, vicarious experience, and physiological and affective states respectively.

Implications

It is critical to the future of STEM education, to not only be able to recruit and train highly effective teachers but to develop these educators in a way that keeps them in the field of education and satisfied. There have been studies focused on curiosity for employees in business (Gino, 2018; Hamilton, 2019; Kashdan et al, 2020; Mussel, 2013; Reio & Callahan, 2004; Rio & Wiswell, 2000), but the results of this study indicate that teacher curiosity is important to keeping teachers satisfied in their roles as STEM teachers.

Educational leaders and administrators should have a goal to create a climate of curiosity in their schools, not just for their students but for their educators as well. Kashdan et al. (2018), highlighted the importance of autonomy to curiosity. Teachers should be encouraged to be creative and add their personal touch and interests to the classroom. This might look like providing teachers a percentage of the year that they should be using the district or school curriculum, but also allowing for times when teachers can explore their curricular interests and passions with students.

Teacher autonomy is not only important to curiosity through lessons but through professional learning also. The use of action research professional learning would allow teachers to identify problems of practice that they are interested in exploring, collaborate with other educators, research potential solutions, try them out with their students, and share their results with colleagues and the school community. In a study exploring collaborative action research of science educators, findings revealed that the structure of action research professional learning enabled the teachers to view professional learning in a new and positive way (Bilican et al., 2021). Future research might look at the impact of using action research professional development on teacher curiosity.

Another implication pertains to how educators and educational leaders are hired. Curiosity in both the classroom and in school culture is only achieved by intentionality. This means that it must be a priority for those who are hiring teachers and leaders in education. Interview questions for teachers and educational leaders may include asking both about their curiosity and about how they will intentionally plan to foster student curiosity.

Further research would be needed to understand the impact of curious teachers on their students. Are curious teachers more effective than less curious teachers? Is there an optimal curiosity profile considering the various dimensions of curiosity that make a teacher more effective? Future research could be done to see how teacher curiosity impacts student curiosity over both a year, and longitudinally through a student's time in education. Building directly on this study, future research could be done around practices that influence teacher curiosity. Can a teacher's curiosity, like a student's, be nurtured and grown over time?

This study only begins to scratch the surface on the potential importance of teacher curiosity. By re-examining relationships and systems in education from the lens of curiosity, education research may begin to reconsider how the educational environments can encourage and impact the learning culture of schools for students and educators alike. The results may bring about structural and policy changes that help to build climates of curiosity and lifelong learning.

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