SSMA

Under the Big Sky:
Where BIG STEM Ideas come to Life!!

Photo Credit: Luke Davis

Proceedings - Volume 9

120st Annual Convention

October 36-39, 2022

Missoula, MT

Julie Herron and
Rebekah Hammack

Editors

PROCEEDINGS OF THE 121ST ANNUAL CONVENTION OF THE SCHOOL SCIENCE AND MATHEMATICS ASSOCIATION

October 26-29, 2022

Missoula, MT

Editors: Julie Herron and Rebekah Hammack

Cite Proceedings Volume as:

Herron, J. & Hammack, R. (Eds.). (2022). *Proceedings of the 121st annual convention of the School Scienceand Mathematics Association* (Vol. 9). Missoula, MT: SSMA.

Cite Proceedings Chapter as:

Author. (2022). Title of chapter. In J. Herron & R. Hammack, (Eds.). *Proceedings of the 121st annual convention of the School Science and Mathematics Association* (Vol. 9). Missoula, MT: SSMA.

Website: www.ssma.org

The proceedings are also available via http://www.ssma.org/convention-proceedings

Copyrights © 2022 left to the authors

Articles published in the Proceedings are copyrighted by the author. Permission to reproduce an article or portions from an article must be obtained from the author.

All rights reserved

ISBN: 978-1-7343159-3-6

SSMA 2022 ANNUAL CONVENTION: MISSOULA, MT

2022 Convention Coordination

Convention Chairs
Georgia Cobbs, University of Montana
Rayelynn Brandl, Montana Tech – Clark Fork Watershed Education Program
Rebekah Hammack, Montana State University

SSMA Leadership

President, 2020-2022
Christa Jackson, Saint Louis University

President-Elect, 2021-2022
Margaret Mohr-Schroder, University of Kentucky

Directors-at-Large, 2019-2022
Oscar Chavez, Illinois State University
Craig Schroeder, Fayette CTY Public Schools

Directors-at-Large, 2020-2023
Susan Cooper, Florida Gulf Coast University
Stephen Scogin, Hope College

Directors-at-Large, 2021-2024
Dittika Gupta, Midwestern State University
Rebekah Hammack, Montana State University

Co-Executive Directors, 2019-2023
Stephanie Hathcock, Oklahoma State University
Toni Ivey, Oklahoma State University

Journal Co-Editor, 2021-2026
Christie Martin, University of South Carolina
Bridget Miller, University of South Carolina

Newsletter Editor, 2020-2022
Georgia Cobbs, University of Montana

Proceedings Editors
Julie Herron, Augusta University
Rebekah Hammack, Montana State University

Special thanks to
The Publications Committee and SSMA members for reviewing and providing valuable feedback on the submitted manuscripts.

Herron, J. & Hammack, R. (Eds.). (2022). *Proceedings of the 121st annual convention of the School Scienceand Mathematics Association* (Vol 9.). Missoula, MT: SSMA

School Science and Mathematics Association
Founded in 1901

The School Science and Mathematics Association [SSMA] is an inclusive professional community of researchers and teachers who promote research, scholarship, and practice that improves school science and mathematics and advances the integration of science and mathematics. SSMA began in 1901, and for more than 120 years, SSMA has provided a venue for many of the most distinguished mathematics, science, and STEM educators to present research and publish manuscripts.

SSMA focuses on promoting research-based innovations related to K-16 teacher preparation and continued professional enhancement in science and mathematics. Target audiences include higher education faculty members, K-16 school leaders and K-16 classroom teachers. Four goals define the activities and products of the School Science and Mathematics Association:

- Building and sustaining a community of teachers, researchers, scientists, and mathematicians
- Advancing knowledge through research in science and mathematics education and their integration
- Informing practice through the dissemination of scholarly works in and across science and mathematics
- Influencing policy in science and mathematics education at local, state, and national level

The proceedings of the 121st Annual Convention serve as a testament to the Association's rich traditions and promising future.

Christa Jackson

Christa Jackson
SSMA President

Herron, J. & Hammack, R. (Eds.). (2022). *Proceedings of the 121st annual convention of the School Scienceand Mathematics Association* (Vol 9.). Missoula, MT: SSMA

PREFACE

These proceedings are a written record of some of the research and instructional innovations presented at the 121st Annual Meeting of the School Science and Mathematics Association held virtually October 27-30, 2021. The blinded, peer reviewed proceedings include ten papers regarding instructional innovations and research. The acceptance rate for the proceedings was 83%. We are pleased to present these Proceedings as an important resource for the mathematics, science, and STEM education community.

Julie Herron & Rebekah Hammack
Editors

Herron, J. & Hammack, R. (Eds.). (2022). *Proceedings of the 121st annual convention of the School Scienceand Mathematics Association* (Vol 9.). Missoula, MT: SSMA

TABLE OF CONTENTS
VOLUME 9

Recruiting Mathematics and Science Teachers: The UTM Noyce Scholars Program

Elliott S. Elliott
eelliot7@utm.edu
University of Tennessee at Martin

Abstract

This paper describes the first year of implementation of a Robert Noyce Teacher Scholarship Program project designed to obtain, train, and retain mathematics and science teachers for rural schools. The project explores the effectiveness of financial incentives, teacher preparation and mentorship, and recruiting techniques.

Keywords: recruiting, noyce, teachers, educator preparation

Introduction

The National Science Foundation's (NSF) Robert Noyce Teacher Scholarship Program provides funding to encourage individuals with STEM degrees to become K-12 teachers. This paper describes the implementation of a Noyce project at a regional comprehensive university in Tennessee. Throughout the paper, the university's project is called the "local program" to distinguish it from the overall NSF program. The local program was funded in spring 2021. The principal investigators (PIs) began recruiting individuals with bachelor's degrees in mathematics, science, or engineering, offering stipends to cover graduate school tuition. Recruited individuals called Scholars complete master's degrees in education, obtain educator licenses, and agree to teach for at least two years in a high need local education agency (LEA). As of fall 2022, the first recruit is in her first semester of teaching, and three more Scholars are completing graduate coursework. This report describes the first full year of the five-year project and outlines the research the authors will pursue during the project.

Objectives

There is a shortage of mathematics and science teachers in the local program's region. The U.S. Department of Education projects an increase in public school enrollment in Tennessee through 2027 (Hussar & Bailey, 2019). The Tennessee Department of Education (2017) projects that half the state's teachers will leave the profession or retire between 2017 and 2027, expanding an existing shortage. In 2018, a nearby LEA had no applications from May through August for a vacant chemistry teacher position. In spring 2022, all the mathematics teachers at a high school in one partner LEA quit their jobs, lured to positions in nearby districts.

As part of a national solution, the five-year local program seeks to obtain, train and retain 25 mathematics or science teachers. Because of its location, the local program focuses on recruiting for rural schools. Further, the local program attempts to answer four questions: Which populations are attracted to the local program? Which advertising and recruiting strategies work? What training helps STEM professionals become effective teachers? What factors lead to retention of STEM professionals in the teaching profession?

Theoretical Framework

The PIs drew from both education research and human resources literature to develop a recruiting strategy. Petty, Fitchett, and O'Connor (2012) described the role of financial incentives in attracting people to the teaching profession, so the local program offers a substantial stipend to attract STEM graduates. Human resource managers inform the local program's approach through the use of recruiting models. In particular, the SHRM Foundation describes a recruiting model with four steps: establish objectives, develop a strategy, carry out recruiting activities, and evaluate results (Breaugh, 2009). Readers familiar with George Pólya's four phases of problem solving (*understand* the problem, make a *plan*, *carry out* the plan, and *look back* at the solution) may recognize these steps as a specific application of a general idea (Pólya, 2004). Much as Pólya elaborated on the steps in the context of mathematics, Breaugh describes specific recruiting techniques that are useful for developing a strategy. The local program adopted some of these techniques as described in the Practice section below.

Petty et al. (2012) also described the importance of actual experience in high-need schools as part of training teachers to serve in these schools. The local program involves high need LEA partners where Scholars can conduct their student teaching. Preparation in the local program also includes growth mindset training to help Scholars understand that ability to learn is not a fixed trait and academic achievement can improve with effort (Dweck, 2008). There are also professional learning meetings to provide ongoing, collaborative experiences (Wei, Darling-Hammond, Andre, Richardson, & Orphanos, 2009).

In addition to effective training, Darling-Hammond (2003) emphasized the importance of mentoring to retain teachers. To help Scholars remain in the classroom beyond their legal teaching commitment, they receive formal mentorship in their first year in the classroom.

These earlier investigations inform the local program's practice to obtain, train, and retain mathematics and science teachers. In addition, the local program studies a specific group of aspiring teachers, college graduates with STEM degrees, in the context of this earlier research. Scholars complete a survey at several points during their training and during their first year in the classroom. The survey includes both free-response and Likert scale questions designed to determine how Scholars learned of the local program and what they find valuable about the local program and a teaching career. Completing the survey at multiple points in their training provides data about changes in Scholar attitudes over time. The first question on the survey asks “How did you hear about the program?” Scholars also respond to Likert items on a 5-point scale ranging from “strongly disagree” to “strongly agree.” These items include the following: “I planned to become a teacher before hearing of [the local program],” “Teaching is an easy job,” “Teaching is a worthwhile career,” “It is important for a new teacher to have a mentor,” and “The $29,000 stipend is about right as an incentive for a STEM major in West Tennessee to become a teacher.” The survey also asks Scholars to describe the importance of aspects of their training such as undergraduate coursework, graduate coursework, COMP training, growth mindset training, mentorship, and participation in professional organization meetings as Likert items using a scale ranging from “not at all important” to “extremely important.” The PIs ask similar questions in interviews or focus groups at several points during the Scholars’ training.

Practice

The local program attempts to recruit individuals who have completed bachelor’s degrees in biology, chemistry, computer science, engineering, geoscience, mathematics, or physics. As an incentive, a $29,000 stipend covers full tuition and fees, with a residue of approximately $5,000 that Scholars may apply to other expenses. Recruiting strategies include spots on college radio, PI visits to career fairs and meetings of student organizations, and posts on Instagram and LinkedIn. The PIs encourage STEM faculty at their own and neighboring universities to suggest the program to students. The PIs use messages developed by Get the Facts Out, an NSF-funded project promoting the teaching profession. University graphic designers created posters and rack cards for the program, and the PIs displayed these and sent copies to faculty and career development offices at neighboring universities.

A professor in the university’s Department of Communications assigned study of the local program as a capstone project in a marketing class for seniors. These marketing students measured levels of awareness of the local program among the university’s STEM students. The marketing students also studied how STEM students had learned of the program. The STEM majors learned of the program mainly through faculty and flyers or posters. The marketing students recommended sponsoring an internship. A marketing intern would focus on social media presence and a direct email campaign. The PIs are actively pursuing this internship as a way to obtain Scholars.

Classroom Examples

Noyce Scholars begin the local program in May and complete a 36-hour master's degree. The Master of Science in Initial Licensure (MSIL) degree is designed for completion in 18 months. Noyce Scholars take a heavy course load to complete the program in one calendar year. They complete 15 credit hours in the summer. In the fall, they take 12 credit hours and must pass a Praxis® exam in their content area. In the spring, student teaching accounts for six credit hours, and there is a single three-credit course. During student teaching, each Scholar submits an edTPA® portfolio. Additionally, Scholars complete Classroom Organization and Management Program (COMP) training during the spring term. The coursework, Praxis® and edTPA® assessments, and COMP training are requirements for all students in the MSIL program. Noyce Scholars complete training beyond these requirements.

Additional training includes MindsetMaker™ online professional development (PD), implicit bias awareness tasks, mentorship, and professional learning meetings. Grant funds pay for the growth mindset PD, and Scholars complete it during the summer term. Scholars complete two Project Implicit® tests during their orientation. These free tests prompt Scholars to "understand that one's own personal cultural lens impacts her/his interpretation of events" as called for by the National Education Association (2020, p. 2). By itself, this short-term event during orientation is unlikely to change behavior (Dobbin & Kalev, 2018). So, Scholars also explore implicit bias during their coursework and after licensure.

Once a Scholar finds a job, the local program finds an experienced teacher in the Scholar's school. The program pays this experienced teacher to act as a mentor for one year. In addition to their daily interactions, Scholars and mentors participate in formal professional learning meetings with the PIs throughout the Scholar's first year in the classroom. During one of these meetings Scholars work with mentors to develop specific ways to overcome implicit biases in their specific schools. Other meeting topics include assessment of student work and differentiation strategies. The goal is for this extended preparation and mentorship to lead to better retention of Scholars in the teaching profession than would otherwise be the case.

Implications

Recruiting Scholars is the most difficult part of the project to date. The local program set a goal to find 11 Scholars in its first two years but found only four. Future authors of Noyce grant proposals should seriously consider setting goals for a smaller number of Scholars than what they first imagine to be reasonable. Whatever the goal, faculty should be a key part of a recruiting plan to reach students. Three of the four Scholars in the local program indicated that they learned of the program from a faculty member. One mentioned seeing a poster advertising the local program, and two mentioned hearing about the program on the radio. Posters, radio advertising and social media are important, but this initial data indicate that college or university faculty are the most important resource for recruiting. All Scholars in the local program indicated that "a teacher I admired" was a very important or extremely important factor in their decisions to become teachers. The profession needs admirable teachers now to produce more teachers in the future.

Scholars rated all of their training as at least moderately important on a 5-point Likert scale with "moderately important" as the middle value. Scholars disagreed or strongly disagreed with the statement "An undergraduate STEM degree is adequate preparation to become a middle- or high-school teacher. Additional education-specific coursework is unnecessary." These initial data reflect Darling-Hammond's conclusion that preparation and mentoring are important factors in the retention of teachers (2003). Further, these data indicate that these factors are important with this subset of preservice teachers, college graduates with STEM degrees.

In the coming year the local program will establish a mentorship for the first Scholar and collect data to see if the mentorship program is effective. The PIs will continue to survey and interview Scholars as they complete graduate coursework to measure how their attitudes change toward components of training as they experience them. Finally, the local program will continue to seek innovative means to recruit more mathematics and science teachers.

References

Breaugh, J. (2009). Recruiting and managing talent: A guide to understanding and managing the recruitment process. Alexandria, VA: SHRM Foundation. Retrieved from https://www.shrm.org/hr-today/trends-and-forecasting/special-reports-and-expert-views/Documents/Recruiting-Attracting-Talent.pdf

Darling-Hammond, L. (2003). Keeping good teachers: Why it matters, what leaders can do. E*ducational Leadership, 60(8)*, 6-13.

Dobbin, F., & Kalev, A. (2018). Why Doesn't Diversity Training Work? The challenge for industry and academia. *Anthropology Now*, *10(2)*, 48-55. doi:10.1080/19428200.2018.1493182

Dweck, C. S. (2008). *Mindset: The new psychology of success*. New York, NY: Ballantine Books.

Hussar, W. J., and Bailey, T. M. (2019). *Projections of Education Statistics to 2027.* U.S. Department of Education, Washington, DC: National Center for Education Statistics.

National Education Association. (2020). Confronting implicit bias through exemplary educator preparation. doi:23840.4.18.cdk

Petty, T. M., Fitchett, P., & O'Connor, K. (2012). Attracting and keeping teachers in high-need schools. *American Secondary Education, 40(2)*, 67-88.

Pólya, G. (2004). *How to solve it: A new aspect of mathematical method* (Expanded Princeton Science Library edition). Princeton University Press

Tennessee Department of Education Office of Research and Strategy. (2017).*Preparation through partnership: Strengthening Tennessee's new teacher pipeline.* Retrieved from https://www.tn.gov/content/dam/tn/education/reports/Preparation_through_Partnership.pdf

Wei, R. C., Darling-Hammond, L., Andree, A., Richardson, N., Orphanos, S. (2009). *Professional learning in the learning profession: A status report on teacher development in the United States and abroad technical report.* Dallas, TX. National Staff Development Council.

Acknowledgements

Support is provided by the National Science Foundation's Robert Noyce Teacher Scholarship Program under Award No. 2049681. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

TEACHER CANDIDATES NOTICING SCIENCE

Christine G. Schnittka
schnittka@auburn.edu
Mark Brenneman
mab0164@auburn.edu
Danielle Hudson
hudsodl@auburn.edu
Auburn University

Abstract

Teacher candidates kept journals of the science they encountered in their daily lives for one semester. Most entries were on biology topics, and the most common NGSS science practices used were asking questions (AQ) and obtaining, evaluating, and communicating information (OEC). The most common biology topic was human physiology/health while the most common chemistry topic was water. The least used practices were analyzing and interpreting data (AID) and using mathematics and computational thinking (MCT). This motivating assignment helped teacher candidates develop their identity as scientists and helped them think about bringing everyday applications of science into their classroom lessons.

Keywords: NGSS practices, MUSIC model, scientific thinking, science teacher education

Introduction

Making sense of the science in the world around us is a critical skill, involving the careful examination of facts, making observations and inferences, and thinking critically. Thinking like a scientist does not only occur in the scientific laboratory; scientific thinking occurs in daily life, involving recognizing the science around us and making sense of it. Connecting everyday life to school science can lead to increased interest in science, better attitudes towards science, and better retention of scientific concepts (Hürcan & Önder, 2012). For students living in urban settings, making this connection is even more critical (Bouillon & Gomez, 2001; Warren et al., 2001).

Scientific thinking does not happen instantly, even if one knows the science content; it is complex, involving keen skills of observation, recognizing the relationships between variables, developing explanations from the observations and data collected, and generating reasonable explanations for those observations. This type of scientific thinking is represented in the NGSS Science and Engineering Practices (SEPs) (NRC, 2012) which describe the diverse ways that scientists and engineers approach their work. Science teachers are tasked with teaching science concepts within the framework of science practices (Kite, Park, McCance, & Seung, 2020). However, many science teachers do not understand scientific practices beyond the scientific method found in textbooks, even with the value placed on students being able to articulate and enact diverse practices (Russ, 2014). Students have misconceptions about scientific inquiry, seeing it as rigid and linear, do not understand the explanatory role of models, have a weak understanding of scientific argumentation, and rarely use computational thinking outside of data analysis (Kite et al., 2021). The eight SEPs, as described in the NGSS, are (1) asking questions/defining problems, (2) developing and using models, (3) planning and carrying out investigations, (4) analyzing and interpreting data, (5) using mathematics and computational thinking, (6) constructing explanations/designing solutions, (7) engaging in argument from evidence, and (8) obtaining, evaluating, and communicating information. While there is importance in the engineering-specific practices of defining problems and designing solutions, in this study, we only focused on the science practices.

In this study, preservice teacher candidates (TCs) enrolled in a methods course kept a science journal for one semester to document the scientific ideas, questions, observations, inferences, and investigations they encountered in their daily lives. The first author, their professor for the semester, responded to each journal entry with probing questions, suggestions, and affirmation, engaging in epistemologically responsive teaching (Berland, Russ, & West, 2020). Reflective journals are an effective way to understand what learners think and know (Kawalkar & Vijapurkar, 2015), and have been used to understand what students learn from class activities (Seeharaj & Samiphak, 2019; Stephens & Winterbottom, 2010). Reflective journals can also formatively assess and can guide instructional decisions in the classroom (Trauth-Nare & Buck, 2011). In this sense, the journal assignment was a tool for determining the science practices that TCs used in their daily lives and determining the science content that was embedded in those practices.

This study fills the gap in the literature in that it focuses on TC's reflection about science outside of the classroom. The TCs used the journals to help them make sense of the natural world. We investigated how TCs employed practices from the NGSS and integrated them with content, with the goal of identifying any gaps in their science knowledge and science practices.

Objectives of the Study

The purpose of this study was to determine the science knowledge and practices that TCs apply to their daily lives. We were interested in what they journaled, what motivated them to journal, and what they may have learned from the practice. We predict that the science they encounter in their everyday lives will impact what and how they teach in their future classrooms.

Science, with its abstract concepts, can be difficult to understand and teach. Science teachers tend to teach the same way *they* were taught (Oleson & Hora, 2014), which is *not* by relating it to everyday life experiences. Making science concrete and engaging to students necessitates relating it to students' lived experiences. Teachers of all school subjects can make science come alive by relating it to everyday life, helping students understand its importance. Students will not think that chemistry is boring if they know how chemistry plays a role in the cosmetics they wear and the food they eat. Connecting school science to everyday life has the potential to help students become lifetime learners, develop critical thinking skills, and value and understand scientific endeavors.

Through journaling about science in their surroundings, we hypothesize that TCs will be motivated to apply these concepts and practices to their teaching. Teaching science through all the SEPs is a challenge (Carpenter, Iveland, Moon, & Rianchini, 2015), and thus, relating the SEPs to everyday life has the potential to help science teachers with this skill.

We conducted our study with the following research questions in mind:
1) What scientific concepts do TCs notice in their daily lives and choose to write about? 2) What do journal entries reveal about TCs understandings about and participation in science practices? 3) What motivates TCs to practice journaling about the science around them? and 4) In what ways did the act of science journaling change the TCs' attitudes and behaviors?

Conceptual Frameworks

The conceptual framework that guided the creation of the journal assignment was Jones's (2009) MUSIC Model of Motivation; it was critical that TCs were motivated to carry their journals around with them and write in them several times a week. The MUSIC Model of Academic Motivation represents eMpowerment, Usefulness, Success, Interest, and Caring. The model predicts that learners are motivated when they feel empowered with some sense of control over their lives, when the content is useful to their lives, when they can be successful in the tasks asked of them, when they are interested in the instructional tasks, and when they feel cared for by their teacher and/or peers.

The National Academy of Sciences Framework for K-12 Science Education (NRC, 2012) was used as the framework for identifying SEPs. The Framework describes eight SEPs that students should engage in so that they can understand the scientific enterprise, see science as an active process, and come to understand the diverse methods that scientists use. Science practices combine skills with knowledge, and students learn scientific concepts better if they are engaged in science practices (NRC, 2012).

Methodology

Participants were enrolled in a science education degree program at a large, public university in the southeastern region of the United States. They were given blank journals on the first day of the semester in their second methods class. They were asked to make scientific observations, develop scientific questions, draw scientific sketches, look up any scientific topics they were curious about, and document any inquiries they undertook. Once a month, for a total of four months, the journals were collected by the first author (their professor), and feedback was provided on almost every entry through questions, encouragement, insight, and amazement.

The feedback was designed to create an interactive dialogue between instructor and student. The assignment served as a pedagogical tool since TCs were exposed to a method that they could use one day with their own students to bring science into real-world contexts. It demonstrated to them how to design assignments that are intrinsically motivating.

Participants

The 18 TCs (7 men/11 women, 6 graduate students/12 undergraduate students) were enrolled in a secondary science education program that led to certification. Eleven of the 12 undergraduates majored in general science education. The other undergraduate majored in chemistry education. The graduate students, enrolled in an M.Ed. program, had undergraduate degrees in biochemistry, forestry, biology, chemistry, and geology. The average age of the TCs was 22. Sixteen TCs identified as White, one was African American, and one was Native American.

Data Sources

In addition to the journals, 13 TCs consented to being interviewed at the end of the semester. The second author interviewed the TCs over Zoom in a semi-structured manner, and the interview was recorded for transcription. The purpose of the interviews was to answer research questions related to motivation; the subset was representative.

Analysis Method

This qualitative study looked inductively and deductively at both the interview dialogue and the journals. Thematic analysis was used to identify themes and patterns across all the data sets (Braun & Clark, 2006). We conducted our data analysis by reading through approximately 50 journal entries per participant, looking for science content and each of the SEPs outlined by the Framework. After conducting interviews with TCs, the interviews were transcribed, and these transcripts were coded. A constant comparison analysis was conducted (Strauss & Corbin, 1998) so that after codes were identified, they were verified on the audio/visual recorded interview. The first and second authors coded the first journal with the practices in mind, then codes were compared, and a codebook was created. Next, the second author coded the subsequent journals with the codebook as a guide. To control for bias, journals were scanned into pdf files, and names were removed. Finally, journals were coded for science concepts. The first and third authors coded the first two journals for science topics, then codes were compared, and a codebook was created. Next, the third author coded the subsequent journals with the codebook as a guide. This was followed up by the first author checking all the work and adding additional codes as necessary.

Key Findings

In this section, findings are organized by research question.

Finding 1: TCs primarily wrote about biology topics

The science journals covered many everyday topics. Table 1 describes the topic distribution across all 18 journals. More than one quarter of all entries were on biology topics.

Table 1

Major science disciplines in journal topics

Disciplines	% of Entries
Biology	26
Chemistry	16
Astronomy	10
Physics	9
Geology	9
General science	6
Food science	6
Engineering	5
Technology	5
Biochemistry	4
Social science	3

Approximately one quarter of the entries in the biology category were about physiology and human health, 21% were about animals, 20% were about human anatomy, 16% were about wildlife, and 13% were about plants. See Table 2. Chemistry was the second most common discipline. Ten percent of chemistry entries were about water, followed by cleaning supplies, vinegar, and candles. In astronomy, 31% of all entries were about the Moon. The most common topic in physics was light, followed by energy, electricity, and sound. In the geology discipline, weather was the most frequent topic followed by global warming. In the weather category, TCs wrote about clouds, condensation, humidity, and rain. The top individual topics in the entire dataset were weather, light, the Moon, the brain, spiders, polymers, energy, eyes, trees, chemical properties, electricity, and sound.

Table 2

Most common topics in biology

Biology Topics	Physiology/health Topics	Animal Topics	Anatomy Topics	Wildlife Topics	Plants
Physiology and health Animals Human Anatomy Wildlife Plants	Nutrition/medicine Hydration Exercise Reproduction	Spider Birds Bugs Fish Ants Insects Bees	Brain Eyes Skin	Fisheries Forestry	Trees

Majors and topics

Over 50% of biology majors' entries were about biology topics. General science majors were most likely to write about biology topics as well, with over 47% of their entries about biology. Chemistry majors wrote about biology (29%) and chemistry (23%). Geology majors also wrote about biology; 62% of the entries were about biology.

Finding 2: TCs primarily wrote about two of the eight practices

The science journals were filled with many entries that aligned with SEPs. All eight of the SEPs were evident in the analysis of the journal entries. Two of these practices dominated: SEP 1 (asking questions) and SEP 8 (obtaining, evaluating, and communicating information.) Scientists must be able to generate appropriate questions to conduct investigations and solve problems. All TCs had entries on SEP 1, with an average of 25 entries each. Overall, 38% of all SEPs in the journals were coded as thus. However, questions did not often lead to investigations. One participant asked, "I saw some condensation on my cup this morning and wondered how pure it was" and another asked, "A wasp was on my rearview mirror today, so I got curious. Why do wasps/hornets build their nests in car doors, under the hood, etc.?"

SEP 8 involves interpreting scientific texts and being a critical evaluator of what one reads online or hears in the news. Also, once a scientific investigation process is complete, scientists must effectively communicate what they have learned. All TCs had entries aligned with this SEP with an average of 25 entries each. Overall, 38% of all SEPs in the journals were coded as SEP 8.

Participants rarely wrote about SEP 4 (analyzing and interpreting data) or SEP 5 (using mathematics and computational thinking). SEP 4 involves looking for patterns, presenting data in graphs or charts, and finding meaning in the data. As scientists conduct investigations, data must be analyzed and interpreted to make connections and answer the questions generated during the investigation process. Two percent of all SEPs in the journals were about data analysis or interpretation. One participant wrote, "I moved my candle on the same table as my plant and I noticed the flame got higher and brighter. To test it again, I lit a match far away from the plant and when I brought it closer the flame grew! This makes sense considering plants release oxygen." SEP 5 involves using quantitative data to solve problems, creating algorithms to solve problems, using algebra or geometry, or using computers to analyze large data sets. One percent of all SEPs in the journals were coded into this category. Primarily, these entries focused on using equations, or on quantity and size. Figure 1 demonstrates that on average, TCs with different science fields of study had equivalent numbers of journal entries that could be coded as SEP 1.

Figure 1

Number of SEP entries per participant with various backgrounds

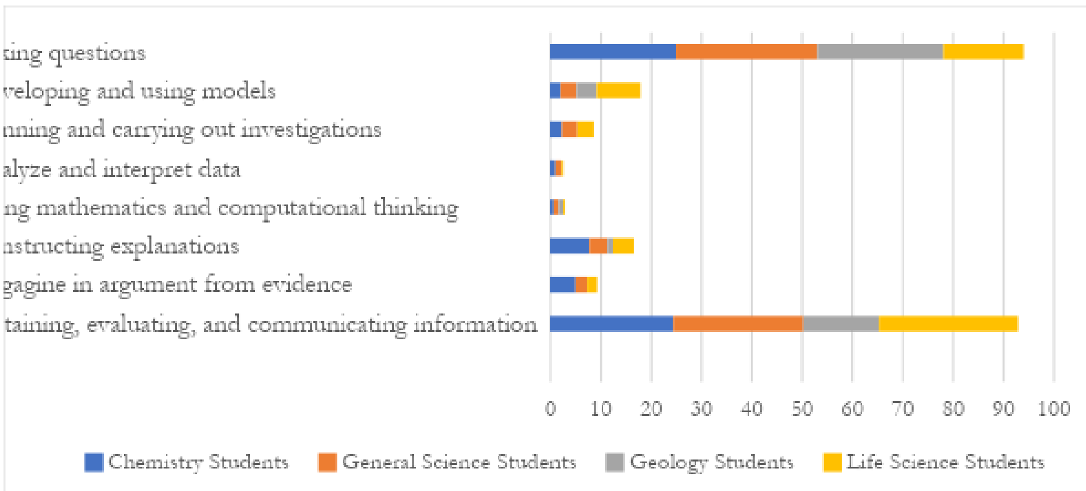
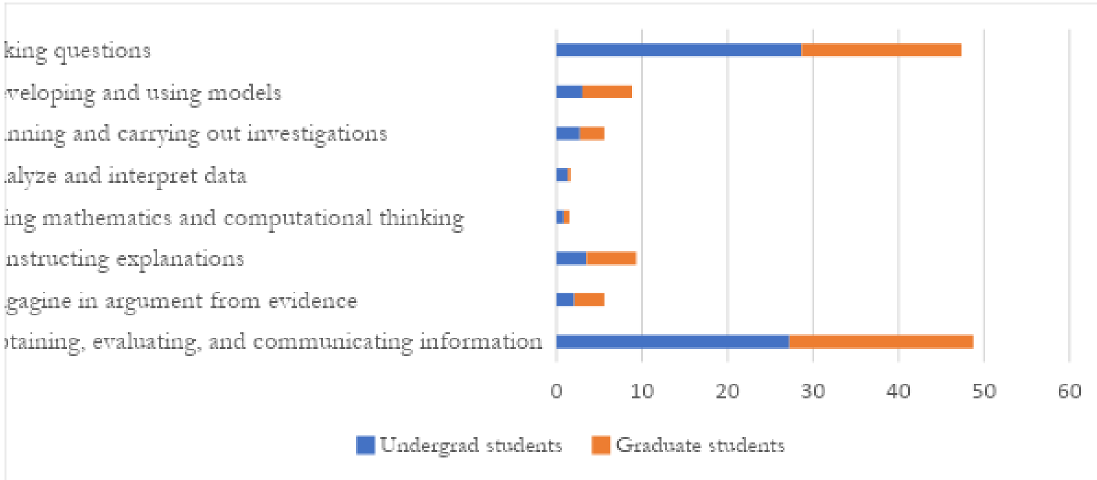


Figure 2 demonstrates that undergraduates and graduate students had almost equivalent entries in the SEP1 and SEP 8 as well, with on average 28 entries per undergraduate participant and 19 entries per graduate participant coded as SEP 1.

Figure 2

Number of entries per participant in undergraduate or graduate programs



Finding 3: TCs were motivated to journal by components of the MUSIC Model

Participant attitudes were initially ambivalent toward the assignment, but these attitudes changed as TCs began to see **value** in it. TCs said that journaling about science was useful in that it helped them find examples to bring into the classroom. Alexis said about students, "Chemistry is all around them every day. They could just kind of go on forever without noticing it unless you point it out for them."

TCs said they felt motivated to complete the assignment because the assignment was **empowering**. Having flexibility and choice gave TCs a sense of control over what they wrote. TCs said keeping a record of scientific thoughts was **useful** and would help them plan lessons in the future. They commented on how the interactive nature of the assignment was motivating because it piqued their **interest** when the professor made suggestions for future research. The instructor read every entry and commented extensively on them. All but one of the interviewed TCs remarked that this showed them how much the instructor **cared** about their thoughts and ideas. David said, "I think I wouldn't have been as motivated… because seeing, like, her spend time on those really helped me to like want to do better on it or find something that was meaningful."

Finding 4: TCs noticed more science in their everyday lives

TCs enjoyed taking the time to look at the world around them and observe the natural world through a scientific lens. It helped them to develop questions about their world. They enjoyed the opportunity to investigate things, either through observation or performing simple experiments. It enhanced their scientific thinking skills and helped them see the science in the everyday lives. It helped them appreciate science more, increasing their desire to pass that on and communicate it to others. Due to these findings, we assert that the assignment caused the participants to think more like scientists in their everyday lives.

> I feel [it has] made me more of like a scientist because, I mean, it makes you way more aware of all kinds of 'sciencey' things that are happening around you and then do the research to prove it or not prove it but explain it and I mean, I think it would make me sort of, I think it made me sort of like a scientist. (Ella)

Discussion and Implications

The use of interactive science journaling may be a way to engage TCs in legitimate participation in the community of scientists (Lave & Wegner, 1991), and it may be a way to support learners through epistemologically responsive science teaching (Berland, Russ, & West, 2020). With science teachers emerging from an unprecedented pandemic, they may be looking for new, innovative ways to encourage scientific thinking and everyday application to their students' lives.

When learners notice and write about the scientific content and practices in their daily lives, and a more knowledgeable other (Vygotsky, 1978) responds with suggestions, encouragement, and ideas, this responsive teaching has the potential to meaningfully encourage participation in science.

By observing, questioning, experimenting, researching, and discussing with their professor, participants engaged in authentic science practices, and connected with science. This assignment was motivating and aligned well with the components of the MUSIC Model of Motivation (Jones, 2009). This assignment helped TCs develop their teacher identity as not merely being teachers of science, but scientists who are teachers.

References

Berland, L.K., Russ, R.S., & West, C.P. (2020) Supporting the scientific practices through epistemologically responsive science teaching. *Journal of Science Teacher Education, 31*(3), 264-290. https://www.tandfonline.com/doi/full/10.1080/1046560X.2019.1692507

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101.

Carpenter, S. L., Iveland, A., Moon, S., Hansen, A. K., Harlow, D. B., & Bianchini, J. A. (2019). Models are a "metaphor in your brain." *School Science and Mathematics, 119*(5), 275-286. https://www.tandfonline.com/doi/abs/10.1191/1478088706QP063OA

Hürcan, N. & Önder, İ. (2012). Determination of the relationships between the science concepts that the 7th grade primary school students learn in science and technology lessons and daily life. National Congress of Science and Mathematics Education, Niğde, September 27-30. https://doi.org/10.12973/ejmste/75375

Jones, B. D. (2009). Motivating students to engage in learning: The MUSIC model of academic motivation. *International Journal of Teaching andLearning in Higher Education, 21*(2), 272-285.

Kawalkar, A., & Vijapurkar, J. (2015). Aspects of teaching and learning science: What students' diaries reveal about inquiry and traditional modes. *International Journal of Science Education, 37*(13), 2113-2146. https://www.tandfonline.com/doi/full/10.1080/09500693.2015.1067933

Kite, V., Park, S., McCance K., & Seung, E. (2021) Secondary science teachers' understandings of the epistemic nature of science practices. *Journal of Science Teacher Education, 32*(3), 243-264. https://doi.org/10.1080/1046560X.2020.1808757

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge University Press.

National Research Council (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. The National Academies Press. https://doi.org/10.17226/13165

Oleson, A., & Hora, M. T. (2014). Teaching the way they were taught? Revisiting the sources of teaching knowledge and the role of prior experience in shaping faculty teaching practices. *Higher Education*, *68*(1), 29-45.

Russ, R. S. (2014). Epistemology of science vs. epistemology for science. *Science Education, 98*(3), 388-398. https://doi.org/10.1002/sce.21106

Seeharaj, A., & Samiphak, S. (2019). Fostering the grade 10 underprivileged students' inquiring mind through science reflective journal writing and active learning. AIP Conference Proceedings 2081, 030002 (2019) https://doi.org/10.1063/1.5094000

Strauss, A., & Corbin, J. (1998). Basics of qualitative research techniques. Sage.

Trauth-Nare, A., & Buck, G. (2011). Using reflective practice to incorporate formative assessment in a middle school science classroom: A participatory action research study. *Educational Action Research, 19*(3), 379-398. https://doi.org/10.1080/09650792.2011.600639

Vygotsky, L. (1978). Interaction between learning and development. *Readings on the Development of Children, 23*(3), 34-41.

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A. S., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of Research in Science Teaching, 38*(5), 529-552. https://onlinelibrary.wiley.com/doi/10.1002/tea.1017

CREATING A SUSTAINABLE SUPPLEMENTAL INDUCTION PROGRAM FOR STEM TEACHERS

Colleen McLean Eddy
colleen.eddy@unt.edu

Karen Bump
karen.bump@unt.edu
University of North Texas

Zhenhua Huang
zhenhua.huang@unt.edu

Abstract

This paper is part of a larger project seeking to create a sustainable infrastructure for engineering students to become STEM teachers in high-need schools. Induction programs are a key component for new teacher retention. A review of literature and systematic review of district partners' induction programs provides content for determining what components are needed for a supplemental induction program. One district focuses more on the expectations of mentors, and the other focuses more on new teacher expectations. The initial findings suggest including financial support for both mentors and mentees, providing university engineering faculty mentors, and opportunities for STEM mentees to collaborate.

Keywords: induction programs, novice teachers, STEM teachers, teacher retention

Introduction

This paper is part of a larger project seeking to create a sustainable infrastructure for engineering students to become STEM teachers in high-need schools, resulting in a pipeline for minoritized students from high school to college to become engineers. Developing pathways for engineering candidates from minoritized groups adds to the small number of current engineering teachers in high-need school districts (Bischoff et al., 2014; Hansen & Quintero, 2018).

Purpose of the Study

The purpose of the study is to determine what components of a supplemental collaborative induction are needed between a university and partner school districts to support and retain engineering majors as STEM teachers.

Related Literature

Many school districts have added engineering courses and engineering content to science and mathematics courses to their secondary programs as a way to integrate mathematics, science, and technology through problem-solving and collaboration (CADRE, 2013). Thus, recruiting engineering students to become STEM teachers has gained importance. The Texas Education Agency has mandated the addition of 'scientific and engineering practices' to the Texas Essential Knowledge and Skills K-12 by 2023 (TEA, 2021). One of the best ways to fulfill these education needs is by recruiting engineering majors to become STEM teachers and retaining these teachers through innovative induction programs.

Induction is a key component of teacher retention, and many states including Texas require school districts to have a new teacher induction program (Ingersoll & Smith, 2004; Ingersoll, 2012; McConnell, 2017). One qualitative study in an urban school district regarding the induction of new science and mathematics teachers included science and mathematics faculty from the university as part of the induction team (ndunda et al., 2017). Other induction programs with strong subject-specific mentoring included a mentoring overlap between the student teaching phase and the new teacher induction that included cooperating teachers and STEM faculty (McConnell, 2017; Morrell & Salomone, 2017). Smith and Ingersoll (2004), using the data set from the Schools and Staffing Survey, found that having a mentor in the same field reduced the risk of leaving by 30%.

ndunda and colleagues (2017) described the team as a professional learning community (PLC) where the faculty lead the PLC. The PLC occurred every week for 1-2 hours either after school or on Saturday, during which time they reviewed student data, completed lesson planning, and identified which instructional strategies worked or did not work. This also included observations in the classroom and debriefings. University faculty served as support beyond the weekly meetings that included "(a) shared values and mission, (b) shared and supportive leadership, (c) collective learning and its application, (d) supportive conditions, and (e) shared personal practice" (ndunda et al., 2017, p144). Smith and Ingersoll (2004) reinforced the importance of a common planning time with their mentors as it reduced the risk of leaving by 43%.

For STEM career changers, peer support is essential for retention and job satisfaction (Grier & Johnson, 2009; Koehler et al., 2013). In their qualitative case study of six STEM career changers, Grier and Johnson (2009) indicated that they valued the experiences of their peers as well as being able to socialize with them. Koehler and colleagues (2013) reinforce Grier and Johnson's (2009) conclusion and include a recommendation for STEM career changers as a cohort in the certification program so that it can continue once they are in the classroom.

The content of induction programs is important as well. Researchers describe how the content of induction programs should include student-centered instructional practices, such as student engagement and evidence of student learning (Thompson et al., 2013; Wong & Luft, 2015). Wong and Luft (2015) found too that teachers who were more student-centered than teacher-centered were more likely to continue teaching.

Communication with campus administrators is another important factor along with a subject-specific mentor and planning time with them (Ingersoll, 2012; Wynn et al, 2007). Campus administrators included the principals, department chairs, and others. The offerings by district and campus administrators matter too, such as seminars for beginning teachers and opportunities to collaborate with other teachers. In Kearney's (2017) international research, the addition of teacher aides and reduced teaching load or schedule were found to contribute to new teacher retention.

A variety of induction programs exist, but those most successful have a subject-specific mentor and a common planning time to collaborate (Smith & Ingersoll, 2004), along with two or more of the following for the greatest impact (Ingersoll, 2012): 1) communication with school administrators (Ingersoll, 2012; Wynn et al, 2007), 2) beginner seminars (Ingersoll, 2012), 3) collaboration with colleagues (Ingersoll, 2012), 4) having a teacher aide (Ingersoll, 2012; Kearney, 2017), and 5) reduced teaching load or schedule (Ingersoll, 2012; Kearney, 2017). In addition, STEM career changers benefit from peer support and socialization from other STEM career changers as they transition from the preparation program to the classroom (Grier & Johnson, 2009; Koehler et al., 2013).

Methodology

After a review of the literature regarding the needed components of a successful induction program as summarized above, a content analysis of the partner district induction programs was evaluated. We discuss the commonalities and differences between the induction programs and then how they relate to the literature. Following this we discuss the implications of sharing this information with partner districts and what components are being considered for the supplemental induction program. For the purposes of anonymity, we use the terms Suburb-Large and City-Large by IES and NCES (n.d.) to name the participating school districts. Because a goal of the larger project is recruiting and retaining engineering majors to teach at high needs schools, schools were chosen that fit this definition (See Table 1 for participant district demographics).

Table 1 Demographics of District Partners

District	**# of Students**	**Race/Ethnicity**					**Title I Designation**
		Hispanic	Black	White	Asian or Asian	Native American & two or	

					Pacific Islander	more races	
Suburb-Large	41,000	54%	25%	17%	2%	2%	X
City-Large	53, 952	27%	13%	32%	24%	4%	X

Results

Both programs for new teachers belong to a two-year induction program. The Suburb-Large mentoring program focuses on the responsibilities of new teachers, while the City-Large focuses on the responsibilities of the mentors. As a result, the discussion below describes first the responsibilities of the mentors followed by the discussion of the responsibilities of the new teachers.

City-Large has mentoring programs for novice teachers and new teachers in the district. For the purposes of this paper, the focus is on novice teachers with less than two years of experience. There is a lead mentor for each campus and mentors of novices. Mentors of novices may have up to five new teachers and meet with them individually and in groups. Six to eight hours is the expectation for meeting with mentees in year one and three to four hours in year two. This time can occur during or after school hours. Mentors receive a stipend and are not necessarily in the same subject area. The district looks for mentors who are active learners, supportive, and effective communicators. New teachers are encouraged to also have a teacher in their subject area but not assigned by the district or campus. Mentors provide instructional support such as learner-centered approaches; support of logistics of the classroom and technology; and provide emotional support both initiated and not initiated.

The suburb-large describes mentoring support at the district and campus levels. The district level specifies expectations for the new teachers. Year-1 focuses on professional development (PD) provided while year-2 allows new teachers to select from a menu of PD opportunities within the district. Year-1 begins in the summer with a new teacher seminar followed by two-hour sessions each month (four in the fall and two in the spring). Each month has a different focus with one of the months focused on subject-specific sessions. The district provides new teachers with a website for access to resources such as district policies, electronic resources, and cheat sheet to commonly used acronyms. One of the electronic resources provides short 90-second videos created by the district.

One of these includes the importance of greeting your students with a smile and knowing and pronouncing your students by their chosen names at the beginning of the school year.

At the campus level, new teachers receive mentoring from the campus mentor and an assigned mentor. The campus mentor is responsible for supporting all new teachers and implementing resources supplied by the PD department. First-year teachers have an assigned mentor who is paid for mentoring and provides ongoing support and receives resources from the PD department. Each assigned mentor has only one mentee. The new teacher mentor characteristics are like the City-Large new teacher mentors who are effective teachers in the classroom, active learners, supportive of peers, and good with communication. While there is no expectation of time to spend with the mentee, the mentor must document at least 10 conversations over the course of a year. Also, the new teacher mentors and mentees are expected to observe each other in the classroom and debrief after each observation. The district provides a substitute for this to occur. (For a summary of comparisons between literature and districts see Table 2 below.)

Table 2

Comparison of District Induction Programs with Induction Practices Recommended by Literature

Induction Practices in Literature	**Suburb-Large District**	**City-Large District**
Subject Specific Mentors	*Have campus mentor along with personal mentor *Personal mentor must meet at least 10 times with mentee *Not a guarantee of subject-specific mentor	May share mentor with up to 5 mentees (Not necessarily subject-specific mentor)
Common Planning Time with Mentor	-	-
Faculty Lead PLCs	Modeled strategies, techniques and resources presented in PLCs	Professional learning Dept offers "New Teacher Labs"
Communication with campus administration	Campus Mentor Liaisons	-
Opportunities to Communicate with Colleagues	-	-
Reduction in Teaching Load	-	-
Beginner Seminars or Videos	*Professional development offered within district 1-2 hour session monthly *Offers resource website	Offers New teachers 1-hour sessions every other month
Mentoring overlap between student	-	-

teaching phase and new teacher phase		

Discussion

Both districts have a comprehensive induction program with the City-Large focused on expectations of mentors and the Suburb-Large more focused on new teacher expectations. Aspects of both programs include some of the research-based best practices of strong induction programs.

Both had administrators at the campus level who were also mentors called lead mentors (Ingersoll, 2012; Wynn et al, 2007). In addition, the Suburb-Large also had district seminars and websites to support new teachers. Neither district provided a teacher aide or reduced teaching load or schedule as suggested by Kearney (2017).

The City-Large expectation of time with mentees included a max of eight hours in year one and four hours in year two during or after school hours. This is in stark contrast to what ndunda and colleagues (2017) describe as meeting 1-2 hours a week after school or on Saturday. Suburb-Large did not describe the amount of time the new teacher mentor was to spend with mentees but did include observations in both the mentor and mentee's classrooms with debriefings after each, which was like ndunda and colleagues (2017).

The subject-specific mentors were described as one of the essential characteristics of a mentor (McConnell, 2017; Morrell & Salomone, 2017; ndunda et al., 2017; Smith & Ingersoll, 2004). However, only City-Large mentions a subject-specific mentor and the mentee must seek out this person on their own. The City-Large did provide mentors to meet with their mentees in groups which could encourage collaboration with each other (Ingersoll, 2012).

Implications

We were able to collect information from partner school districts regarding their induction programs and related articles about best practices for induction programs. City-Large was focused on the responsibilities of the mentors and Suburb-Large was focused more on the mentees. Because district partners typically have only one engineering teacher per campus, identifying a subject specific mentor is not always possible. Some areas that the university and district partners could build on these initial findings include expectations for both mentors and mentees, subject matter mentors, and opportunities for STEM mentees to collaborate.

Our plan is to build on these initial findings of school district induction programs and design a supplemental induction program for STEM Teachers. We took this information to our partner school districts to identify with them what is wanted for the supplemental induction program. At the time of this article there was concern for both mentors and mentees to provide financial support for the mentor and mentee relationship rather than the expectations. We discussed initially finding grant funding to support mentor and mentee stipends. The reason is that most of this work happens outside the school day and we should value the additional time expected of them.

As a university, we need to consider how to provide university engineering mentors to new STEM teachers (ndunda et al., 2017). As the districts do not always have two or more engineering teachers on a campus, they are unable to provide a subject specific mentor. Our district partners agree that a supplemental induction program containing robust mentoring that includes university engineering faculty to serve as the subject specific mentor is essential.

Lastly, opportunities should be provided for STEM mentees to collaborate for social and peer support (Grier & Johnson, 2009; Koehler et al., 2013). Our district partners sighted that the supplemental induction program include both virtual and face-to-face meetings. The face-to-face meetings should take place in a common meeting place such as a coffee house to collaborate, socialize, and do book studies. By building the capacity to support engineering majors to be STEM teachers, we will be able to support their professional needs while also building a pipeline for future students especially those underrepresented to excel in STEM education.

References

Bischoff, P., French, P., & Schaumloffel, J. (2014). Reflective Pathways: Analysis of an Urban Science Teaching Field Experience on Noyce Scholar-Science Education Awardees' Decisions to Teach Science in a High-Need New York City School. *School Science and Mathematics*, 114(1), 40-49. https://doi.org/10.1111/ssm.12057

Grier, J. M., & Johnston, C. C. (2009). An inquiry into the development of teacher identities in STEM career changers. *Journal of Science Teacher Education, 20*(1), 57-75.

Hansen, M., & Quintero, D. (2018). *Can states lean on diverse teacher recruitment to stem teacher shortages?* Brown Center Chalkboard. https://www.brookings.edu/blog/brown-center-chalkboard/2018/01/17/can-states-lean-on-diverse-teacher-recruitment-to-stem-teacher-shortages/

Ingersoll, R. (2012). Beginning teacher induction: What the data tell us. Phi Delta Kappan, 93, 47-51. https://dx.doi.org/10.1177/003172171209300811

Ingersoll, R., & Smith, T. M. (2004). Do teacher induction and mentoring matter? *NASSP Bulletin, 88*(638), 28-40.

Institute of Educational Sciences, & National Center for Education Statistics. (n.d.). Education demographics and geographic estimates. https://nces.ed.gov/programs/edge/Geographic/LocaleBoundaries

Kearney, S. (2017). Beginning teacher induction in secondary schools: A best practice case study. *Educational Research*, 27(4), 784-802.

Koehler, A. A., Feldhaus, C. R., Fernandez, E., & Hundley, S. (2013). STEM alternative certification programs & pre-service teacher preparedness. *Journal of STEM Education: Innovations and Research*, *14*(4), 44-55.
McConnell III, J. R. (2017). A model for understanding teachers' intentions to remain in STEM education. *International Journal of STEM Education*, 4(1), 1-21. https://doi.org/10.1186/s40594-017-0061-8
Morrell, P. D., & Salomone, S. (2017). Impact of a Robert Noyce scholarship on STEM teacher recruitment. *Journal of College Science Teaching, 47*(2), 16-21. https://doi.org/10.2505/4/jcst17_047_02_16
ndunda, m., Van Sickle, M., Perry, L., & Capelloni, A. (2017). University-urban high school partnership: Math and science professional learning communities. *School Science and Mathematics*, 117(3-4), 137-145. https://doi.org/10.1111/ssm.12215
Smith, T. M., & Ingersoll, R. M. (2004). What are the Effects of induction and mentoring on beginning teacher turnover? *American Education Research Journal*, 41(3), 681-714.
Thompson, J., Windschitl, M., & Braaten, M. (2013). Developing a theory of ambitious early-career teacher practice. *American Educational Research Journal*, 50(3), 574-615.
Wong, S. S., & Luft, J. A. (2015). Secondary science teachers' beliefs and persistence: A longitudinal mixed-methods study. Journal of Science Teacher Education, 26(7), 619-645.
Wynn, S. R., Carboni, L. W., & Patall, E. A. (2007). Beginning teachers' perceptions of mentoring, climate, and leadership: Promoting retention through a learning communities' perspective. Leadership and Policy in Schools, 6, 209-229.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 2149596. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

VIDEO-BASED TASK ANALYSIS ON GRAPHS OF THE QUADRATIC FUNCTION

Miran Byun
miranbyun@jalc.edu
John A Logan College

Eunmi Joung
ejoung@uvu.edu
Utah Valley University

Abstract

The current study investigates the effects of a video-based task on the topic of graphing quadratic functions and explores students' perceptions towards a video-based task. An exploratory case study is utilized. Results from analyzing students' responses through their video-based task show a positive effect on learning graphing quadratic functions. Students' conceptual and procedural knowledge of this content is discussed. In addition, from exploring how students feel about their experiences of a video-based task through surveys, this study shows positive effects of a video-based task in learning quadratic functions.

Keywords: video-based task, formative assessment, quadratic functions, technology

Introduction

The COVID-19 pandemic has changed everyone's lives in many fields such as school, business, and even medicine (Hess, 2021; Kramer et al., 2020; Pugh et al., 2020). There has been a huge impact on the education field as classes have moved to the online environment. As all educators experienced this transition, assessment has been challenging, especially in the teaching and learning of mathematics. Many mathematics teachers have relied on online testing programs to adapt to these changes (Bocanet et al., 2021). The Common Core State Standards of Mathematics (2010) recommend that students should be able to solve quadratic equations by taking square roots, completing the square, using the quadratic formula, and factoring and solving a quadratic equation in two variables algebraically and graphically. In this study, video-based tasks were implemented in college algebra courses to improve students' mathematical understanding and critical thinking ability.

Objectives of the Study

The purpose of the study is to investigate the effects of a video-based task focusing on students' procedural and conceptual knowledge about graphing quadratic functions and to explore students' perception towards a video-based task. The research questions are listed below:

1. How did a video-based task affect the students' performance conceptually and procedurally in graphing a quadratic function?
2. What do students think of a video-based task while graphing a quadratic function?

Related Literature

Video-Based Tasks

To provide alternatives to the traditional approach, many instructors use web-based assignment management systems such as MyMathLab and WebAssign (Serhan & Almeqdadi, 2020). These systems can be used as effective and flexible instructional tools that provide immediate feedback and virtual aids that are suitable for students' needs. However, those management systems may be limited in assessing students' understanding of specific mathematics concepts and learning processes. Studies (e.g., Dunekacke et al., 2015) support that a video-based assessment, on the other hand, provides the following benefits: 1) promoting students' motivation to learn mathematics, 2) easily identifying misconceptions or errors, and 3) developing pre-and in-service teachers' mathematics content knowledge, pedagogical knowledge, and confidence levels. Video-based assessments allow students to become "expert learners" (Bada & Olusegun, 2015, p.70) by questioning themselves and their strategies. In recent years, a growing body of research shows the positive effect of pedagogical advantages using a video-based assessment for preservice teachers in teacher education programs (Dunekacke et al., 2015; Santagata et al., 2021). As pedagogical content knowledge (PCK) has been a central focus in mathematics teaching and learning, studies have addressed PCK by incorporating technology in designing various approaches such as examining students' written work, analyzing videos, and conducting clinical interviews (Norton et al., 2011). Among them, the concept of video assessment has been introduced resulting in innovative, more applicable approaches to analyze teachers' formative assessment interactions with students (Gotwals et al., 2015). However, limited research using a video-based task has been implemented in mathematics courses, in particular, students' understanding of how graphs and quadratic functions are related (Listiawati1 & Juniati, 2021). Thus, this study will help mathematics researchers and educators identify the effects of a video-based task for students who take college algebra courses.

Conceptual and Procedural Knowledge of Quadratic Functions

Algebra is one of the main subjects of mathematics education and is important in real-life situations. Students' inability to learn algebra may prevent them from understanding various advanced-level mathematical subjects and succeeding in university-level mathematics (Williams, 1997). One of the difficulties students face in learning algebra is quadratic functions (Hoon et al., 2018; Suzanne, 2015). More specifically, disconnections between the definition of quadratic functions and applying those functions in representation can be one of the reasons students face difficulties in learning quadratic functions (Hoon et al., 2018). Eisenhart et al. (1993) defined procedural knowledge as the mastery of computational skills and knowledge of procedures. Conceptual knowledge is the understanding of the relationships and interconnections of mathematical ideas. In learning quadratic functions, working with different representations can promote conceptual knowledge, allowing students to revisit and develop their procedures (Schwartz, 2008). Using different representations, students can identify the connections between the graphs of quadratic functions and standard form (Parent, 2015). For instance, creating graphs of the quadratic function is considered as conceptual knowledge and the process of converting to the vertex form (i.e., $f(x)=a(x-h)^2+k$) from the standard form (i.e., $f(x)= ax^2 +bx +c$) of quadratic function is considered as procedural knowledge.

Methodology

This exploratory case study aims to investigate the effects of a video-based task on students' understanding of graphing quadratic functions.

Participants

The present study involves two sections of a college algebra course at a community college in the Midwest region of the United States. Among the two sections of the one math course, 7 students from both the experimental and the control groups participated, respectively. The experimental group used a video-based task as the intervention, while the control group used a traditional pencil and paper.

Instruments

The researchers developed the following three instruments: 1) a video-based formative quiz, 2) the unit exam, and 3) an open-ended follow-up survey questionnaire. In the video-based task, students were asked to find all properties of the function (e.g., vertex, concavity, axis of symmetry, intercepts, and extrema) and to sketch the graph of the quadratic function while recording themselves. The unit exam was applied to evaluate how much of the content they retained. The results of the exam from both the experimental and control groups were compared. Lastly, an open-ended follow-up survey was used to collect students' perceptions and opinions from their experience. The following questions were included in the survey:

1. How did you prepare for this assignment?
2. Did you face any difficulties? If yes, what were your difficulties while preparing for this task?
3. What do you think the benefits are in doing the video task assignment?

4. Did you enjoy preparing for this assignment? If yes, why? If no, why not?

Procedures

First, after both experimental and control groups had the same lessons of graphing quadratic functions from the same instructor, the experimental group was assigned to submit the self-recorded video presentations. Second, the two researchers analyzed students' video recordings and coded their scores based on the coding sheet (see Table 1) with detailed feedback from the instructor. Third, to measure the students' retention, this study assessed students' performance on graphing quadratic functions on their unit test and compared those in the experimental group with the control group. Lastly, a follow-up survey was given to the students who submitted their video recordings, and their results were reported.

Table 1

Coding Criteria

Code	Sub-Codes	Criteria
C1 Procedural Knowledge (4)	C1-1 Quadratic Function in the form of $f(x)=a(x-h)^2+k$ (2)	No error of procedural steps (2) Minor error of procedural steps (1) Multiple errors of procedural steps or not reporting this form (0)
	C1-2 Vertex (0.5)	Accurate vertex (0.5) Otherwise (0)
	C1-3 Axis of Symmetry (0.5)	Correct equation of axis of symmetry (0.5) Otherwise (0)
	C1-3 Graph Orientation (0.5)	Correct graph orientation (0.5) Otherwise (0)
	C1-4 Maximum or Minimum Value (0.5)	Accurate maximum or minimum value (0.5) Otherwise (0)
C2 Conceptual Understanding (4)	C2-1 Understanding of completing the square (1)	Explain the relation between completing the square form and vertex (1) Otherwise (0)
	C2-2 Representation of graph (2)	Explain how the graph is constructed based on all properties (2) Explain some properties on the graph (1) Otherwise (0)
	C2 -3 Using Definition of quadratic Function (1)	Explain the relation between the definition of a quadratic function and graph orientation (1) Otherwise (0)

Results and Discussion

To respond to the first research question, the results of the video task for the experimental group were scored, and the unit test as a measure of students' knowledge was used to compare students' scores between the experimental and control groups.

A Video-Based Task

The results of the video-based task (Table 2) for the experimental group using the coding criteria showed that the overall mean of student performance of graphing a quadratic function was 6.35 out of 8. We had two following codes: *Procedural Knowledge* (C1), and *Conceptual Knowledge* (C2). As presented in Table 2, for C1, four students showed the correct process of converting from the quadratic function to the vertex form and finding the maximum or minimum value without errors. Three students made minor errors while they factored out the leading coefficient to complete the square, resulting in the students being unable to find the correct vertex form. Among the three, one student failed to find the vertex form but found the correct extreme value using the formula (i.e., $x= -b/2a$). All students in the experimental group showed the correct responses for the graph orientation. For C2, all students clearly understood the concept of the relation between completing the square and vertex of the quadratic function, explaining the definition of quadratic function while explaining the orientation (i.e., concavity) of the graph.

Table 2

The Result of Student's Scores of the Video-Based Assessment

Subject	1	2	3	4	5	6	7	Mean
Procedural Knowledge (C1)	1.5	2	3	4	4	4	4	3.21/4
Conceptual Knowledge (C2)	3	3	3	3	3	3	4	3.14/4
Sum	4.5	5	6	7	7	7	8	6.35/8

In particular, Figure 1 presents examples of detailed feedback from the instructor for two students. Subject 1 had only 1.5 out of 4 points on the procedural knowledge showing several algebraic errors with incorrect signs and factoring (e.g., $-(x^2+4x+4) + 1=-(x-2)^2-1$). In contrast, Subject 7 not only successfully converted the quadratic form into the standard form with a clear procedure but also conceptually represented every property (i.e., vertex, axis of symmetry, etc.) of the quadratic function on the graph.

Figure 1

Scoring Rubric for Video Task

MAT 108 Video Presentation Rubric **Name: _______S1___________**

Content Knowledge

Knowledge	Content	Score:	Comments
Procedural Knowledge	Quadratic Function in the form of $f(x) = a(x-h)^2 + k$	___1___/2	Algebraic errors (sign)
	Vertex	___0__/0.5	Incorrect answer from incorrect vertex form
	Axis of Symmetry	___0__/0.5	Algebraic errors (Sign)
	Graph Orientation	__0.5___/0.5	
	Maximum or Minimum Value	___0__/0.5	Algebraic errors (Sign of x coordinate)
Conceptual Understanding	Understanding of completing the square	___1___/1	
	Representation of graph	___1___/2	Axis of symmetry is missing, and incorrect language (x-axis reflection?)
	Using Definition of quadratic Function	___1___/1	

Score: ___4.5__ /8

MAT 108 Video Presentation Rubric **Name: _______S7___________**

Content Knowledge

Knowledge	Content	Score:	Comments
Procedural Knowledge	Quadratic Function in the form of $f(x) = a(x-h)^2 + k$	___2___/2	Good explanation using the accurate math definition and language showing clear steps and procedure.
	Vertex	__0.5__/0.5	
	Axis of Symmetry	__0.5__/0.5	
	Graph Orientation	__0.5__/0.5	
	Maximum or Minimum Value	__0.5__/0.5	
Conceptual Understanding	Understanding of completing the square	___1___/1	
	Representation of graph	___2___/2	
	Using Definition of quadratic Function	___1___/1	

Score: ___8__ /8

Retention Measure Comparison

To compare students' scores after the intervention, their scores for the unit test were analyzed using the coding (see Table 1). Table 3 shows the mean difference between the two groups on procedural and conceptual knowledge of the graphing quadratic function task. In general, the experimental group performed better than the control group on both types of knowledge.

Table 3

Group Difference of Mean Scores of each partin the Graphing Quadratic Function Task

	Procedural Knowledge (C1)					Conceptual Knowledge (C2)		Total
Groups	CSF (2)	V (.5)	AS (.5)	C (.5)	E (.5)	Understanding of CSF (1)	Graph (3)	Sum (8)
Experimental Group	1.57 (79%)	.33 (66%)	.29 (58%)	.5 (100%)	.29 (58%)	1 (100%)	2.86 (95%)	6.83 (85%)
Control Group	.71 (36%)	.33 (66%)	.29 (58%)	.5 (100%)	.21 (38%)	.57 (57%)	2.4 (80%)	5.05 (63%)

Note. CSF: Completing the Square Form; V: Vertex; AS: Axis of Symmetry; C: Concavity; E: Extrema

For analyzing students' procedural knowledge, the major differences were shown in the process of converting to the standard form using completing the square and finding the min/max value. When analyzing conceptual knowledge, students in the experimental group showed a deeper understanding in explaining their method of completing the square to find the vertex of the function and drawing graphs (without using the vertex formula ($-b/2a$, $f(-b/2a)$). In contrast, the students (79 %) in the control group failed to convert the quadratic function to the vertex form due to a lack of procedural knowledge. Although they converted the quadratic equation form to the vertex form by completing the square, the students may not have conceptually understood why they had to use completing the square to find the vertex. This led them to reuse the vertex formula to find the vertex. The video-based task allowed students to make connections between the vertex in the standard form and the graph as well. The results of the study support that a video-based task can promote students' procedural and conceptual knowledge of graphing quadratic functions.

Survey Questionnaire Analysis

To respond to the second research question, we summarized the findings of students' perceptions and thoughts on learning graphing quadratic functions using the four survey questions. To prepare for their video assignment, the majority of the students went over their notes taken from the class. Some students watched YouTube and other resources. Most of the students spent about an hour completing the assignment. When asked what difficulties students faced when preparing the video presentation, 71% of students had technical problems sending the video to the instructor through email because most emails have a limited memory space, so students needed to convert the video into a zip file or Dropbox file. In contrast, 29% of students had difficulties understanding the content of the assignments. All students anonymously agreed that this assignment helped them improve their understanding of quadratic function problems, converting a quadratic equation form into a vertex form, and retaining the formula in their memory. Most students mentioned that they enjoyed doing this assignment and learning how to solve given problems by reviewing all the resources available to them. Thus, this supports that a video-based task provides benefits for students' learning processes (e.g., Dunekacke et al., 2015).

Implications

The findings of our research offer a different way of assessment for mathematics courses and suggest that video-based tasks may have a positive impact on students' learning of quadratic functions both procedurally and conceptually. However, since this study was conducted with a small sample size, there is a need for quantitative research by increasing the sample size to support the evidence of video-based tasks in mathematics teaching and learning. Future research should be focused on video-based tasks with different topics or with different groups.

References

Bada, S. O., & Olusegun, S. (2015). Constructivism learning theory: A paradigm for teaching and learning. *Journal of Research & Method in Education,5*(6), 66-70.

Bocanet, V. I., Brown, K., Uukkivi, A., Soares, F., Lopes, A. P., Cellmer, A., & Estela, M. R. (2021). Change in gap perception within current practices in assessing students learning mathematics. *Sustainability, 13*(8), 4495.

Dunekacke, S., Jenßen, L., & Blömeke, S. (2015). Effects of mathematics content knowledge on pre-school teachers' performance: A video-based assessment of perception and planning abilities in informal learning situations. *International Journal of Science and Mathematics Education, 13*(2), 267-286.

Eisenhart, M., Borko, H., Underhill, R., Brown, C., Jones, D., & Agard, P. (1993). Conceptual knowledge falls through the cracks: Complexities of learning to teach mathematics for understanding. *Journal for Research in Mathematics Education, 24*(1), 8-40.

Hess, S. F. (2021). Zooming to video: Rapidly converting a large-scale research consultation program from face-to-face to online. *Ticker: The Academic Business Librarianship Review, 5*(2).

Hoon, T. S., Singh, P., & Halim, U. K. A. (2018). Understanding of function and quadratic function among secondary school students in Selangor. *Asian Journal of University Education, 14*(1), 77-88.

Kramer, M., Förtsch, C., Stürmer, J., Förtsch, S., Seidel, T., & Neuhaus, B. J. (2020). Measuring biology teachers' professional vision: Development and validation of a video-based assessment tool. *Cogent Education, 7*(1), 1823155.

Listiawati, E., & Juniati, D. (2021, February). An APOS analysis of a student's understanding of quadratic function graphs. In Journal of Physics: Conference Series (Vol. 1747, No. 1, p. 012028). IOP Publishing.

Parent, J. S. S. (2015). *Students' understanding of quadratic functions: Learning from students' voices*. The University of Vermont and State Agricultural College.

Pugh, C. M., Hashimoto, D. A., & Korndorffer Jr, J. R. (2021). The what? How? And who? Of video-based assessment. *The American Journal of Surgery,221*(1), 13-18.

Santagata, R., König, J., Scheiner, T., Nguyen, H., Adleff, A. K., Yang, X., & Kaiser, G. (2021). Mathematics teacher learning to notice: A systematic review of studies of video-based programs. *ZDM–Mathematics Education*, 1-16.

Schwartz, J. E. (2008). A distinction between conceptual knowledge and procedural knowledge. Elementary Mathematics Pedagogical Content Knowledge: *Powerful Ideas for Teachers*: Pearson Allyn Bacon Prentice Hall.

Serhan, D., & Almeqdadi, F. (2020). Students' perceptions of using MyMathLab and WebAssign in Mathematics classroom. *International Journal of Technologyin Education and Science, 4(*1), 12-17.

Williams, S. (1997). *Algebra: what students can learn*. The nature and algebra in the K-14 curriculum. Proceedings of a National Symposium, Washington, DC, May 27-28.

EXPLORING STEM EDUCATION IN PREKINDERGARTEN SETTINGS: A SYSTEMATIC REVIEW

Jeffrey Radloff
Jeffrey.radloff@cortland.edu
Kate McCormick
kate.mccormick@cortland.edu
SUNY Cortland

Abstract

Most STEM education research focuses on K-12 levels of education. However, evidence suggests preschool children may also benefit from early STEM exposure. Yet, studies analyzing pK STEM integration are lacking. This systematic review identifies and characterizes how STEM is integrated at the pK level. Following PRISMA systematic review protocols, 20 articles were reviewed and categorized in terms of pK STEM teaching, learning, and curriculum. Results reflect current literature and suggest STEM is effective within pK contexts. Implications are provided for prekindergarten STEM teachers and researchers.

Introduction

A strong STEM workforce is crucial to address major global issues and promote scientific, technological, engineering, and math (STEM) literacy (Bryan & Guzey, 2020). Yet, research repeatedly describes the need to repair a "leaky" STEM career pipeline and increase students' STEM performance (van Den Hurk et al., 2019). As such, reform pushes for the use of "integrated STEM" instruction (NGSS Lead States, 2013), an interdisciplinary science teaching approach defined by the student-led development of solutions to real-world problems (Pleasants, 2020). By engaging in complex problems or tasks, learners can build so-called '21st-century skills' like critical thinking, creativity, and adaptability (Roehrig et al., 2021a).

Interestingly, most research in STEM education focuses on K-12 STEM education (Bryan & Guzey, 2020). However, STEM is also embedded within prekindergarten (pK) academic standards and reform (NAEYC, 2013), and additional work suggests preschool children also benefit cognitively and affectively from early exposure to STEM (Wan et al., 2021). Yet, less is known about how STEM is integrated within pK settings, and related systematic analyses are lacking at this level of education. As such, the current study employs systematic review techniques to identify and characterize existing pK STEM education research and how STEM is integrated within pK contexts.

Objectives of the Study

The objectives of this study were to: 1) Explore STEM curriculum and instruction within pK classrooms, and 2) Understand the impact of this enactment on prekindergartners' STEM understandings. The research questions guiding this study were:

1. How is integrated STEM introduced in prekindergarten settings?
2. What are measured STEM learning outcomes in prekindergarten settings?

Related Literature: Research in K-12 STEM Education

While "STEM" is defined differently across literature (Akerson et al., 2018), research has revealed several central components (Roehrig et al., 2021a). These include a focus on 21st century skills, opportunities for design justification and feedback, an anchoring discipline (e.g., S, T, E, M) and process (e.g., scientific inquiry; engineering design), immersion into real-world contexts, and disciplinary content and practices (Bryan & Guzey, 2020). Effective K-12 STEM instruction requires teachers to facilitate learners' development of design solutions. This means recognizing and supporting students' varying design progress and having adaptable STEM understandings (Crismond & Adams, 2012). Implemented effectively, K-12 integrated STEM instruction provides several benefits for students (Bryan & Guzey, 2020). These benefits include increases in students' STEM learning and engagement, as well as improved STEM attitudes and perceptions (Roehrig et al., 2021a). Yet, little is known about how these trends manifest within pK settings.

Systematic Review Methods

Systematic review methods were employed (Page et al., 2020) to summarize and characterize STEM integration in pK settings with the goal of expanding STEM within pK contexts. While reviews exist about the *presence* of science in pK contexts (O'connor et al., 2021), we were unable to find analyses about how it is *integrated*. "Population, Intervention, Comparison, Outcome, and Study Design" (PICOS) parameters were used to facilitate our investigation (Table 1).

Table 1

PICOS Framework Mapped to Current Study

Component	**Considerations**
Population	International pK children
Intervention	Integrated STEM instruction, in-and-out of classroom settings
Comparison	Previous inquiry-based approaches to science curriculum and instruction
Outcome	Effectiveness of intervention, for teachers and students
Study Design	Review empirical and analytical studies with a focus on items measured, outcomes

Eligibility criteria

Several exclusion and inclusion criteria were defined to gather pertinent studies (Table 2). Our research questions suggested clarifying a STEM definition and detailed search terms (see *Defining STEM* above) and focusing on empirical pK studies (i.e., ages 3-5) that utilized STEM teaching as an intervention. We included all eligible studies that focused on student, teacher, and/or curricular outcomes and were written in English. To note, pK studies were based on children's ages (i.e., 3-5 years old) rather than level of education to reflect international differences in annotation (e.g., what is considered "prekindergarten" versus "kindergarten").

Table 2

Inclusion/Exclusion Criteria

Criteria	**Considerations**
Content Area	Include records that use the term "STEM"
	Exclude records with fewer than two disciplines identified (e.g., science/math)
	Include any records with age/setting of pK/preschool
Participants	Included ages 3-5; in-service practitioners
	Exclude other ECE settings, pre-service practitioners
Location	Include studies internationally
	No exclusions
Date of Studye	Include 2013-2021
	Exclude prior*
Type of Publication	Include peer-reviewed publications including journals, conference proceedings, and reviews
	Exclude non-peer reviewed and practitioner articles

*NGSS and NSTA ECE Standards were published in 2013

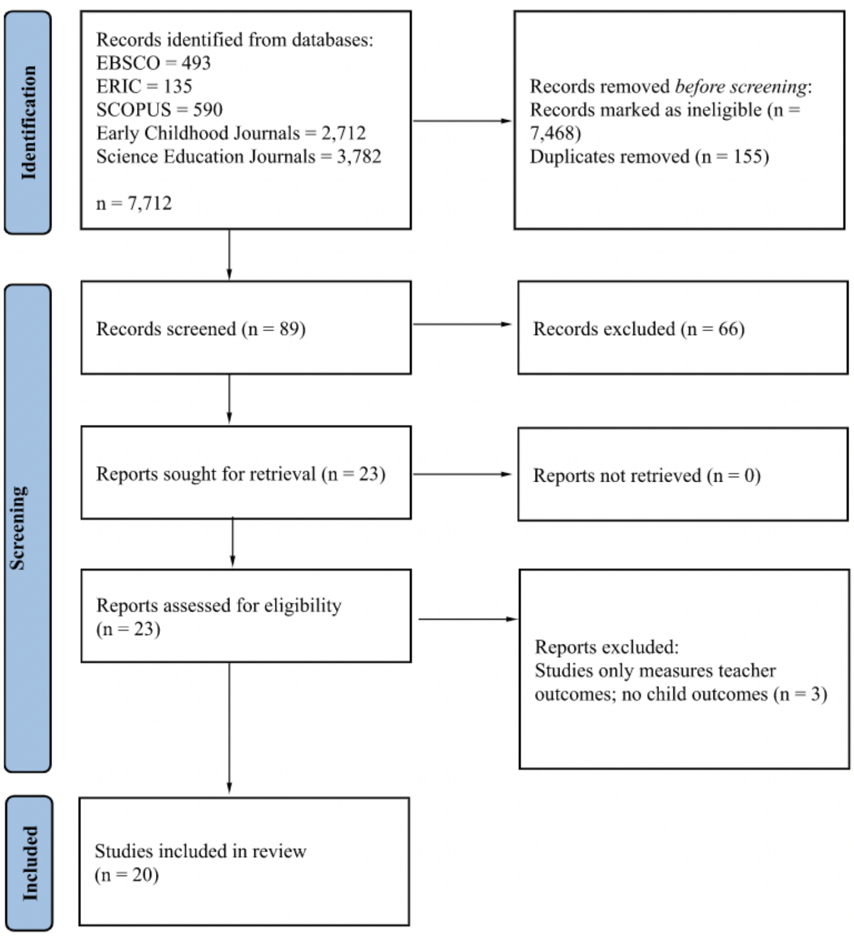
Information sources and search strategy

Sources scoured for eligible studies in fall 2021 included: (a) *EBSCO Educational Full-text*; (b) *SCOPUS*; (c) *ERIC*; and (d) commonly cited early childhood and science education journals. Early childhood included: *Australian Journal of Early Childhood,Contemporary Issues in Early Childhood, Early Childhood Education, Early Childhood Research Quarterly, Early Education and Development, European Early Childhood Education Research, International Journal of Early Childhood, and International Research in Early Childhood Education Journal.* Science education journals were *Science Education, Science and Education, School Science and Mathematics, Journal of Science Teacher Education, Journal of Research in Science Teaching,* *Science Education and Technology, International Journal of STEM Education, Research in Science Education, International Journal of Science Education, and the International Journal of Math and Science Education.*

Our initial search yielded a high number of articles (n = 7,712), but included relevant results (n = 20), confirming our search terms. Researchers screened eligible articles independently and eliminated 66 studies after the initial search that, upon closer inspection (e.g., scanning text), did not meet inclusion criteria. Reasons for exclusion included: full text not available; not published in English; K-12 settings; defined as “STEM” but emphasized less than two disciplines; not peer-reviewed or practitioner-based; meta-analyses; no results provided; or “STEAM” rather than “STEM”. The inclusion of articles published between 2013-2021 aligned with the release of the NGSS (NGSS Lead States, 2013) and the NSTA position statement on early childhood education (NSTA, 2013). Figure 1 below depicts the different phases of our review.

Figure 1

Identification of studies via databases and journals



Data collection and analysis

Eligible studies were and analyzed independently by the researchers to avoid bias. First, the researchers gathered data about *publication year, study location, participants, STEM definitions, intervention designs* (e.g., implementation, instruments used), and *study outcomes*. Then, the researchers analyzed the data using open coding with an emphasis on *how pK STEM is defined and integrated* and *suggested study outcomes and measurements*. This meant summarizing and comparing data (i.e., STEM definitions and measures) across studies. Researchers then met to compare and corroborate codes and interrater reliability was established using Cohen's kappa (IRR = .98) (Miles et al., 2018). Findings were organized according to the research questions (i.e., how is pK STEM integrated, measured).

Results and Discussion

Results uncovered several trends in pK STEM literature related to STEM integration and outcomes. Complete data are included as *Supplementary Information* (below).

Publishing Trends

Findings first revealed a low number of pK STEM publications since 2013. Only 20 articles fit our search criteria, with an average of three related manuscripts published per year. The majority of these originated in the US (n = 10) and Turkey (n = 2), with the rest (n = 1/country) from Italy, China, Canada, Australia, and Argentina. Three did not report their location of origin. Participants in the studies were children of ages 3 (n = 2), 4 (n = 6), and 5 (n = 12) years old.

Defining STEM

We also sought to identify pK STEM definitions. Interestingly, half of all eligible studies (n = 10) did not explicitly define STEM, while the remainder (n = 10) described STEM generally as 'a set of related disciplinary knowledge, practices, and careers.' Studies also emphasized different STEM disciplines. The majority focused on science (n = 19), and technology (n = 15), engineering (n = 15), and math (n = 14) were equally represented.

Type of Study

Over half (60%) of the included studies enacted experimental designs with 'control' and 'intervention' groups. To clarify, these (e.g., Alade et al., 2016) had a control group(s) and a group(s) that received the STEM intervention. The other eligible studies (40%) were exploratory in nature. These were generally quasi-experimental and featured one intervention for all participants (e.g., Schlesinger and Richert, 2017). Many required engineering design to complete a task (70%).

Interventions (75%) largely consisted of children completing non-digital, play-based STEM tasks or activities like engaging in immersive literature-based 'play worlds' (e.g., Fleer, 2021). Others asked children to complete tasks digitally using technology (25%) like robots or tablets (Furman et al., 2019). Interventions ranged from as little as one class session (e.g., Pila et al., 2020) to a year or more (e.g., Uret & Ceylan, 2021). Most studies (80%) involved researcher-created activities and were implemented by the researchers (e.g., Kermani & Aldemir, 2015).

Research Outcomes

STEM interventions were most often used as a catalyst to explore and/or support children's STEM learning (40%) or to increase their STEM interest (40%); it was shown to meet both goals. STEM interventions were also used to foster the development of 21st century skills (25%), promote school STEM readiness (10%), and improve teacher self-efficacy (10%). To clarify, teacher self-efficacy was measured in tandem with learner outcomes (i.e., not the main focus of the studies). Data sources mostly included teacher/researcher observations (e.g., Fleer, 2021), surveys (e.g., self-efficacy scales; Master et al., 2017) and artifacts (e.g., Yalcin & Erden, 2021).

Discussion and Implications

Findings appeared to support pK STEM as an emerging field of study and pointed to several implications for future pK STEM research. Included studies were largely based in the US and focused on children five years old, but also showed success in younger ages. This suggested STEM interventions could be effective for children younger than five, but that consideration is needed when generalizing results internationally. Second, there was a variability in STEM definitions (or lack thereof) across studies. This trend reflected current research (Akerson et al., 2018) and suggested more attention is needed to articulate STEM definitions or frameworks. Defining STEM is highly contextualized (Bryan & Guzey, 2020) and therefore may significantly inform ensuing interventions.

Differences in STEM integration across studies also mirrored existing work depicting multiple methods of integrating STEM (Roehrig et al., 2021b). However, intervention types were not compared. Research should explore if existing methods of STEM integration are effective in pK settings and how, comparing these approaches. In a similar way, variability in pK STEM interventions suggested research could focus on understanding what interventions are best and when (e.g., digital vs. physical; short-term vs. long-term). Research outcomes appeared to focus on a small number of constructs (e.g., STEM achievement and interest; 21st century skills; teacher self-efficacy). Research should continue these agendas but expand to include topics related to pK STEM equity and literacy.

The major limitation to this study was the low number of eligible studies. While this could relate to our inclusion and exclusion terms, the amount of pK STEM research is lacking, despite its apparent effectiveness (Wan et al., 2021). If we intend to foster a STEM literate citizenship, research appears to suggest that pK contexts are a rich place to start.

Supplementary Materials

For a full summary of study characteristics and references, please visit: https://bit.ly/3AcB8gK

References

Akerson, V. L., Burgess, A., Gerber, A., Guo, M., Khan, T. A., & Newman, S. (2018). Disentangling the meaning of STEM: Implications for science education and science teacher education. *Journal of Science Teacher Education*, *29*(1), 1-8.

Aladé, F., Lauricella, A. R., Beaudoin-Ryan, L., & Wartella, E. (2016). Measuring with Murray: Touchscreen technology and preschoolers' STEM learning. *Computers in Human Behavior, 62*, 433–441. https://doi-org.libproxy.cortland.edu/10.1016/j.chb.2016.03.080

Aldemir, J., & Kermani, H. (2017). Integrated STEM curriculum: Improving educational outcomes for Head Start children. *Early Child Development & Care, 187*(11), 1694–1706. https://doi-org.libproxy.cortland.edu/10.1080/03004430.2016.1185102

Ata-Aktürk, A., & Demircan, H. Ö. (2020). Supporting preschool children's STEM learning with parent-involved early engineering education. *Early Childhood Education Journal, 49*(4), 607–621.

Bryan, L., & Guzey, S. S. (2020). K-12 STEM Education: An overview of perspectives and considerations. *Hellenic Journal of STEM Education*, *1*(1), 5-15.

Convertini, J. (2020). What is the task about? Exploring the issues discussed by preschool children in engineering activities at kindergarten. *Review of Science Mathematics & ICT Education, 14*(2), 85–104.

Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education*, *101*(4), 738-797.

Fleer, M. (2021). Re-imagining play spaces in early childhood education: Supporting girls' motive orientation to STEM in times of COVID-19. *Journal of Early Childhood Research, 19*(1), 3–20. https://doi.org/10.1177/1476718X20969848

Furman, M., De Angelis, S., Dominguez Prost, E., & Taylor, I. (2019). Tablets as an educational tool for enhancing preschool science. *International Journal of Early Years Education, 27*(1), 6–19. https://doi.org/10.1080/09669760.2018.1439368

Kermani, H., & Aldemir, J. (2015). Preparing children for success: Integrating science, math, and technology in early childhood classroom. *Early Child Development & Care, 185*(9), 1504–1527. https://doi-org.libproxy.cortland.edu/10.1080/03004430.2015.1007371

Lin, X., Yang, W., Wu, L., Zhu, L., Wu, D., & Li, H. (2021). Using an inquiry-based science and engineering program to promote science knowledge, problem-solving skills and approaches to learning in preschool children. *Early Education and Development, 32*(5), 695–713. https://doi.org/10.1080/10409289.2020.1795333

Master, A., Cheryan, S., & Meltzoff, A. N. (2017). Social group membership increases STEM engagement among preschoolers. *Developmental Psychology, 53*(2), 201 – 209. https://doi.org/10.1037/dev0000195

Miles, M. B., Huberman, A. M., & Saldaña, J. (2018). *Qualitative data analysis: A methods sourcebook*. Sage publications.

Mulvey, K. L., & Irvin, M. J. (2018). Judgments and reasoning about exclusion from counter-stereotypic STEM career choices in early childhood. *Early Childhood Research Quarterly, 44*, 220–230. https://doi.org/10.1016/j.ecresq.2018.03.016

NSTA. 2013. National Science Teachers Association Position Statement: Early Childhood Science Education. www.nsta. org/about/positions/earlychildhood.aspx.

NGSS Lead States. 2013. Next Generation Science Standards: For states, by states. Washington, DC: National Academies Press.

O'connor, G., Fragkiadaki, G., Fleer, M., & Rai, P. (2021). Early childhood science education from 0 to 6: A literature review. *Education sciences*, *11*(4), 178.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., et al. (2020). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. doi: 10.1136/bmj.n71

Piasta, S. B., Logan, J. A. R., Yeager Pelatti, C., Capps, J. L., & Petrill, S. A. (2015). Professional development for early childhood educators: Efforts to improve math and science learning opportunities in early childhood classrooms. *Journal of Educational Psychology, 107*(2), 407–422. https://doi-org.libproxy.cortland.edu/10.1037/a0037621

Pila, S., Piper, A. M., Lauricella, A., & Wartella, E. (2020). Preschoolers' STEM learning on a haptic enabled tablet. *Multimodal Technologies and Interaction, 4*(4), 87. https://doi.org/10.3390/mti4040087

Pleasants, J. (2020). Inquiring into the Nature of STEM Problems. *Science & Education*, *29*(4), 831-855.

Roehrig, G. H., Dare, E. A., Ellis, J. A., & Ring-Whalen, E. (2021a). Beyond the basics: a detailed conceptual framework of integrated STEM. *Disciplinary and Interdisciplinary Science Education Research*, *3*(1),1-18.

Roehrig, G. H., Dare, E. A., Ring-Whalen, E., & Wieselmann, J. R. (2021b). Understanding coherence and integration in integrated STEM curriculum. *International Journal of STEM Education*, *8*(1), 1-21.

Schlesinger, M. A., & Richert, R. A. (2019). The role of gender in young children's selective trust of familiar STEM characters. *Media Psychology, 22*(1), 109–132. https://doi-org.libproxy.cortland.edu/10.1080/15213269.2017.1328311

Sullivan, A., Kazakoff, E. R., & Bers, M. U. (2013). The wheels on the bot go round and round: Robotics curriculum in pre-kindergarten. *Journal of Information Technology Education, 12*, 203-219. https://doi.org/10.28945/1887

Thwaite, A., & McKay, G. (2013). Five-year-olds doing science and technology: How teachers shape the conversation. *Australian Journal of Language &Literacy, 36*(1), 28–37.

Tippett, C. D., & Milford, T. M. (2017). Findings from a pre-kindergarten classroom: Making the case for STEM in early childhood education. *International Journal of Science and Mathematics Education, 15*(1), 67-86. https://doi.org/10.1007/s10763-017-9812-8

Toran, M., Aydin, E., & Etgiier, D. (2020). Investigating the effects of STEM enriched implementations on school readiness and concept acquisition of children. *Ilkogretim Online, 19*(1), 299–309. https://doi-org.libproxy.cortland.edu/10.17051/ilkonline.2020.656873

Üret, A., & Ceylan, R. (2021). Exploring the effectiveness of STEM education on the creativity of 5-year-old kindergarten children. *European Early Childhood Education Research Journal*, 1-14. https://doi.org/10.1080/1350293X.2021.1913204

van den Hurk, A., Meelissen, M., & van Langen, A. (2019). Interventions in education to prevent STEM pipeline leakage. *International Journal of ScienceEducation*, *41*(2), 150-164.

Vick Whittaker, J., Kinzie, M. B., Williford, A., & DeCoster, J. (2016). Effects of MyTeachingPartner-Math/Science on Teacher-Child Interactions in Prekindergarten Classrooms. *Early Education and Development, 27*(1), 110–127. https://doi.org/10.1080/10409289.2015.1047711

Wan, Z. H., Jiang, Y., & Zhan, Y. (2021). STEM education in early childhood: A review of empirical studies. *Early Education and Development*, *32*(7), 940-962.

Yalçın, V., & Erden, Ş. (2021). The Effect of STEM Activities Prepared According to the Design Thinking Model on Preschool Children's Creativity and Problem-Solving Skills. Thinking Skills and Creativity, 41 100864. https://doi.org/10.1016/j.tsc.2021.100864

Yıldırım, B. (2021). Preschool STEM Activities: Preschool Teachers' Preparation and Views. *Early Childhood Education Journal, 49(*2), 149–162. https://doi-org.libproxy.cortland.edu/10.1007/s10643-020-01056-2

Zucker, T. A., Williams, J. M., Bell, E. R., Assel, M. A., Landry, S. H., Monsegue-Bailey, P., Crawford, A., & Bhavsar, V. (2016). Validation of a brief, screening measure of low-income pre-kindergarteners' science and engineering knowledge. *Early Childhood Research Quarterly, 36*, 345–357. https://doi.org/10.1016/j.ecresq.2015.12.018

BRING KITES TO YOUR STEM CLASSROOM WITH NASA AREN

Suzanne Taylor
taylor@montana.edu
Montana State University

Jeanette Chipps
jeanette.chipps@montana.edu
Montana State University

Mike Jabot
Michael.Jabot@fredonia.edu
State University of New York at Fredonia

Abstract

NASA's AEROKATS and ROVER Education Network offers a unique "aerial perspective" to learners of all ages using large kites, cameras, and sensors to explore Earth from 500 feet above. We fly 10-foot kites and remote sensing equipment to simulate a NASA mission for students: preparation, technology, safety, inquiry and data collection. AREN covers science, technology, engineering and mathematics as well as writing, history, art and other topics. This paper describes three AREN activities within a problem-based learning framework: mini kite design challenge; kite aerial photography; and an exercise for considering how aerial images and data can solve a local problem.

Keywords: problem-based learning, kite, NASA, aerial photography, STEM

Introduction

The nationwide NASA AEROKATS and ROVER Education Network (AREN) offers a unique "aerial perspective" to learners of all ages using large kites (up to 10 feet across) equipped with cameras and sensors on a payload platform (Figure 1 and 2). Just like all NASA missions, a kite flight requires planning and preparation; tools, technologies and safety protocols; delineation of team member roles; formulation of the scientific questions to be answered by the mission; and a post-mission debrief and interpretation/communication of the data collected. Like other aeronautic technologies such as satellites, kites can give students a view of

Figure SEQ Figure * ARABIC 1
Project participants fly large kites to collect data for NASA.

Figure SEQ Figure * ARABIC 2
A payload platform hangs beneath the kite to hold a camera or remote sensing instruments.

their community from above, but kites—with their string tethered to the Earth and the hands of the human kite pilot—connect people to place in a way that is inherently local. AREN content helps fulfill standards across STEM content areas with plenty of room for other topic areas, such as history, reading, art, writing and more. Activities can be scaled for most grade levels and can apply to out-of-school/informal education settings. The project also lends itself to advancing the skills most valued by STEM employers, such as teamwork and problem solving (McGunagle & Zizka, 2020) as well as the introduction of varied cultural perspectives of science. Ultimately, we hope students can use data collected from kites as the gateway to more complex thought on how we can use data to solve local environmental problems.

Purpose

This proceedings paper will introduce a NASA Science Activation (aka "SciAct") project that connects NASA science experts, real content and experiences with community members to do science in ways that activate minds and promote deeper understanding of our world and beyond (https://science.nasa.gov/learners). This paper outlines three classroom activities that dovetail to offer students a unique way to think about their place in the world and the socioscientific issues that may affect it:

- an engineering design challenge introduces the concepts of kites and flight: aerodynamics, kite design and vocabulary, and the engineering mindset
- Kite Mysteries, a phenomenon-influenced activity based on Kite Aerial Photography (KAP) guides students through questions presented as "mysteries" through images. Students identify how light, shadow, color, shape and context reveal information, and they discover how aerial photography offers a unique perspective on known places.
- A group activity prompts students to think about how aerial photography and environmental data from kites or other sources can help solve a local problem.

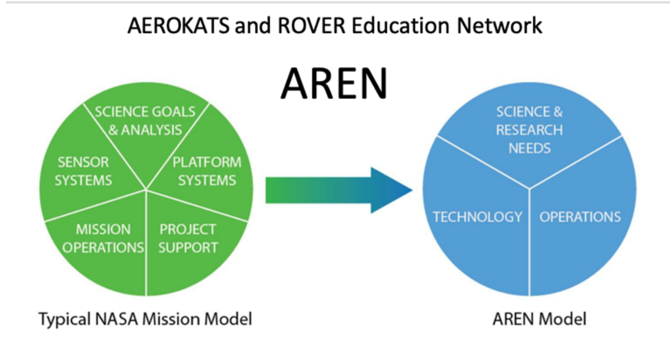
Instructional framework

Though we outline just three activities here, the NASA AREN project offers a broad suite of STE(A)M activities that draw upon concepts from several instructional frameworks, including guided inquiry, engineering design challenges, and both place-based and problem-based learning.

The three activities we describe are deliberately selected for their alignment with the key concepts of Problem-based Learning, through which students connect to authentic situations in which they "step inside the learning situation and own the problem." (Torp & Sage, 2002, p. 19).

According to Wirkala & Kuhn (2011), "Problem-based learning (PBL) is a teaching and learning method in which students engage a problem without preparatory study and with knowledge insufficient to solve the problem, requiring that they extend existing knowledge and understanding and apply this enhanced understanding to generating a solution" (p. 1157).

The process of comparing a kite flight to a NASA mission is a useful infrastructure (Figure 3). For the NASA AREN project, we distill a typical NASA Mission Model into a condensed model useful in the broader educational environment by combining sensor and platform systems into *technology*; and mission operations and project support into *operations*. Science goals and analysis are key features of a Problem-Based Learning exercise. "Like a rocket launch, each (kite) flight or mission is a team effort in which all participants have specific roles, checklists are developed and followed, risks are assessed and mitigated, and operations are preceded and followed by comprehensive briefings," said AREN team member David Bydlowski. (NASA Spinoff newsletter, 2018). Additionally, AREN allows for the expansion of current technologies into classroom practice to help students understand the role of these technologies across STEM fields and careers (Kerski, et al., 2019)



Importantly, through NASA AREN, students can identify and reflect on environmental or socioscientific issues in their local communities or neighborhoods, then consider how those problems can be tackled by collecting information through aerial images or other data. Preliminary activities introduce students to kite building, Kite Aerial Photography (KAP) and data collection.

Practice and Innovation

NASA AREN "integrate(s) technology and fun" (Xie et al, 2014), by introducing kites—a technology that is recognizable to nearly everyone—with an innovative twist that will be new and attractive to most students (and likely adults, too): kites for scientific inquiry.

Kites are familiar, fun and instantly engaging. In two Montana State University workshops for teachers, 30 out of 31 participants said they had flown a kite before. In a similar workshop for high school students, most students said they had flown a kite, with many students offering detailed and nostalgic stories about flying with parents, grandparents, cousins, siblings and friends. People who have flown a kite can typically conjure up detailed descriptions of the kite—its shape, colors and style—as well as the people they flew with; the place where they flew; and even the wind and weather conditions of the day. These vivid images and memories set the stage for further exploration into how kites can be more than a toy.

Despite their familiarity with kites, few people who have flown a kite for recreation are aware that kites can also be used to collect data about the Earth, and that a kite flight can simulate a NASA mission as is done through NASA AREN.

It is this aspect of NASA AREN—the surprising twist of data collection and its accompanying procedures and operations—that sets it apart from other kite-based curricula and activities. To increase accessibility to the concepts of NASA AREN, the activities presented below can be done indoors and with minimal cost, risk and investment of time while introducing students to the broader concepts of solving local problems through data collected from a kite. The project also offers ample opportunities to weave in art, history, ethics and other non-STEM topics.

Classroom Examples

Mini-Kite Design Challenge. This activity introduces students to the concepts of kites and the forces of flight in order to prepare them for further inquiry into using kites in the process of science. Students follow an instruction sheet to construct a miniature kite based on a NASA design, with specific materials, sizes and specifications. Students learn the vocabulary of kite geometry: span, surface area, aspect ratio, as well as the forces of aerodynamics: lift, drag, weight and pull. When built to specifications, the mini kite—less than 3 inches across—will exhibit aerodynamic properties and loft into the air (Figure 4). Students hypothesize what attributes of the kite make it a successful design, and then they plan, build, test—and often rebuild—their own kite designs. Students use an engineering mindset to capture their design ideas; hypothesize on their kite's performance; figure out how to measure success; and then modify their designs.

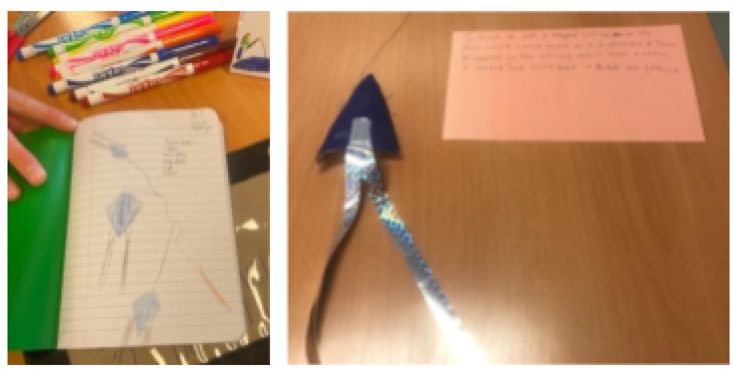


Figure SEQ Figure * ARABIC 4
Students plan and sketch their suggested design modifications before building mini-kite prototypes.

Kite Mysteries/Aerial Photography. Students are presented with aerial images (Figure 5) taken from a variety of sources (airplanes, drones, balloons or even a pigeon) and learn how aerial photos and mapping can assist with environmental monitoring (such as flooding, deforestation or the surface area of an oil spill). Students then view images taken from a camera attached to a kite (Kite Aerial Photography or KAP). Students answer guided questions about the photo and are prompted to articulate how they "know what they know" about an image, using shapes, colors, context, light and shadow, etc. as guides. Many aerial photography sources can be used, including Google Earth images or the beautiful satellite images from NASA's Earth as Art collection (Friedl et al, 2012). A deeper dive for older students can include color correction, land cover classification or NDVI (normalized differentiated vegetation index – an indicator of dense green leaves).

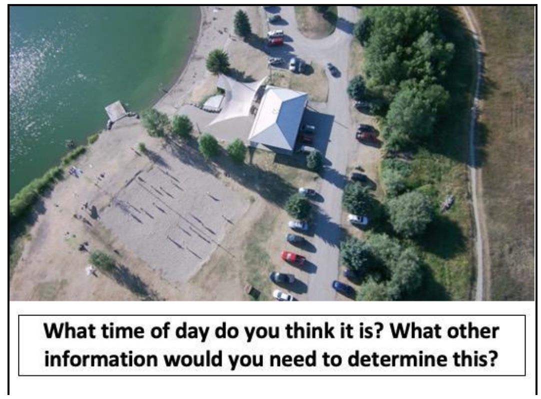


Figure SEQ Figure * ARABIC 5
Kite Aerial Photography prompts students to look at light, shadow, color and context in images.

Aerial images of nearby landmarks can help students connect on a personal level, such as a photo of a local river or corn maze (Figure 6). Likewise, aerial images of culturally significant areas can strengthen personal connections and recognize various cultural worldviews of science. In our Montana workshop, an image of Big Horn Medicine Wheel in northern Wyoming was familiar to Native American students who had traveled there with their families.

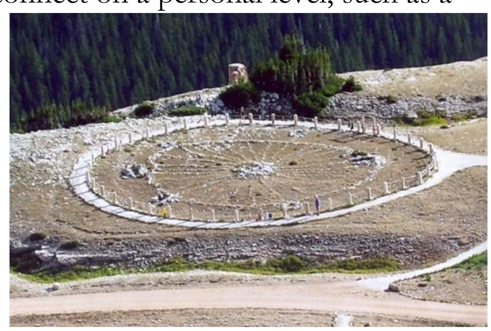


Figure SEQ Figure * ARABIC 6
Aerial photos of local and/or culturally significant places amplifies personal connections. Photo courtesy U.S. Forest Service.

Using Data to Help My Community. Lastly, students use personal reflection, small-group discussion and guided questions to discover how kites (Activity A) and Kite Aerial Photography (Activity B) can come together to solve a local problem. Students answer four questions:

- Question 1: What are the natural features of your community?
- Question 2: What do you love about your community
- Question 3: What is one thing that worries you about the environment where you live?
- Question 4: How could you use aerial photography or environmental data to solve the problem you identified.

First, they use two colors of sticky notes to share natural features of their community or neighborhood (e.g., a park, buttes, Yellowstone River) and then what they love about their communities (e.g., mountains, our FFA chapter, caring people). Sometimes these categories overlap. Students use a third sticky note to name an issue in their community that worries them. For the final question, students work in pairs or small groups to discuss the challenge they identified and brainstorm how aerial images or other data could help solve the problems they identified (Figure 7). If students need guidance, the instructor can share some possible challenges, such as floods, drought or homelessness and describe ways in which aerial photography and/or data can help solve that particular challenge.

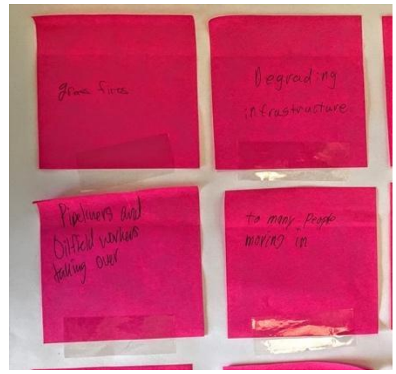


Figure 7
Students articulate challenges in their communities.

High school students in a recent workshop mentioned such problems as grasshoppers, pollution, and "too many people moving in." Middle schoolers in a previous workshop wrote about smoke, "flooding at my house," and the "possible shooting of deer in town," among other issues. Extensions on this activity could include further probes into geospatial solutions for environmental justice, including the study of global climate change.

We have outlined three activities in detail, but the NASA AREN project includes many more activities that we will not describe here, including:

- Practicing art, design and making as students construct and decorate Frustrationless Flyer sled kites (Figure 8). Art can be student choice or an instructor-assigned topic, such as fractals, book characters or other elements of interdisciplinary learning.
- How kite-based activities dovetail with authentic citizen science projects such as GLOBE Observer's clouds and land cover protocols (http://observer.globe.gov)
- Kite-based mathematics (wind speeds, string angles, etc.)
- Connections to the arts and humanities—kites in literature, history, ethics etc., and
- 21st Century STEM skills such as teamwork, self-motivation, communication, and problem-solving.

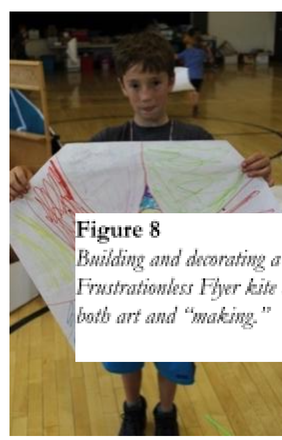


Figure 8
Building and decorating a Frustrationless Flyer kite combines both art and "making."

Implications

NASA AREN offers a breadth of flexible STEM and non-STEM activities for the classroom—from remote sensing and geospatial technologies to engineering skill development and data capture and analysis (Henry & Bland, 2020)—all surrounding an object that is fun, familiar, and accessible (a kite) and an organization that is known and intriguing (NASA). Students who learn about NASA AREN and its data collection via kites are often surprised to rethink the notion that NASA studies not only stars and galaxies but our own planet, Earth, as well. NASA AREN also opens the doors to non-STEM activities, including the study of global cultures and diverse perspectives of science. "Creative Arts, integrated into design and visualizations, are also an important element, particularly for attracting a wide and diverse learning audience"(Henry & Bland, 2020).

NASA AREN's flexible kite-related activities span the gamut from K to 12 and are often attractive to parents, caregivers and other adult learners, as well. AREN allows for easy access for students to learn about their "place" and is both at a scale that allows them to do deeper analysis and is a much easier entry for a classroom environment than using other remotely sensed data, such as the Landsat satellite program. The concept of kites for data collection opens doors to think about how science and data can be used to solve local problems, as even the youngest students are surprisingly interested in and aware of the challenging issues in their communities.

References

Friedl, L. et al (Ed.). (2012). *Earth as Art*. NASA. Retrieved from https://www.nasa.gov/connect/ebooks/earth_art_detail.html

Henry. A, & Bland, G. (2020) Novel Tools and Approaches from NASA and the AREN Project for STEAM Based Learning. [Conference presentation abstract]. American Geophysical Union Fall Meeting 2020, abstract #ED041-05. https://ui.adsabs.harvard.edu/abs/2020AGUFMED041.05H/abstract

Kerski, J.J., Baker, T.R. (2019). Infusing Educational Practice with Web GIS. In: de Miguel González, R., Donert, K., Koutsopoulos, K. (eds) Geospatial Technologies in Geography Education. Key Challenges in Geography. Springer, Cham. https://doi.org/10.1007/978-3-030-17783-6_1

McGunagle, D., & Zizka, L. (2020). Employability Skills for 21st Century STEM Students: The Employers' Perspective. *Higher Education, Skills and Work-Based Learning*, 591-606. https://doi.org/10.1108/HESWBL-10-2019-0148

NASA. What is SMD's Science Activation (SciAct) program? (n.d.) Retrieved from https://science.nasa.gov/learners

NASA. (2018). NASA Kite Invention Spurs Ever-Growing Educational Program [newsletter]. Retrieved from: https://spinoff.nasa.gov/Spinoff2018/ee_8.html

The GLOBE Program. About GLOBE Observer (n.d.) Retrieved from https://observer.globe.gov/

Torp, L. and S. Sage. (2002). *Problems as Possibilities: Problem-Based Learning for K-16 Education*. 2nd edition. Association for Supervision and Curriculum Development.

Xie, Y. (2014). Linking climate change education through the integration of a kite-borne remote sensing system. *Journal of Science and TechnologyEducation*, 4(3), 120–137. https://doi.org/10.3926/jotse.113

Wirkala, C., & Kuhn, D. (2011). Problem-based learning in K–12 Education: Is it effective and how does it achieve its effects? *American Educational Research Journal*, *48*(5), 1157–1186. https://doi.org/10.3102/0002831211419491

Acknowledgement

This work is supported NASA Science Mission Directorate Science Education Cooperative Agreement Notice (CAN). Solicitation: NNH15ZDA004C. Award Number: NNX16AB95A. Principal Investigator: Andy Henry.

All photos are the authors' unless otherwise noted.

LEARNING BY SCIENTIFIC DESIGN: USING COGNITIVE SCIENCE TO IMPROVE MATH AND SCIENCE METHODS COURSES

Andrea Foster
asf004@shsu.edu
Sam Houston State University

Kristi Matin
kmx138@shsu.edu
Sam Houston State University

Abstract

This study draws out the implications of a Learning by Scientific Design (LbSD) initiative to improve teacher candidates' thinking about their teaching and children's learning. LbSD emphasizes a cognitive science approach to prepare future science and mathematics teachers with a deeper understanding of how students learn. So, future educators can make instructional decisions that lead to deeper and more equitable learning for generations of PK-12 students. This study examines the impact on teacher candidates' thinking after experiencing three learning science modules in their elementary and middle-level math and science methods courses. We will share assessment data centered on learning science principles and provide a few insights for revising math and science coursework to emphasize a cognitive science approach that equips future science and mathematics teachers with a deeper understanding of how students learn.

Keywords: Cognitive Science; Learning Science; Teacher Preparation; Math and Science Teaching.

Introduction

Effective preparation of science and mathematics teachers is the work of teacher educators. In 2019, the Deans for Impact established Learning by Scientific Design (LbSD) by asking ten teacher preparation programs across the country to reimagine and redesign the arc of teacher-candidate experiences to ensure candidates are prepared with the best scientific understanding of how students learn. In the Spring of 2020, Deans for Impact launched a second cohort of five universities to work with teams of faculty to build their understanding of the learning science principles. Our teacher preparation program, which prepares over 300 teacher candidates each year, was one of the five universities selected to take part in the second LbSD cohort. A team of dedicated faculty and administrators have been engaged in deepening their understanding of learning science principles and how knowledge of these principles supports instructional decision-making. In the first year of LbSD work, we gauged our current programmatic practice and found areas where our program might improve. We designed and implemented changes to our coursework and then measured changes to our program to help our new teachers understand and apply learning science principles in their classrooms. Early assessments and initial classroom observations showed our elementary (EC-6) and middle level (4-8) teacher candidates appreciated experiential "hands-on" activity-driven learning for student engagement but needed further development in prioritizing and engaging students in deep thinking. We also found that our teacher candidates understand the value of teaching questioning but needed further support in designing and sequencing intentional questions that support students in effortful thinking and making connections between "what" and "why." Once we set our focus, we piloted LbSD course modules that centered on deepening meaning and Learning in our elementary and middle-level math and science methods courses.

Purpose

The purpose of this study is to explore the impact of LbSD Deepening Meaning & Learning–focused modules, including three teacher actions – 1) Attention to Meaning (ATM), 2) Effortful Thinking (EFT), and 3) Examples/Non-examples (ENE). These modules focus on candidates' thinking about learning science principles and more importantly, we are exploring how are our teacher candidates apply learning science to their practical teaching experiences. Our research questions are as follows:

1. Is there an increase in teacher candidates' scores on an assessment of learning science principles after experiencing three learning science modules?
2. In what ways have our teacher candidates' thinking about learning science principles shifted after experiencing three learning science modules in their methods classes?

In this paper, we share the early impact of using a learning science approach in EC-6 and 4-8 mathematics and science teacher preparation methods courses. We also consider the shifts made in our teacher candidate's thinking about teaching and their students' learning of math and science.

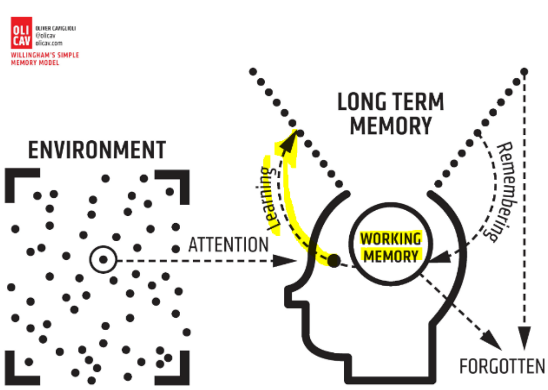
Theoretical Framework

Cognitive science is becoming the foundation for understanding how students learn and is transforming how we prepare future teachers. Rather than focus our teacher candidates' attention on outdated learning theories of the past, why not arm them with new understandings of how the human brain learns and how to make learning stick? The Deans for Impact Learning by Scientific Design (LbSD) Network supports programs in preparing novice teachers with a deep understanding of learning science principles and the ability to apply that knowledge in service of student learning. Two fundamental questions that the Science of Learning seeks to answer are 1) What do we know about how children learn? and 2) What does that mean about how we teach?

Many teachers often know little about how learning works. Somehow, even though cognitive science--also known as the science of learning or learning science--has been around for decades, it is not addressed in intentional ways in teacher preparation programs (Goodwin et al., 2020). As knowledge about human development and learning has grown at a rapid pace, the opportunity to shape more effective educational practices has also increased. Taking advantage of these advances, however, requires integrating insights across multiple fields—from the biological and neurosciences to psychology, sociology, developmental, and learning sciences—and connecting them to the knowledge of successful approaches that are appearing in education (Darling-Hammond, et al, 2020). Studies of popular textbooks used in preservice programs found that none accurately describe six key instructional strategies grounded in the science of learning (Pomerance et al., 2016). According to the authors of the report, new teachers are not learning "the most fundamental information needed to make learning 'stick'" (p. v). As a result, new teachers enter the classroom with an incomplete toolkit, which can leave them frustrated and overwhelmed and leave students short-changed (Goodwin et al., 2020). Students will continue to experience shallow, disconnected learning and be confused about content because they do have opportunities to process new content deeply. According to Woodford-Richens (2021), "Cognitive science is understanding how the structure and functions of the brain affect our ability to learn. It is a branch of science that considers brain architecture when thinking about how to embed learning into the minds of our students" (p.1) Human cognition can be broadly divided into our working memory or short-term memory and long-term memory (Figure 1).

Figure 1

Willingham's simple memory model



Willingham's (2009) simple memory model illustrates that environments are full of stimuli. According to Manners (2019), we learn what we pay attention to. Because working memory is limited, teacher candidates need to be able to create lessons where students are thinking about what we want them to think about. For learning to be remembered and stored in long-term memory, it must be thought about and encoded. Effortful thinking is a prerequisite for learning and building knowledge, so students who are denied the opportunity to think effortfully about rigorous content are less likely to encode what they learn into long-term memory. This means they will have trouble building new learning on foundational concepts - a trend that just compounds over time. Learning science focuses on a set of cognitive principles and their practical implications for the classroom. The LbSD Network emphasizes five learning science principles and teacher actions: 1) Managing the learning load, 2) Connecting the dots, 3) Deepening meaning and learning, 4) Practicing with purpose, and 5) Creating a motivating environment. For this study, we explored our teachers' candidates' understanding of cognitive science principle #3 Deepening meaning and learning, which focuses on how students understand what information means and why it is important. Students should think about meaning when they encounter material to be remembered. Three teacher actions are associated with this principle: 1) Teachers' questions and tasks must focus students' attention on the meaning of content; 2) Teachers' questions and tasks require students to engage in effortful thinking, and 3) Teachers' prompt students to connect and distinguish varied examples and non-examples.

Methodology

A mixed methods concurrent design (Creswell & Plano Clark, 2018) was used in this study. We used the LbSD Assessment of Learning Science Principles to collect quantitative data about our teacher candidates' knowledge of the learning science principles. To benchmark progress, we administered the 30-minute online knowledge assessment given to teacher candidates in sections of EC-6 and 4-8 methods courses at the end of the Fall 2020 (N=105) and Fall 2021 (N=155). The assessment's three domains are designed to illuminate a candidate's skills and knowledge of learning science principles both theoretically and practically, as well as a candidate's beliefs about the importance of those principles.

We collected student work from note catchers, exit tickets, and reflections from the LbSD modules taught in the math and science methods courses to analyze qualitatively. Teacher candidates completed note catchers as they worked through the modules either in class or asynchronously and completed exit tickets after the end of each module. Finally, instructors asked teacher candidates to reflect on their experiences with the learning science modules and how they connected the ideas they had learned with their future classrooms. These three sources of data were used to triangulate the qualitative artifact data.

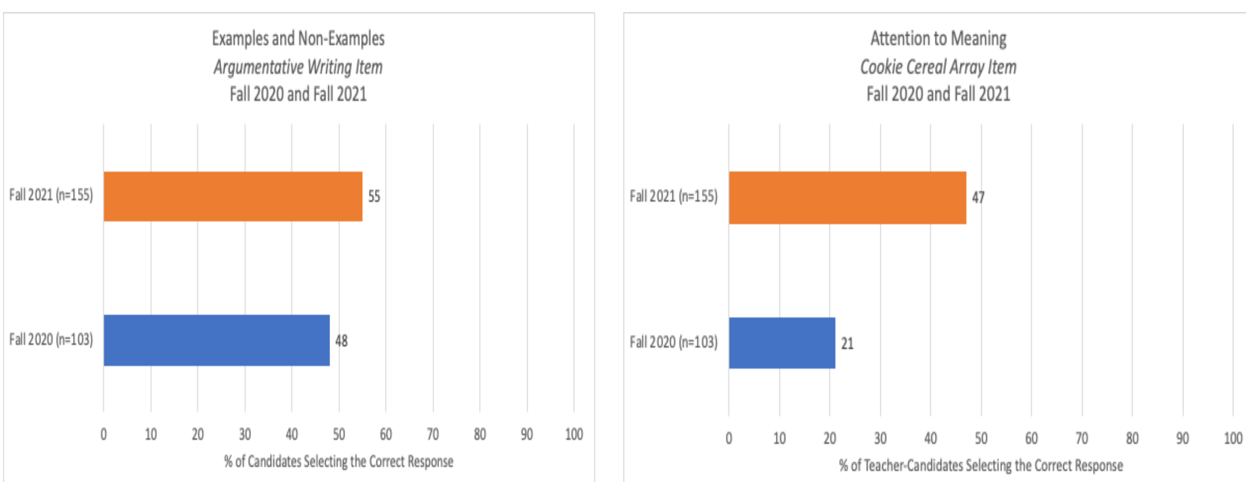
Results and Discussion

Teacher candidates in math and science methods courses experienced the Deepening Meaning and Learning Modules, which included three different teacher actions. From the Fall of 2020 to the Fall of 2021, scores on the test of learning science principles for all students in the teacher education program increased from 56% to 63% correct for this principle. Scores also increased from 37% to 47% correct on the learning science principle of connecting the dots, which was experienced in literacy methods.

We further analyzed two learning science assessment items, as shown in Figure 2. One question addressed the teacher's action of Examples and Non-Examples, which had been taught in math methods, in an English-Language Arts context. Correct answers for this question increased from 48% to 55%. The other question addressed the teacher's action of Attention to Meaning, which had been taught in science methods, in a math context. This question increased from 21% correct to 47% correct. The increases in both questions show that teacher candidates' knowledge of the learning science principles increased and that they were able to apply the principles outside of the subject area that they have been taught.

Figure 2

Scores on Two Teacher Action Questions in Fall 2020 and Fall 2021



From classwork and exit tickets on the learning science principles, we began to see a shift in how teacher candidates analyzed lessons and thought about the learning science principles. For example, on an exit ticket for one of the modules, a 4-8 mathematics teacher candidate explained her reasoning for choosing sample Lesson A over sample Lesson B, "Lesson B was definitely trying to make math fun. Even though that is good at times, using those higher-order thinking words really [made Lesson A the] better lesson. A different 4-8 mathematics teacher candidate explained her reasoning "All the to-be-remembered content is addressed in Lesson A. … The students would have fun doing the activities in lesson B but it is not addressing the information that the students are responsible for learning." These in addition to other responses show that our teacher candidates started to shift their focus from picking "fun" lessons to engage students to lessons that focused on higher order thinking and addressed content. This shift is important and has practical implications for their classroom practice.

On final reflection, we also saw evidence that teacher candidates were applying their knowledge to planning lessons in their student teaching placements, which took place concurrently with their science methods course. One EC-6 teacher candidate shared a connection between the model of the mind and her teaching, "When I see the diagram of the model of the mind, I see my students and I'm more aware of what my students are paying attention to and how important my role is in focusing their attention on the to-be-learned content for that lesson." Another teacher candidate studying 4-8 mathematics connected the modules to the lessons she planned stating that

> The main takeaway I got from the LbSD work is to focus students' attention on the to-be-learned material and try not to distract their attention away from what they should be learning. I have incorporated this thinking into all my lessons I've taught this semester by making sure everything I say and have students do points back to what I'm trying to teach them.

This connection to their classroom practice is important because our overall goal is to improve their classroom teaching. These reflections show that our teacher candidates are making those connections and thinking about the learning science principles as they plan lessons and activities for their student teaching and future classrooms.

Implications

While still early in the implementation of the LbSD work through our EC-6 and 4-8 math and science courses, we are beginning to see deeper, more durable connections by our teacher candidates in their coursework and lesson planning. We feel that using a cognitive science approach as a foundation for preparing next-generation science and mathematics teachers strengthens teacher candidates' thinking about what and how they are teaching. This cognitive science approach not only strengthens teacher candidates' understanding of how children learn, but also, helps future teachers think about how to prepare math and science lessons that maximize learning by using strategies that focus students' attention on the meaning of the content and think about it in effortful ways. Teacher candidates often come to us with a superficial understanding of their content and as a result, they sometimes "drift' from the aim of the lesson planning and use "fun" activities which draws learning away from the content to be learned. The Learning by Scientific Design modules can help new teachers think about how to best teach their content. With knowledge of Willingham's (2009) Simple Memory Model and cognitive science teacher actions and learning strategies, we hope novice science and mathematics teachers will affect P-12 learners in robust and durable ways.

Next Steps

We are in the third year of our LbSD learning implementation arc, in which we are continuing revisions in mathematics and science coursework and integrating other LbSD learning modules. Mathematics and science methods faculty have been onboarded and are piloting LbSD modules in their courses. We are seeing and analyzing pedagogical practice and enactment in clinical practice in Years 1 and 2 of the residency semesters. A third LbSD assessment will be administered Fall 2022.

References

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). Sage.

Darling-Hammond, L, Flook, L Cook-Harvey, C, et al. (2020) *Implications for educational practice of the science of learning and development* Applied Developmental Science, 24*(*2), 97-140.

Deans for Impact: The science of learning. Retrieved. Oct. 14, 2022 https://deansforimpact.org/resources/the-science-of-learning/

Goodwin, B., Gibson, T., & Rouleau, K. (2020). *Learning that sticks: A brain-based model for K-12 instructional design and delivery.* ASCD: McRel.

Manners, A. (2019). The science of learning: Three big ideas for faculty. *Seneca Academic Newsletter.* *https://employees.senecacollege.ca/spaces/153/academic-newsletter/articles/june-2019/8830/the-science-of-learning-three-big-ideas-for-faculty*

Pomerance, L., Greenberg, J. & Walsh, K. (2016). *Learning about learning: What every new teacher needs to know.* National Council on Teacher Quality.

Woodford-Richens, K. (2021). Using cognitive science to improve classroom practice. Head Teacher Update. Retrieved from https://www.headteacher-update.com/best-practice-article/using-cognitive-science-to-improve-classroom-practice-metacognition-cognitive-load-theory-sweller-wiliam-working-memory-long-term-short-term-pedagogy-1/236323/

Acknowledgements

The researchers would like to acknowledge *Deans for Impact and the Learning by Scientific Design Network* for supplying support for a second cohort of educator-preparation programs (Spring 2020-Summer 2023).

ENGAGING WITH COFFE: A TEACHER'S EXPERIENCE WITH AUTHENTIC INQUIRY AND IDENTITY

Jeanette Chipps
jchipps3@jh.edu
Johns Hopkins University

Abstract

This single-case study reports on the outcome of a professional development designed to inform teachers of the role of authentic inquiry in developing STEM identity. In this professional development series, the participating teacher learned about the constructs of authentic inquiry and STEM identity, designed a lesson series which engaged learners in authentic science inquiry, and then reflected on the outcome of the lesson series. The findings here report on changes in teacher knowledge, measured through qualitative analysis of pre- and post-intervention interviews and researcher field notes, following the workshop series.

Keywords: STEM identity, science inquiry, single-case design

Introduction

This paper presents the results of a professional learning experience that sought to increase teacher knowledge of the constructs of STEM or science identity, authentic inquiry, and the role of authentic inquiry in supporting identity development for marginalized learners. The context was a single research site, located in Southern California, in which the researcher had first conducted a small needs assessment-type study. The work presented here sought to address a local opportunity gap by race and gender with regards to student course-taking and performance on a state science test. In an initial survey, teachers indicated a low level of knowledge and use of practices which support STEM identity and thus the professional learning described here was designed to increase teacher knowledge of the importance of STEM identity and authentic inquiry.

Related Literature

Several papers have described student experiences with authentic science as a mechanism for developing student science identity (Chapman & Feldman, 2017; Shaner et al., 2018; Williams et al., 2018). In these cases, students are given the opportunity to engage in scientific endeavors that external experts would engage in, and oftentimes have the opportunity to connect directly with the researchers engaged in the work. However, in these cases the role of the teacher is not well-documented as the science experience is driven by the research team investigating the experience. There is also literature to suggest a need to be theoretically explicit in supporting STEM teachers in developing culturally relevant classrooms (Brown et al., 2018). Previous work by Smith and Darfler (2012) demonstrated how science teachers in a graduate course were introduced to science identity and instructional practices that support identity. In this research, Smith and Darfler presented identity work principles to teachers and documented barriers to implementing this work reported by teachers. These reported barriers included time to implement the identity work and a need to address curricular demands. The current study sought to provide theoretically explicit professional development over the course of six months, with ongoing supports and workshops in order to support teachers with an emphasis on specific instructional strategies and curricular connections that could be made to support development.

Objectives of the Study

The objectives of the current work were to document the teacher experience, particularly in terms of changes in teacher knowledge, as they sought to develop learning experiences for their students that were more authentic and provide greater opportunity for identity development. To reach these objectives, a set of workshops were designed as well as additional supportive check-in sessions with the teachers to provide an effective professional development experience (Darling-Hammond et al., 2016). In addition to measuring the outcome of the professional learning on teacher knowledge, this work also presents the results of a process evaluation on this professional development given that this focus within the professional development is unique. The research questions addressed included:

(1) To what extent is the participating teacher engaged in the learning activities? (process)
(2) To what extent does the intervention support the participant's knowledge of STEM identity and authentic inquiry? (process)
(3) In what ways does the teacher's knowledge of student STEM identity and authentic inquiry change after participation in the intervention? (outcome)

Theoretical Framework

There were three theoretical frameworks applied within this study: Rodriguez's (1998) sociotransformative constructivism guided the design of the professional learning, Burgin's (2020) framework on authentic inquiry, and Carlone and Johnson's (2007) science identify framework. Zozakiewicz and Rodriguez (2007) presented an example of a sociotransformative constructivism-informed professional development aimed at helping support teachers to create multicultural, gender-inclusive science classrooms, called Project Maxima, and the guiding principles from Project Maxima were used within the current professional development design. In particular, Zozakiewicz and Rodriguez suggest that professional learning should be theoretically explicit, and therefore, the current workshop design sought frameworks for the constructs of interest, science identity, and authentic inquiry that would be approachable for K-12 educators as well as rooted in education research. Carlone and Johnson's identity model was used to inform the work of Chapman and Feldman (2017) in analyzing the student experience during an authentic science experience in which students partnered with a university researcher studying algal biofuels. In fact, Chapman and Feldman created an identity work rubric aligned to the Carlone and Johnson (2007) model that could be used to analyze student work samples. The identity framework recognizes the interaction of a students' racial, gender, and ethnic identities with their science identity, which is composed of the performance, recognition, and competence dimensions. Burgin's (2020) authentic inquiry framework was also chosen as it had a rubric that teachers and researchers could use to determine the degree to which an inquiry experience was authentic as measured by the dimensions of relevance to learner, relevance to others, and likelihood of practice being employed by scientists. These two rubrics enabled the user to have a more concrete method of determining whether they were addressing the constructs within their lesson design and implementation.

Methodology

During the fall of 2021, all STEM teachers from a large, suburban charter school in Southern California were recruited to participate in the professional development. While interest in the topic was evident in responses to the recruitment email, teachers often reported a lack of time due to the return to classroom for the first semester in over a year due to the COVID-19 pandemic. Thus, only a single teacher was able to commit to the workshop series and a single-case study design was chosen (Onghena et al., 2019). This case study teacher was a female, veteran science teacher with over 15 years of experience in the classroom, but the teacher had only taught the specific course chosen for this research study for a single year (remotely due to the COVID-19 pandemic). Data collection began in September 2021, with a pre-workshop series interview and classroom observation. Three workshops were held in October, December, and March, with several formal and informal support sessions included between workshops. Table 1 provides a brief description of the topics of each workshop and the activity which the teacher engaged in during the workshop.

Table 1

Workshop Topic and Activities

Workshop	Topic	Teacher activity	Researcher role
1 (Oct 2021)	Introduction to constructs	Engaged in hands-on inquiry activities Considered the meaning of constructs of interest Explored theoretical frameworks related to constructs of interest	Provided hands-on inquiry activities of varying degree of authenticity Prompted reflection on constructs of interest Presented evidence to support the use of authentic inquiry in supporting identity formation for marginalized learners
2 (Nov 2021)	Lesson planning	Began lesson planning	Encouraged the use of rubrics aligned to theoretical frameworks to guide planning
3 (March 2022)	Lesson study/ evaluation	Reflected on the effectiveness in the lesson delivery based on student work sample	Encouraged reflection rooted within framework-aligned rubrics Prompted consideration of next steps for the participant in continuing this work

The support sessions enabled the researcher to assist the case study teacher with lesson plan preparation and to provide guiding questions and ideas regarding material support. However, the researcher ensured that the direction of the authentic science experience designed by the teacher came from the teacher rather than the researcher, with the researcher providing collaborative support that would have been provided in a professional learning community (DuFour & Eaker, 2009). The findings regarding changes in teacher knowledge after the professional development which are presented here are supported by the qualitative interviews as well as researcher notes from the support sessions and professional development workshops. The pre- and post-workshop interview transcripts were coded using thematic analysis, with several *a priori* codes utilized from the identity work principles of Smith and Darfler (2012) on teacher knowledge of identity as well as constructs within the theoretical frameworks of Carlone and Johnson (2007) and Burgin (2020). To enhance trustworthiness of the qualitative analysis, the participant engaged in member checking with the researcher to confirm that the findings reflected the participant's experience. The first two research questions addressed in this work are part of a process evaluation of the workshop series. The process evaluation specifically addressed the constructs of participant responsiveness (RQ #1, Dusenbury et al., 2003) and program differentiation (RQ #2, Dusenbury et al., 2003). The participating teacher was asked to complete Likert scale surveys at the end of each workshop and was asked questions regarding specific aspects of the program that supported their growth in understanding STEM identity and authentic inquiry.

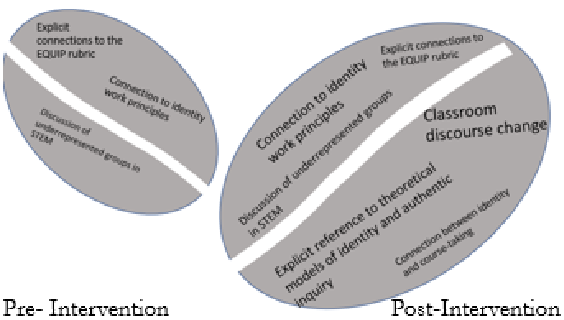
Results and Discussion

Process evaluation: The process evaluation results included data from the post-workshop surveys as well as the final interview responses. The first research question addressed participant responsiveness throughout the intervention, which was measured through Likert scale items in the post-workshop surveys. The participant was asked to indicate their level of engagement with the workshop and each workshop was rated at the highest level, indicating a high responsiveness, and due to the nature of the single case-study design, the workshops were scheduled to enable full participation. Additionally, in response to how the program enabled growth within their understanding of the constructs of interest, the participant reported that the structure of the PD workshops and presentation manner were largely supportive of, rather than barriers to understanding authentic inquiry and STEM identity. Specifically, the participant reported "you had different points where maybe I'm more focusing on STEM identity, but then there's other times where I could focus on the authentic piece. And then there was like times where we could bridge that and make sure that we're meeting our targets, with both kind of integrated together." Furthermore, when asked about particular components of PD that might differentiate this experience from others in enabling the teacher to understand STEM identity and authentic inquiry the teacher responded, "I really liked using the rubrics and seeing what rubrics would tell me, like how I could look at something and see if I was actually meeting the targets for like a Level 1, 2, or 3." Overall, the emergent themes from a qualitative analysis of the responses to the interview questions regarding the process evaluation was that the teacher a)was able to identify the intended structure of the PD workshop and b) reported that structure as supportive to their personal understanding of the constructs.

Outcome evaluation: In addition to understanding how the teacher came to experience changes in their understanding of STEM identity and authentic inquiry, it was also important to document those changes. Researcher field notes taken during the workshops and support sessions, as well as analysis of the interview transcripts taken from pre- and post-interventions enabled this comparison. During the workshops, the teacher designed a lesson series surrounding the effects of caffeine on cellular division. This decision was made as it connected to the students' lives as the students often brought coffee or tea into the classroom in the morning and yet represented a line of scientific research that is ongoing which the teacher could use to connect students' lines of inquiry. Early indicators of changes to teacher knowledge were present during the support session after the first workshop and during the second workshop, as the teacher began to utilize the language of the Carlone and Johnson (2007) identity framework. In figure 1, the codes from the teacher's interview are represented visually as coffee beans to honor the teacher's choice to root the lesson series within the students' experience. The coffee bean on the left indicates the codes present in the pre-intervention interview, while the coffee bean on the right shows changes after the intervention workshop series.

Figure 1

Codes from pre- and post- intervention interviews



The font size for each code indicates how often in was present. Before the workshop series, the participating teacher was well-versed in inquiry, as evidenced by her explicit references to aspects of quality inquiry found in the EQUIP rubric (Marshall et al., 2009) which was used to measure changes in instructional practices, such as statements regarding particular instructional strategies related to the 5E instructional model (Bybee et al., 2006).

Additionally, the teacher had a broad definition of STEM identity, stating that it is "someone who is naturally inquisitive about the world around them and wants to further investigate how they can explain natural, and human-made phenomenon through the lens of STEM and using those to progress their understanding and interest… a STEM person can be truly anybody and truly any age." And when asked to describe how she supported identity before the workshop series, she referred to strategies related to the 5E instructional model (Bybee et al., 2006). In the figure, one can see that after the workshop series, the participant brought new ideas about supporting STEM identity through authentic inquiry. The teacher discussed how her knowledge changed, resulting in a new form of classroom discourse and questioning approach. In particular, after the workshop series, the teacher reflected more on how she used specific practices such as authentic inquiry to support STEM identity, saying that although she had used authentic science experiences in the past by bringing students to researchers and field trips, after the workshops she began to view these authentic inquiry opportunities as a "lens… to create identity within students" and that "authentic inquiry is a really good mindset for students to learn how to think in science, act in science collaborate in science, communicate in science." The largest changes were regarding the teacher's use of the theoretical models and how she approached classroom discussions after learning about the role of authenticity in supporting identity. These two changes indicated that a workshop series emphasizing the connection between the constructs of interest was able to result in changes in teacher knowledge and subsequent approaches to classroom interactions. Additional work from this study explores changes to teacher practices during this intervention as well.

Implications

The goal of this research was to identify the changes that a single teacher could make within their own classroom to make learning experiences more authentic in service of developing STEM identity. The teacher was able to better understand the role of authentic inquiry in supporting identity development within science through this experience, suggesting that this model of professional development can increase teacher understanding of the importance in designing instructional experiences with the specific goal of supporting student identity. In particular, teachers wishing to make such changes within their own classrooms could be supported through the use of the explicit tools provided within this PD, namely the rubrics for authentic inquiry and identity.

References

Brown, B. A., Boda, P., Lemmi, C., & Monroe, X. (2019). Moving culturally relevant pedagogy from theory to practice: Exploring teachers' application of culturally relevant education in science and mathematics. Urban Education, 54(6), 775–803. https://doi.org/10.1177/0042085918794802

Burgin, S. R. (2020). A three-dimensional conceptualization of authentic inquiry-based practices: A reflective tool for science educators. International Journal of Science Education, 42(9), 1465–1484. https://doi.org/10.1080/09500693.2020.1766152

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. Colorado Springs, Co: BSCS, 5, 88-98.

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. Journal of Research in Science Teaching, 44(8), 1187–1218. https://doi.org/10.1002/tea.20237

Chapman, A., & Feldman, A. (2017). Cultivation of science identity through authentic science in an urban high school classroom. Cultural Studies of Science Education, 12(2), 469–491. https://doi.org/10.1007/s11422-015-9723-3

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). Effective teacher professional development [Research brief]. Learning Policy Institute, https://learningpolicyinstitute.org/sites/default/files/productfiles/Effective_Teacher_Professional_Development_REPORT.pdf

DuFour, R., & Eaker, R. (2009). *Professional learning communities at work: Best practices for enhancing students achievement.* Solution Tree Press.

Dusenbury, L., Brannigan, R., Falco, M., & Hansen, W. B. (2003). A review of research on fidelity of implementation: implications for drug abuse prevention in school settings. *Health Education Research, 18*(2), 237–256. https://doi.org/10.1093/her/18.2.237

Marshall, J. C., Horton, B., Smart, J., & Llewellyn, D. (2009). EQUIP: Electronic Quality of Inquiry Protocol: Retrieved from Clemson University's Inquiry in Motion Institute.

Onghena, P., Maes, B., & Heyvaert, M. (2018). Mixed methods single case research: State of the art and future directions. Journal of Mixed Methods Research, 13(4), 461–480. https://doi.org/10.1177/1558689818789530

Rodriguez, A. J. (1998). Strategies for counterresistance: Toward sociotransformative constructivism and learning to teach science for diversity and for understanding. Journal of Research in Science Teaching, 35(6), 589–622. https://doi.org/10.1002/(SICI)1098-2736(199808)35:6%3C589::AID-TEA2%3E3.0.CO;2-I

Shaner, A., Watson, S., Bakerman, M., & Buxner, S. (2018). ExMASS: A viable model for authentic student-scientist research partnerships. Acta Astronautica, 152, 1–9. https://doi.org/10.1016/j.actaastro.2018.07.031

Smith, M. C., & Darfler, A. (2012). An exploration of teachers' efforts to understand identity work and its relevance to science instruction. Journal of Science Teacher Education, 23(4), 347–365. https://doi.org/10.1007/s10972-012-9281-4

Williams, D. R., Brule, H., Kelley, S. S., & Skinner, E. A. (2018). Science in the Learning Gardens (SciLG): A study of students' motivation, achievement, and science identity in low-income middle schools. International Journal of STEM Education, 5(1), Article 8. https://doi.org/10.1186/s40594-018-0104-9

Zozakiewicz, C., & Rodriguez, A. J. (2007). Using sociotransformative constructivism to create multicultural and gender-inclusive classrooms: An intervention project for teacher professional development. Educational Policy, 21(2), 397–425. https://doi.org/10.1177/0895904806290126

GOING PLACES: TRANSITIONING FROM CLASSROOM INSTRUCTION TO INFORMAL SCIENCE

Merryn Cole
merryn.cole@unlv.edu

Jake R. Johnson
johnsj85@nevada.unlv.edu
UNLV

Maizie V. Dyess
millem39@unlv.nevada.edu

Abstract

We designed a place-based education program for middle school students as part of a five-week long informal STEM program; content biology and geology of the university campus. This program provided an opportunity to teach local scientific phenomena outside of the traditional classroom structure, while also highlighting some of the challenges associated with informal science. In this paper, we use a phenomenography lens through which we describe the three authors' experiences in developing, implementing, and reflecting on the program. Results can inform classroom teachers wanting to expand their teaching to informal settings.

Keywords: informal science, middle school, place-based education

Introduction and Objectives of the Study

Informal science education is the continued learning of scientific concepts outside of the constraints of the traditional classroom setting, such as alignment to curriculum; learning can offer a lower stakes environment to better engage students with scientific phenomena (Leonard et al., 2016; Kim & Dopico, 2014). Informal science education has the potential to collaborate with classroom educators to create deeper connections with the material (Kim & Dopico, 2014). Formal educators can also take part in the delivery of informal science, potentially shaping their practices as science educators (Katz et al., 2013). We chose to focus on the experiences of the teachers planning informal instruction because while there is literature about how preservice teachers benefit from implementing informal science experiences (e.g., Hsu, 2016; Katz et al., 2013) or experiences of the audience (e.g., Kerby et al., 2016; Roberts et al., 2018), there are fewer articles that explore the experiences of in-service teachers in implementing informal science. Slagus and Kelly (2022) investigated the experiences of middle school science teachers in a long-term situated learning situation in informal science settings. They found improved teacher motivation and improved perceptions of science as a result of participating in the program. While people learn science in both formal and informal settings throughout their life, the bulk of that learning occurs in informal settings, such as media, everyday experiences, or structured out-of-school programs (NRC, 2009). The K-12 school years are when most learning occurs in the formal school setting; even then, approximately 18.5% of a student's waking hours are spent in the formal setting (NRC, 2009). Thus, it is important to design and examine informal science learning opportunities as well. This study uses a phenomenography lens to investigate how two classroom teachers planned and experienced community-based science outreach, translating their ideas of classroom instruction to the informal space. We chose phenomenography as it can explain how different people can experience the same things under the same circumstances differently (Cibangu & Hepworth, 2016).

Theoretical Framework and Related Literature

Phenomenography

From a phenomenological point of view, we only have access to the world through our own personal experiences (Marton, 1981). In phenomenography, there can be an objective reality, but understanding that reality is limited by the ways in which the person experiencing the reality can describe it. Phenomenology focuses on the essence of a phenomenon; phenomenography seeks to understand how people experience or understand a phenomenon. The investigation is directed towards the variation in people's understanding of or experiences with a phenomenon rather than towards understanding the phenomenon itself (Marton, 1981; Larsson & Holmström, 2007).

Place-Based Education

Place-based education (PBE) is a mode of instruction that relies on local phenomena as part of the curriculum and allows for the intersection of the community with what is learned in schools (Smith, 2002). Within the sciences, PBE has been incorporated into teaching a wide variety of phenomena (Barnes et al., 2019). Looking at informal spaces, place-based science instruction has been demonstrated in summer camps and Saturday programs (Leonard et. al., 2016; Buxton, 2010). PBE has been used to teach these phenomena in formal education settings, where place-based science instruction is provided in along with relevant science standards, and can be limited by instructional pacing (Buck et al., 2016). In both formal and informal spaces, PBE has been shown to improve student engagement and understanding of scientific phenomena (Leonard et. al., 2016; Buxton, 2010). Furthermore, place-based instruction can help students connect the concepts they are learning with their life experiences (Barnes et al., 2019; Brkich, 2014). This is especially true for students living in urban settings, who can tie the phenomena that they are learning to their community (Brkich, 2014). These place-based connections are "...a potentially powerful mechanism for engaging students, particularly those that seem to be underserved by the current educational framework," (Dentazu, 2013, p. 170).

Methodology

We used a phenomenography lens through which the experiences of two high school science teachers and a university science education faculty member design and implement science outreach for a group of middle school students. This is the first time the two teachers have translated their teaching to an informal setting. The data consists primarily of weekly memos from the instructors and reflections based on student artifacts that were collected throughout the program. Each instructor used their own memos to write reflections about the experience, which were shared, discussed, and compared. In this paper, we describe the program, the teachers' experiences, and the reflections of the supervising faculty member.

STEM Program

A STEM program was conducted on five consecutive Saturdays at a public university in the southwestern United States in spring 2022. A variety of courses themed around different STEM topics were offered for elementary or middle school students. Students were selected through an application process through a campus STEM center. The course, Campus Science Explorers (see Table 1), included twenty middle school students and covered biology and geoscience topics relevant to the campus. Each week included learning activities in the science classroom, followed by a place-based activity on campus connected to the topic. In Week 1, students identified living and nonliving objects on campus. Week 2 saw students take the paper plate sundials they had made and transfer those skills to create an outdoor human sundial. For Week 3, rock samples collected from various locations on campus were tested and identified. Week 4 featured a nature walk in which students identified adaptations that helped plant and insect species survive in their environment. Week 5 had students conduct a survey of the number of different plant, animal, and insect species in several locations to highlight biodiversity. Each student received a notebook to guide the weekly activities. The theme differed each week, but the format of the notebook pages was the same: a few graphics mirroring the presentation, space for notes, and a reflection page that asked questions about the day. During the last 10 minutes of the day, students were asked to reflect on their experiences and record things learned or questions. After each session, the instructors debriefed together on the successes and challenges in order to adapt the next week's plan. Instructors created a memo addressing their own personal experience from the previous session.

Table 1

Outline of Course Topics and Activities

Week	Theme	Activity 1	Activity 2	Activity 3
1	Intro; Living/Non-living	Welcome/Intro	Scavenger Hunt	Concept Mapping
2	Telling Time	Modeling Earth's Motions	Paper Plate Sundials	Human Sundials
3	Rock Identification	Rock Exploration Stations	Rock Collection	Identifying Rock Samples
4	Adaptation and Evolution	Camouflage Butterflies	Bird Beak Lab	Nature Walk
5	Wrap-up	Tree Virus Simulation	Biodiversity Hunt	Wrap-Up; Concept Mapping

Instructor Participants

Maizie (geoscience) and Jake (biology) are currently high school science teachers who are also enrolled in a doctoral program in Science Education. They have four- and five-years teaching experience, respectively. Merryn is currently a faculty member in science education with more than 20 years' experience in planning and implementing STEM outreach.

Results and Discussion

Maizie's Reflections

Participating in STEM Saturday from the perspective of a high school science teacher with little practice planning outreach events proved to be a much bigger learning experience than imagined. Campus Science Explorers was my first experience teaching middle school students and my first time planning a 2.5-hour lesson without knowing the students' prior knowledge. It was a bit overwhelming at first, but as I gained experience became rewarding. The first Saturday students did not get settled and started until around 30 minutes past the anticipated start time. As we noticed the we were behind, we had students start brainstorming living vs. nonliving characteristics and making a chart on paper. We then introduced the course. The first activity was to complete a concept map together in small groups on living vs. nonliving things before we took them outside to find items for a scavenger hunt. Students were excited about the scavenger hunt and they were eager to participate. The wrap-up of the lesson was rushed because of the slow start, but that was resolved by week two.

The second Saturday focused on Earth's rotation, revolution, and telling time using the Sun. The day started with a discussion about the content, followed by two in-class demonstrations: one to model earth's revolution around the sun and one to model earth's rotation on its axis. The students had prior knowledge on the subject and were able to contribute more to the discussion than anticipated. Many students returned from week one and were familiar with the space and set up, so it felt more organized. Because of the amount of prior knowledge, I did not account for, I had a hard time keeping the questions at a high enough level to keep every student engaged. After the discussion, students created a paper sundial as a first draft. They had little guidance other than our class discussion, a list of directions, and a reference photo. Once ready, we took the sundials outside to test them and find the current time. Students made notes and drawings on a notebook page before constructing a chalk sundial. The chalk sundials were accurate but they took more scaffolding than I thought. The students were excited about the paper sundials and seemed to complete them with ease, but had a harder time with the chalk sundials. When we got back in the classroom most of the students were confidently identifying the methods of telling time and the science content.

The third Saturday in this program was an introduction into Rock Identification and Collection. The morning was planned in smaller chunks consisting of 20 to 30-minute activities. The activities included a rock cycle lab, sample collection and identification station, a HCl bubble lab, and a fossil game. We did not make it to the game because the other activities took longer than planned. Timing is one of the hard parts of informal science because of the lack of knowledge on how the group works together. The final two Saturdays are when we got the timing right. Jake planned the lesson on adaptations and evolution and we started with a discussion and a camouflaging butterfly activity. The kids and I had a lot of fun participating in this activity. We picked spots around the classroom and did our best to camouflage a butterfly to fit its surroundings. Some struggled but some were really impressive. We saw a clear difference in the prior knowledge between students. After that, we talked about bird beak evolution and completed a lab identifying which bird beak was the most useful. The students had fun competing against each other and filling in the class data on the board. The last activity was the nature walk where students were given many opportunities to see adaptations on campus like cactus, ivy, succulents, etc.

Jake's Reflections

As a high school science educator, transitioning to informal, place-based science instruction was an incredible learning experience. While you get comfortable teaching in your style in a formal classroom setting, informal teaching requires you to adapt all of the skills you are familiar with. While challenging, it was also very rewarding and gave me new ideas that I can apply to future formal and informal instruction. The first major difference I found in teaching informal science came after Maizie and I agreed to teach the program, where we were told to pick a theme to focus on. Used to having a list of concepts and skills that must be taught, the freedom to teach topics we were passionate about was great. This allowed us to take time to explore our place-based environment and take ownership of our activities.

While the liberty to choose place-based learning activities was a welcome change, our planning and lesson delivery had challenges. The Week 1 lesson relied heavily on classroom practices we were familiar with: mind mapping, a nature walk, and notes. While this session was not bad, our follow-up group discussion highlighted that the activities could be less "classroom-esque" and more rigorous and engaging within the time available. During the subsequent sessions, Maizie and I worked to create interactive handouts and short, engaging activities to accompany Earth's rotations, Rock Types, Natural Selection, and Biodiversity. While this required a shift in our practices, we agreed to a format consisting of two to three activities and one outdoor walk connecting the week's topic to the place. This shift seemed to increase engagement for the rest of the program.

Merryn's Reflections

I wanted Jake and Maizie to take the lead in planning activities that fit the place-based theme of the program and their background expertise. Our campus provides ample opportunities to pursue a variety of topics within biology and geoscience. During the planning phase, I prompted them to think about the topics, the activities, organizing students, and planning a schedule. Beyond that, I left it open for them to decide. As the weeks unfolded, I guided the debriefing discussions around issues each of us experienced during the week as well as what went well. Whether good or bad, these identified areas of focus helped us to adjust for the following week. For instance, during the first week we noticed that students knew more than Jake and Mazie had expected. Combined with some parent feedback in the hallway that perhaps students weren't being challenged enough, the following weeks incorporated more challenging activities and questions. There were still some obstacles in matching instruction to the students, but it improved. One of the big topics of conversation related to planning was how the informal science space was different from a formal classroom. Sometimes this was focused on lesson delivery; things like whether it made sense to do more activities to learn content or take notes before activities. In an informal setting we often only see students for a short duration. We also don't have required attendance. If students are not both engaged and challenged by the activities they may not return.

Focusing on PBE afforded opportunities for the students to get excited about the science around them that most don't pay attention to. Students were motivated by exploring the campus surroundings. They were excited to find unique rocks around the campus and then bring them inside to identify them. They also enjoyed finding new plants and animals on campus and identifying those. They asked a lot of questions about what they were seeing on campus, indicating an interest in learning about the *place* around them. By incorporating nature walks, we were able to capitalize on the benefits of PBE, including motivation, engagement, and discovery of the science that can be found on campus (Brkich, 2014; Dentazu, 2013).

Discussion

While each of us experienced the planning and implementation of an informal, place-based, Saturday STEM program at the same time, we each came out with different expressed experiences (Cibangu & Hepworth, 2016). Three major themes emerged in the reflections: student engagement; challenges of student backgrounds; and the need to reflect, adapt, and be flexible with instruction. Students were engaged with the content, especially in seeing how these ideas could be directly observed around campus rather than only learning about them in a classroom setting. The students were able to see how the science they were learning was relevant to their lives, since we connected it to the place they live. Even though the place in this case was not their own neighborhoods, the campus has plenty of areas that represent the local environment, providing opportunities for students to connect to what they see at home or around town (Smith, 2002). The place-based connection is important when considering these students live in an urban area where it is easy to overlook the science around you.

Students bring a variety of understandings, misconceptions, and experiences to the classroom and the same can be said for an informal science setting. A difference is that while the teacher may have some indication of what students know prior to entering their classroom, in an informal setting we often do not. Also, we have students in a mixed age group, so even their formal classroom experiences covered different required topics. One of the advantages of being flexible and adapting instruction in the moment and between sessions is to build upon what students have already learned in their formal classroom environments. As the NRC (2009) noted, during the K-12 years is when people get the most formal science instruction, though it's estimated to be less than 20% of our time.

Implications

Teachers have practice in planning and implementing classroom instruction, but many have not translated that pedagogical or content knowledge to informal science education. As these teachers experienced, it can be a challenge to plan for students who have different (and unknown) understandings, misconceptions, and prior experiences with the content planned. Teachers planning for informal science should also consider the need to be flexible with each meeting and adapt to the students present, and the local conditions. Most importantly, if teachers and others planning for informal STEM instruction learn nothing else from Maizie and Jake's experience, they should note that classroom instruction is unlikely to work well when directly implemented in an informal setting without some adaptations being made first. That being said, teachers may benefit from implementing informal science education. Maizie and Jake both came away from the experience with an increased motivation for incorporating PBE and more local science into their own classrooms (Slagus & Kelly, 2022). As an example, Maizie has since introduced a local landforms project into her geoscience classroom and has referenced mountains next to the school as a local related place. For researchers, we should further investigate the experiences of practitioners of informal science, particularly those who have experience teaching in formal settings. It would also be beneficial to follow those teachers to better examine how their experiences in informal settings impact their daily classroom teaching.

References

Barnes, M. A., Cox, R. D., & Spott, J. (2019). Place-based learning with out-of-place species & students: Teaching international students about biological invasions. *American Biology Teacher, 81*(7), 503–506.

Brkich, K. (2014). Urban fifth graders' connections-making between formal earth science content and their lived experiences. *Cultural Studies of Science Education,9*(1), 141–164.

Buxton, C. A. (2010). Social problem solving through science: An approach to critical, place-based, science teaching and learning. *Equity & Excellence in Education, 43*(1), 120–133.

Cibangu, S. K., & Hepworth, M. (2016). The uses of phenomenology and phenomenography: A critical review. *Library & Information Science Research*, *38*(2), 148-160.

Hsu, P. L. (2016). Science Teaching Experiences in Informal Settings: One Way to Enrich the Preparation Program for Preservice Science Teachers. *Universal Journal of Educational Research, 4*(5), 1214-1222.

Katz, P., McGinnis, J.R., Riedlinger, K., Marbach-Ad, G., & Dai, A. (2013). The influence of informal science education experiences on the development of two beginning teachers' science classroom teaching identity. *Journal of Science Teacher Education, 24*(8), 1357-1379.

Kerby, H. W., DeKorver, B. K., Cantor, J., Weiland, M. J., & Babiarz, C. L. (2016). Demonstration show that promotes and assesses conceptual understanding using the structure of drama. *Journal of Chemical Education*, *93*(4), 613-618.

Kim, M., & Dopico, E. (2014). Science education through informal education. *Cultural Studies of Science Education, 11*(2), 439-445.

Larsson, J., & Holmström, I. (2007). Phenomenographic or phenomenological analysis: Does it matter? Examples from a study on anaesthesiologists' work. *International Journal of Qualitative Studies on Health and Well-being*, *2*(1), 55-64.

Leonard, J., Chamberlin, S., Johnson, J., & Verma, G. (2016). Social justice, place, and equitable science education: Broadening urban students' opportunities to learn. *Urban Review, 48*(3), 355–379.

Marton, F. (1981). Phenomenography: Describing conceptions of the world around us. *Instructional Science, 10*, 177-200.

National Research Council. (2009). *Learning science in informal environments: People, places, and pursuits*. P. Bell, B. Lewenstein, A.W. Shouse, & M.A. Feder (Eds.). National Academies Press.

Roberts, T., Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Cavalcanti, M., ... & Cremeans, C. (2018). Students' perceptions of STEM learning after participating in a summer informal learning experience. *International journal of STEM education*, *5*(1), 1-14.

Smith, G. A. (2002). Place-based education: Learning to be where we are. *The Phi Delta Kappan, 83*(8), 584–594. http://www.jstor.org/stable/20440205

Stolz, S. A. (2020). Phenomenology and phenomenography in educational research: A critique. *Educational Philosophy and Theory*, *52*(10), 1077-1096.

PARENT MATHEMATICS PROGRAM: PERCEVEING PERSERVICE TEACHERS' PEDAGOGY AND GROWTH MINDSET

Anh Pham ngocqueanh.pham@utsa.edu
Bailey Devine bailey.devine@utsa.edu
Emily P. Bonner Emily.Bonner@utsa.edu
Traci Elmore Traci.Elmore@utsa.edu
The University of Texas at San Antonio

Abstract

The Parent Mathematics Program (PMP) aims to enhance the learning of mathematics and pedagogy through culturally responsive practices by providing free mathematics tutoring via preservice teachers (PSTs) to parent scholars (PaS) in low-income areas in a city in the U.S. Southwest. This study describes how the PMP improves mathematical knowledge for both PaS and PSTs and investigates whether offering tutoring enhances PSTs' growth mindset. The findings reinforce the importance of training and mentoring programs in mathematics teacher education, which lay a foundation of practice for PSTs to serve in classrooms.

Keywords: mathematics training programs, mathematics tutoring program, preservice teachers, parents, growth mindset

Introduction

Research shows that parents for low-income backgrounds have difficulties with school involvement due to demographics, phycological obstacles, and teachers' attitudes and connections with them (Van Velsor & Orozco, 2007). Concurrently, the Association of Mathematics Teacher Educators (2017) suggests that a focus on collaboration with families is important for children's mathematical development. In a teacher preparation program, it is critical to engage in the mutual sharing of resources and ideas between preservice teachers and students' families to support students' mathematical learning (Association of Mathematics Teacher Educators [AMTE], 2017). Therefore, this research shows a need for teacher preparation programs that focus on the development of a teacher-family connection to enhance math outcomes for students.

Mathematics in schools is less likely to connect students' lived experiences and identities than other content being taught (Gutiérrez, 2013; Tate, 1994). This lack of connection may begin in teacher preparation programs. According to Gutiérrez (2013), teacher education programs invest in teachers' professional development without providing them with in-depth mathematics or flexible ways to form a deep connection with learners. Similarly, Tate (1994) emphasizes the importance of using cultural constructs in mathematics and the connection between mathematics pedagogy and students' lived experiences. Tate (1994) and Gutiérrez (2013) demonstrate a need to provide teachers with preparation programs that emphasize the importance of each students' culture, lived experiences, and identity in mathematics.

A growth mindset may also positively impact mathematics students' learning and motivation (Dweck, 2008), and we recognize an association between teachers' mindsets and students' mindsets (Boaler, 2013; Dweck, 2008; Mesler et al., 2021). When teachers believe that their learners' ability can grow and give them an opportunity to achieve high levels, it can help learners achieve at higher levels (Boaler, 2013). Therefore, to help students improve their mathematics ability, teachers need to enhance their growth mindset in the student's learning processes, pedagogical thinking, and practices (Schmidt et al., 2015; Rissanen et al., 2018). As this awareness of teachers' growth mindset impacts learners, there is a call to the growth mindset examination of preservice teachers. This is particularly important to enhance due to the limited time needed to promote productive mindsets for teachers in teacher education, which could result in widespread teaching practices once they become in-service teachers (Soleas & Hong, 2020).

The work reported in this paper directly addresses this issue, challenging the concept that mathematics is universal and neutral while embracing the mathematical funds of knowledge that communities and lived experience bring to formal learning environments. We hypothesize that connection and collaboration between preservice teachers (PSTs) and parents of school-aged children could enhance mathematics knowledge for both PSTs and parents and can help PSTs more culturally responsive to mathematic learners.

Objectives of the Study

The Parent Mathematics Program (PMP) responds to the community's local needs through innovative outreach programs to provide equitable access to mathematical knowledge. The project aims to enhance the learning of mathematics and pedagogy through innovative, culturally responsive practices related to local and national needs by providing free mathematics tutoring via PSTs enrolled in a training program at a public research university in the Southwest to parent scholars (PaS) in low-income areas.

The COVID-19 pandemic pushed students to learn online leading to parents becoming co-teachers for their children (Wang, 2021). The PMP project is timely, given the prevalence and need for online models for teacher education (Laferriére et al., 2006). Within the program, PSTs were paired with a parent from the local community for mathematics tutoring. Using virtual manipulatives and online tools, the pairs met for one hour per week and focused on sense-making, problem solving, and multiple representations of mathematical ideas. PSTs were trained to use effective questioning to elicit deep thinking from parents and used evidence from sessions to plan future tasks (Hinojosa & Bonner, 2021).

Finally, the PMP provides a context in which PSTs consider parents' individual learning needs, cultural experiences, language, socioeconomic status, personal interests, and prior mathematical knowledge to select tasks and plan instructional sessions (Gutiérrez, 2013; Tate, 1994). This provision allows parents to share how they do mathematics and engage in meaningful learning experiences to teach their elementary aged children at home. The program validates parents' knowledge base in math and helps PSTs connect to parents' knowledge. We approach this with the idea that parents already have a source of life events that help them connect to mathematical knowledge and what their children learn in school. This project also focuses on mathematical reasoning and sense-making, allowing parents to use mathematical strategies that make sense to them.

Research Questions

1. What do PSTs learn about teaching mathematics after the PMP mentoring program?
2. Does the PMP improve PST's mathematical pedagogy? How does the PMP mentoring program improve PSTs' mathematical pedagogy?
3. What can we learn about PSTs' growth mindset through PMP?

Related Literature

The authors use culturally responsive teaching (Gay, 2002) and growth mindset theory (boaler, 2013; Dweck, 2008) to confirm, elaborate, and analyze the outcomes of this study. According to culturally responsive teaching (CRT), knowledge and skills related to students' life experiences can help them feel more meaningful, interested, and eager to learn (Gay, 2002). CRT is a student-centered strategy for classroom organization that calls for the learning of students from diverse racial and socioeconomic backgrounds in a way that connects the students' lives in and out of school to create rich learning experiences (Bottoms et al., 2017). Culturally Responsive Mathematics Teaching (CRMT) incorporates mathematics content knowledge with learners' mathematical thinking, culture, and language (Aguirre & del Rosario Zavala, 2013). Further, CRMT can help bridge the gap between school and home, providing a supportive, engaging, and challenging instructional context (Bonner, 2014). This teaching promotes learners to improve their mathematical abilities (Abdulrahim & Orosco, 2020). In the PMP tutoring program, PSTs create more relevant mathematical tasks and explanations, and their teaching inherently becomes more culturally responsive to parents (who are their "students") by using CRMT.

Effective teachers understand students' beliefs in math and recognize students' mathematical mindset (Boaler, 2013; Dweck, 2008). Boaler (2014) defined a mathematical mindset as a person's belief that they have abilities in mathematics. Meiners et al. (2020) asserted that having preservice teachers recognize their own growth mindset may help them more successfully facilitate and engage future students with complex mathematical problems.

Methodology

The study used exploratory sequential mixed methods approach emphasizing quantitative data (Creamer, 2018; Cresswell & Cresswell, 2018). Mixed methods allow us to explore what mathematical pedagogy PSTs learn (qualitative data) and investigate the mathematical knowledge and growth mindset (quantitative and qualitative data). Pre- and post-tests were used to detect PSTs' mathematical knowledge changes. A growth mindset survey which was distributed at the beginning of the program provided evidence of PSTs' growth mindset. This study uses observation of video clips and interviews to comprehensively understand PSTs' mathematical knowledge and pedagogy. We used descriptive statistics to compare the difference in pre- and post-tests and analyze the growth mindset survey. Thematic analysis was applied to analyze videos, interview artifacts, and open-ended questions in the growth mindset survey. Items are open coded then grouped until themes emerged. Themes are constantly compared to new codes as additional data is analyzed. Thematic analysis is in progress to analyze at this point.

The study setting was an online PST training program and parent-scholar tutoring program. As this is an ongoing project, the authors gathered pre-and post-tests and growth mindset survey data in fall 2021, spring 2022, and summer 2022. In 2021-2022, 11 PSTs fully completed the pre- and post-tests, and 14 participants responded to the growth mindset survey.

Preliminary Results and Discussion

During the mentoring and tutoring sessions, PSTs learn how to apply a sense-making approach and virtual manipulatives in mathematics to teach PaS. Sense-making pedagogy is an approach in which learners can make sense of mathematics by resolving their absent knowledge through the co-construction of knowledge and building from prior knowledge (Hinojose & Bonner, 2021). Virtual Manipulatives are an online tool for teaching mathematical involved in mathematical concepts that can create senses, abstract ideas, and symbols that are more meaningful and understandable to learners (Durmy & Karakirik, 2006). Furthermore, through the tutoring program, PSTs have an opportunity to engage with parents and access their mathematical assets to tutor them to help children at home with mathematics.

Figure 1

The Change in Pre-test and Post-test Scores of Preservice Teachers

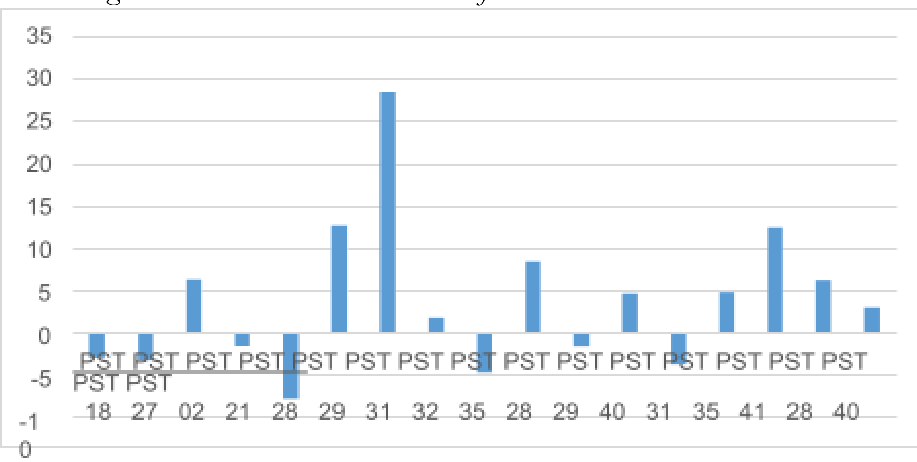


Figure 1 showed significant change in pre- and post-test scores of PSTs from 1.82% to 28.57%. As we can see, PSTs 18, 21, 28, and 35 did not have significant growth as on the pre-test scores, however, they demonstrated a mastery of arithmetic math concepts (above 90%) on pre-tests. We considered they were experiencing a "ceiling effect." Any pre-test scores of 90% or above were considered the "ceiling effect." In the case of PST number 27, there was a small decrease which is around 3.23% in postscore. However, we can note that she was already nearing the "ceiling effect." PST 29 had an increase in the score when completing fall 2022, around 12.73%. She continued to participate in spring 2022, and her posttest score decreased slightly by 1.61%. Similarly, the score of PST 31 increased significantly, around 28.57% in spring 2022, and dropped insignificantly by 3.72% in summer 2022. This slight change in score could be due to testing artifacts such as running out of time, internet connectivity issues, or minimal errors. However, on average, PSTs experienced a higher score after the program than when they first arrived at the program.

The Growth Mindset Perspectives of Preservice Teachers

Table 1 summarizes the results from each response descriptive statistics analysis. The survey has four main ideas to learn about PSTs growth mindset: the growth mindset, barriers to success on the pre-test and post-test, a "problem solver" mindset, and relative preference for challenging math problems. In general, the results from questions 1 to 4 showed that most PSTs had a positive belief in their improvement and hard work in math. To understand their choice, we also asked for their explanation for which answers they chose. Most of their responses demonstrated their positive belief in practice and hard work that can help them be better in math.

Regarding the barriers to success on the pre-test and post-test (questions 6 to 8), on average, PSTs responded strongly disagree to disagree that it is because they are not smart or good at math, or the quiz is unfair. Furthermore, when we asked about their solution to be better at math (questions 9 to 12), a large number of PSTs agreed that spending more time studying and working harder can improve their mathematical knowledge and skills. Remarkably, all PSTs did not believe in cheating as a solution. Their explanations regarding their choice of those questions were positive with asking for help and taking more effort into learning. As we can see, their choice and their explanation consistently illustrated their positive solution to grow in math, not through cheating on the quiz.

Table 1

Descriptive Statistics: Perspectives of PSTs about growth mindset in math

Survey Item (N=14)	*Mean*	*SD*
Q1: I believe I can always substantially improve my math intelligence.	4.64	.50
Q2: To be honest, I don't think I can really Change how intelligent I am in math.	1.50	.65
Q3: If I'm not good at math, working hard won't make me good at it.	1.71	1.14
Q4: When something in math feels hard, it just makes me want to work more on it, not less.	3.57	1.22
Q5: The main reason why you failed the quiz? [I wasn't smart enough.]	1.43	.94
Q6: The main reason why you failed the quiz? [The quiz was unfair, too hard for the class.]	1.64	.75
Q7: The main reason why you failed the quiz? [I'm just not good at math.]	1.50	.86
Q8: What do you think you would do next? [I would spend less time on this class from now on.]	1.43	.65
Q9: What do you think you would do next? [I would spend more time studying.]	4.29	.83
Q10: What do you think you would do next? [I would work harder in this class from now on.]	4.43	.51
Q11: What do you think you would do next? [I would try to cheat on the next quiz.]	1.21	.58

Note. From Q1 to Q8: agreement scale (1-5) with 1 indicating strongly disagree and 5 indicating strongly agree. Other questions: likelihood scale (1-5) with 1 indicating very untrue and 5 indicating very true.

Additionally, to learn about PSTs' relative preference for challenging math problems, we created a scenario where they could choose one of two math problems to gain extra credit in the class. No matter which problem they chose, they would have the same amount of time to finish and the same credit whether their answers were right or wrong. Table 2 demonstrates that although most PSTs believed in their ability and improvements in math, fewer PSTs (28.6%) prefer to take challenges and effort to do math.

Table 2

Preservice Teachers' Perspectives in Challenging Math Problems

The Choice to Pick an Assignment to Solve	The Percentage of Response (N=14)	Explanation Keywords
Option A. Maria works five days a week, Monday through Friday. She is paid the following way: On her first Monday she makes $1. Then Tuesday her pay is increased to $2, Wednesday her pay is increased to $4. If these daily patterns continue following the same pattern, how much will Maria earn in 4 weeks?	28.6%	Like challenges, complex problems Self-confidence in problem-solving Curiosity Belief in improving involved math concepts
Option B. Tom is paid $15/hour and works Saturday through Wednesday. Over a 4-week period he works 20 hours the first week, 20 hours the second week, 15 hours the third week, and 25 hours the fourth week. Over these 4 weeks how much will tom earn?	71.4%	Easier Fewer workdays Contextually makes sense to the individual Afraid to try and not succeed

Implications

This study has implications for teacher training programs and tutoring problems in mathematics teacher education. Ultimately, our findings reinforce the vital role of teacher training and mentoring programs in PSTs' mathematical knowledge and pedagogy. To help PSTs gain confidence in teaching, it is necessary to create a community for PSTs to practice and apply mathematical approaches. In this program, PSTs use the sense-making approach to tutor parent scholars in low-income settings. As such, they can learn how to engage with parents, which can improve the relationship between teachers and parents through understanding their experiences with doing math. Concurrently, the pre- and post-test of the 2021-2022 PSTs provided evidence that they completed PMP with an improvement in math compared to when they began the program.

Mathematical knowledge is also essential for teachers to teach effectively. The growth in pre- and post-tests of PSTs supports the necessity of mathematical knowledge for PSTs. Finally, teacher training programs and instructional mathematics coaches should consider the growth mindset of teachers as it impacts students' learning of math (Dweck, 2008). We found that although teachers have significant beliefs in the ability of students to learn math, the preference for taking challenges in math also needs to improve. This result suggests further research about how to help teachers become more confident in taking challenges in doing math which significantly enhances their growth mindset in math. In general, teacher training and tutoring programs lay a foundation of practice for preservice teachers that provide experiences to serve them well in the classrooms.

References

Abdulrahim, N. A., & Orosco, M. J. (2020). Culturally Responsive Mathematics Training: A Research Synthesis. *The Urban Review, 52*(1), 1-25. doi: 10.1007/s11256-019-00509-2

Aguirre, J. M., & del Rosario Zavala, M. (2013). Making culturally responsive mathematics teaching explicit: A lesson analysis tool. *Pedagogies: An International Journal, 8*(2), 163-190. doi:10.1080/1554480X.2013.768518

AMTE Standards for Preparing Teachers of Mathematics. (2017). *Chapter 4: Elaborations of the Standards for the Preparation of Early Childhood Teachers of Mathematics*Retrieved from https://amte.net/sptm/amte-standards-preparing-teachers-mathematics/chapter-4-elaborations-standards-preparation

Boaler, J. (2013). Ability and Mathematics: The mindset revolution that is reshaping education. *FORUM, 55*(1), 143.

Bonner, E. P. (2014). Investigating practices of highly successful teachers of traditionally underserved students. *Educational Studies in Mathematics, 86*(3), 377-399.

Braun, V., & Clarke, V. (2012). Thematic analysis: In H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, & K. J. Sher (Eds.), *APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological*. (pp. 57-71). American Psychological Association. doi:10.1037/13620-004

Brown, J. P. (2017). Teachers' perspectives of changes in their practice during a technology in mathematics education research project. *Teaching and Teacher Education*, *64*, 52-65.

Creamer, E. G. (2018). *An Introduction to Fully Integrated Mixed Methods Research*. SAGE Publications, Inc.

Creswell, J. W., & J David Creswell (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. SAGE Publications.

Durmu, S., & Karakirik, E. (2006). Virtual Manipulatives in Mathematics Education: A Theoretical Framework. *The Turkish Online Journal of EducationalTechnology, 5*(1), 7.

Dweck, C. S. (2008). Mindset: The new psychology of success. Random House Digital, Inc.

Gutiérrez, R. 2013). The Sociopolitical Turn in Mathematics Education. *Journal for Research in Mathematics Education, 44*(1), 37-68.

Hinojosa, D. M. & Bonner, E. P. (2021). The Community Mathematics Project: Using a Parent Tutoring Program to Develop Sense-Making Skills in Novice Mathematics Educators. *Mathematics Education Research Journal*. doi:10.1007/s13394-021-00401-x.
Laferriére, T., Lamon, M., & Chan, C. K. K. (2006). Emerging E-Trends and Models in Teacher Education and Professional Development. *Teaching Education, 17*(1), 75-90.
Meiners, A., Choi, K. M., & Hong, D. (2020). Quantitatively Investigating the Effects of Multiple Strategies on Pre-Service Teachers' Mindset and Persistence. *Research in Mathematics Education, 23*(2), 113-133. doi:10.7468/JKSMED.2020.23.2.113
Mesler, R. M., Corbin, C. M., & Martin, B. H. (2021). Teacher mindset is associated with development of students' growth mindset *Journal of Applied Developmental Psychology, 76*. doi:10.1016/j.appdev.2021.101299
Rissanen, I., Kuusisto, E., Hanhimäki, E., & Tirri, K. (2018). Teachers' implicit meaning systems and their implications for pedagogical thinking and practice: *A case study from Finland. Scandinavian Journal of Educational Research, 62*(4), 487-500. doi:10.1080/003113831.2016.1258667
Schmidt, J. A. Shumow, L., & Kackar-Cam, H. (2015). Exploring teacher effects for mindset intervention outcomes in seventh-grade science classes. *Middle Grades Research Journal, 10*(2), 17-32.
Soleas, E. K., & Hoag, J. (2020). The school of hard knocks: Pre-service teachers' mindset and motivational changes during their practicum. *Foro de Educación, 18*(2), 237-257.
Tate, W. F. (1994). Race, Retrenchment, and the Reform of School Mathematics. *The Phi Delta Kappan, 75*(6), 477-484.
Van Velsor, P., & Orozco, G. L. (2007). Involving Low-Income Parents in the Schools: Community-centric Strategies for School Counselors. *Professional School Counseling, 11*(1).
Wang, C. X. (2021). CAFÉ: An Instructional Design Model to Assist K-12 Teachers to Teach Remotely during and beyond the Covid-19 Pandemic. *TechTrends, 65*(1), 8-16.

Acknowledgements

Project funded by the Department of Education Title V Funds Award #P031S180160, Northwest Vista Community College, lead institution.