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International Collaboration in Science and Mathematics Education: Two Exemplars in Practice

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In the previous editorial, the first in a series, we expressed ICRSME and *EJRSME*'s commitment to promoting genuine, international collaboration to advance science and mathematics education (Quebec Fuentes & Bloom, 2020). In particular, we framed such collaboration with the construct of *communities of practice*, "groups of people who share a concern, set of problems, or passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis" (Wenger et al., 2002, p. 4). For a community of practice to establish a *shared goal* (Clausen et al., 2009, Quebec Fuentes & Spice, 2017) and engage in the *co-construction of knowledge* (Palinscar et al., 1998, Sim, 2010), its members must navigate and learn from conflict, institute means of communication, and build trust. We also identified some of the challenges and opportunities communities may encounter when engaging in such work, some unique to international collaboration, and closed with a set of questions to guide regular reflection.

In line with the aforementioned commitment, the theme of the ICRSME 2022 Virtual Conference was *International Collaboration in Science and Mathematics Education*. The conference highlighted collaborative, international work through two plenary presentations:

- *A Model Institute for Innovation in Research & Education*
  Dr. Marisín Pecchio, Instituto de Investigaciones Científicas y Servicios de Alta Tecnología de Panamá (INDICASAT-AIP)

- *Lessons Learned from Collaborative Place-Based Learning Programs in Yucatán, Mexico and Belize*
  Dr. Grace Bascopé, Botanical Research Institute of Texas (BRIT) and Maya Research Program

In what follows, we describe the nature and intricacies of this work in the context of communities of practice and their attributes. Our hope is that we can learn from these two exemplars as we move forward with our goal of fostering genuine, international collaboration.

INDICASAT-AIP

Dr. Marisín Pecchio is a research scientist at INDICASAT-AIP. She received her bachelor's degree in Pharmacy from the University of Panamá and her Doctoral degree in Pharmacy from the University of Navarro in Spain. Dr. Pecchio's research interests involve the discovery of drugs from natural products; examinations of the effects of bioactive compounds; and novel delivery systems for drugs. In addition to her research, one of her roles at INDICASAT-AIP is Coordinator of the Center for Academic Affairs and Collaboration, for which she directs the design, development, implementation, coordination, and supervision of academic and research training programs.

INDICASAT-AIP was founded in 2002 by la Secretaría Nacional de Ciencia, Tecnología e Innovación de Panamá (SENACYT) with the aim of supporting the economic and sociocultural development of Panamá through scientific research. Specifically, la misión de INDICASAT-AIP is:

> establecerse como una plataforma para el avance científico y tecnológico de Panamá, contribuyendo a la formación de recursos humanos de excelencia en investigación – desarrollo aplicado a la diferentes disciplinas prioritarias para el avance del país. (INDICASAT-AIP, 2020)

La visión de INDICASAT-AIP is to establish the Institute as *un centro de excelencia* with a national and international reputation in biomedical research and technology services and with the role as a hub for knowledge transfer to other (especially Latin American) countries (INDCASAT-AIP, 2020). In line with esta visión, INDICASAT-AIP has four main objectives: (1) recruiting top-tier scientists; (2) conducting collaborative (national and international), interdisciplinary biomedical research; (3) offering professional development and academic activities that foster una cultura científica; and (4) supporting socio-economic development through services and knowledge dissemination.

In her plenary presentation, Dr. Pecchio shared the INDICASAT-AIP activities that meet the aforementioned objectives. INDICASAT-AIP has multiple centers through which research is conducted (e.g., Center for Biodiversity and Drug Discovery and Neuroscience Center), the communication of knowledge generated is facilitated (Center for Innovation and Technology Transfer), and academic activities are coordinated (Center for Academic Affairs and Collaboration). Currently, 30 scientists are conducting research in a variety of areas, including the treatment of malaria, tissue engineering, and a response to COVID-19. The work of the scientists has been documented through more than 400 published papers, patents, and the hosting of an international conference on biomedical and interdisciplinary research. INDICASAT-AIP also has several doctoral programs, provides opportunities for undergraduate and master's student research, and conducts academic programming for K-12 students.

An examination of the complex and multifaceted work of INDICASAT-AIP through the lens of collaboration reveals the characteristics of a community of practice (Wenger et al., 2002). INDICASAT-AIP is a *community of people* who care about the *domain* of scientific research for the betterment of local, national, and international communities. Further, through the various programs, INDICASAT-AIP is developing a *shared practice* that revolves around conducting, sharing the findings of, and introducing K-12 students to scientific research.

INDICASAT-AIP also exemplifies two foundational components of communities of practice, namely a shared goal (Clausen et al., 2009) and the co-construction of knowledge (Palinscar et al., 1998; Sim, 2010). The interdisciplinary nature of the scientific research conducted at INDICASAT-AIP involves the contributions of persons with diverse areas of expertise. For instance, the Center for Biodiversity and Drug Discovery focuses on the development of drugs through the identification of molecules from the marine biodiversity of Panamá (INDICASAT-AIP, 2020). This work is conducted by scientists from various fields, such as organic chemistry, biomedicine, ecology, and bioengineering. Additionally, the research, development, and commercialization of the drugs requires the collaboration between higher education, governments, and industry (INDICASAT-AIP, 2020).

Through its aforementioned misión y visión, INDICASAT-AIP has a shared goal to contribute to the socio-economic development of Panamá and other countries via scientific research. This *shared but given goal* permeates the work of INDICASAT-AIP. However, the various INDICASAT-AIP activities additionally establish a *shared beyond given goal* that falls under the umbrella of the shared but given goal but also centers on a specific area of need through a mutually established endeavor (Quebec Fuentes & Spice, 2017). For example, as previously described, the Center for

Biodiversity and Drug Discovery investigates the local marine biodiversity for its potential in drug development.

Further, the Center for Academic Affairs and Collaboration strives to establish and maintain a pipeline of research scientists through programming across various populations. At the doctoral level, INDICASAT-AIP in collaboration with Acharya Nagarjuna University in India created a PhD program in Biotechnology, the first of its kind in Panamá. In partnership with a multitude of national and international universities, INDICASAT-AIP provides the infrastructure and opportunity for undergraduate and master's student research. The Student Research Innovation Program invites secondary school students to propose research projects that they conduct with the support of one of their teachers and a scientist from INDICASAT-AIP. For another program, scientists or doctoral students visit a school and engage students in problem solving about a scientific issue in the local community. As demonstrated, INDICASAT-AIP has built local, national, and international communities centered on science research through its partnerships and collaborations.

Maya Research Program

Dr. Grace Bascopé is an ethno-environmental medical anthropologist, who taught for many years at Texas Christian University and the University of North Texas. Dr. Bascopé holds a Bachelor of Arts degree from Baylor University, a Master of Science in Social work from the University of Texas, and a PhD in Medical Anthropology from Southern Methodist University. She is currently a Resident Research Associate at the Botanical Research Institute of Texas (BRIT) in Fort Worth, Texas and leads field research and education initiatives for the Maya Research Program (MRP), which is affiliated with the University of Texas at Tyler.

The MRP is a non-profit organization that leads ethnographic and archaeological research throughout Middle America. Over the past 30 years, more than 3000 students and volunteers have partnered with MRP to document and protect ancient Maya sites and attend to the needs of local communities. Two key goals of the MRP are to:

- Conduct research that helps us better understand the complex ancient societies of the Americas, and
- Encourage the participation of students and volunteers – anyone who wants to experience the real world of archaeological or anthropological research and understand how we learn about other cultures. (Maya Research Program, n.d.)

Participants in the MRP have come from the United States, Australia, Canada, Europe, Latin America, and Japan and have ranged in age from 18 to 80. Dr. Bascope's major MRP initiatives center around collaborative, place-based learning programs in the village of Yaxunah, Yucatán, Mexico and in northwestern Belize. In her plenary talk, Dr. Bascope shared one of the major MRP initiatives - *Yaxunah Ethnographic Project*.

For over 30 years, Dr. Bascopé has been working with the village of Yaxunah, which is a small Yucatec Maya community (population approximately 600) in the state of Yucatán, Mexico. In the early years, Dr. Bascopé was involved as an ethnographer studying the ancient Maya city adjacent to the village. In later years, she led ethnographic and ethno-botanical field schools. Through these experiences, Dr. Bascopé learned the importance, especially in such a small group of people, of carefully attending to the societal norms, values, and needs of those with whom you collaborate. Figure 1, from her plenary talk, depicts a typical village meeting where MRP participants and community members discuss goals of the partnership and expectations of all parties to build productive collaboration. Such village meetings include questions such as:

- What is inbounds and what is off limits for visiting students/volunteers?
- What projects might be helpful/meaningful to community members?
- What empirically trained village experts (defined as having learned by doing; think indiginous knowledge) might be available to participate in instruction?
- What local members might benefit from participating as students in the field school experience?
- Who in the community might be available to mentor students' projects? (Bascopé, 2022)

Meetings like these were a means of *communication* to establish *trust* and to frame *conflict* as an ongoing process that results in mutual learning (Achinstein, 2002, p. 425) and resulted in successful, authentic collaboration.

For one such example of an ethnographic and botanical school experience in the Yucatan, participants were tasked with building a reference collection of local plants for the Yucatan State Herbarium. The members of the community of practice included students who were taking a class for college credit, members of the Yaxunah village (including those with deep indiginous knowledge), research scientists, and volunteers. Additionally, members ranged in their field experience and botanical knowledge from novice to expert. Locals were familiar with the native wildlife, could identify potentially harmful plants and animals, and knew about dangerous features of the landscape; non-local members had much to learn. This diverse and *distributed expertise* allowed for the knowledge development of the collective.

Figure 1
Meeting with the Members of Yaxunah Community

Part of this educative process included establishing a *shared practice*, both at a surface and at a deeper level. Among the members of the community were some who spoke only Yucatec Mayan, only English, Spanish and English, Spanish and Mayan; only one individual spoke all three languages. Despite such language barriers, the members found a means of effectively communicating amongst themselves. However, this shared practice extends to "a set of frameworks, ideas, tools, information, styles, language, stories, and documents that community members share … and enables the community to proceed efficiently in dealing with its domain" (Wenger et al., 2002, p. 29), as evidenced in the present example. While the shared beyond given goal of creating a botanical collection was achieved, so much was gained by members of the community, including the development of botanical collecting skills among novices and the documentation of indiginous medical and ethnographic knowledge of local plants used for medicine (to treat a variety of diseases) and for rainfall prediction (for agricultural purposes). Through purposeful communication to navigate conflict and build trust, the community established genuine and effective collaboration and cooperation.

Conclusion

The work of INDICASAT-AIP and MRP both demonstrate the attributes and factors that support the formation of communities of practice (e.g., shared goal, co-construction of knowledge, communication, conflict, and trust). Further, the shared practice of each indicates that members of the community actively mediated the *border politics*; that is, negotiated "the bounds of membership and beliefs of a given community" (Achinstein, 2002, p. 426). In particular, the members contemplated who was included in the community, how various members were included, how and whose knowledge contributed to and is represented in the collective work, and who are the beneficiaries of the collaboration (Atweh & Keitel, 2007). These two exemplars of genuine, international collaborations provide us with considerations as we embark on such work within the domain of science and mathematics education.

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Scientists, Religious Experts, and other Sources of Knowledge: Non-Science Majors' Beliefs about Controversial and Noncontroversial Questions

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ABSTRACT

This study explores the beliefs of non-science majors in an undergraduate biology classroom as part of a larger study on evolution education. Groups of students (n=12) were given fourteen questions, some potentially controversial and some non-controversial, and asked to create categories based on what type of authority students would turn to as a source of knowledge. Examples of questions included "How did all lifeforms come to live on Earth?", "What happens to us after we die?", and "How did the Grand Canyon form?" We coded card sort results to examine how the sources of knowledge categories differed depending on the controversial nature of the question, its science/non-science content, and student groups' evolution acceptance survey scores. Student groups created 35 sources of knowledge ranging from broad sources such as "scientist" to very specific sources such as "God" and "environmental biologist". Results also showed that seven out of 10 controversial questions were placed in categories of questions to be answered by God or religious experts, while non-controversial questions were deemed answerable by scientists. This study shows that students' beliefs about knowledge and authority vary, and that biology educators should be aware that their non-major students often consider non-scientific sources of knowledge when thinking about controversial scientific issues.

Keywords: biology education, epistemology, evolution education, community colleges

Introduction

This study explores non-science majors' beliefs about sources of knowledge in an undergraduate biology classroom. The ability to evaluate sources of knowledge as valid and pertinent is an important part of all students' learning. It is especially important in science education as students are often confronted with science knowledge about topics such as evolution, climate change, or vaccines that can be considered controversial by the public. In this paper, we will examine and describe non-science majors' beliefs about what sources of knowledge should be considered when thinking about both controversial and non-controversial topics.

This data is part of a larger study consisting of community college students (Green & Delgado, 2021). The larger study included a carefully designed intervention based on the cultural border crossing (Aikenhead, 1997) theoretical framework, which posits that some students might experience a figurative border crossing between their home cultures and the science classroom culture. The intervention was also based on the collateral learning theoretical framework, in which Jegede (1995) suggested that students might use collateral learning as a cognitive process that allows them to accommodate possibly conflicting ideas. These two theoretical frameworks were the basis of an intervention designed to allow biology students in the sample to increase understanding and acceptance of evolution without being asked to discard any religious beliefs, or worldviews, that seemingly contradict evolution (Green & Delgado, 2021). The research discussed in this paper is part of that intervention.

Sources of Knowledge and Science Learning

The ability to evaluate knowledge sources, consult multiple sources, and use reliable scientific sources are important goals in science education. The Science and Engineering Practices embedded into the Next Generation Science Standards (NGSS Lead States, 2013) reflect the importance of this epistemological development in Practice eight. Obtaining, Evaluating, and Communicating Information. The Grades 6-8 and 9-12 recommendations highlight the use of multiple sources of knowledge and the assessment of the credibility, accuracy, and bias of sources (NGSS Lead States, 2013). While the AAAS *Vision for Change in Undergraduate Biology* does not specifically address the importance of sources of knowledge, it advocates for student-centered biology core competencies that position undergraduate biology students to take ownership of their learning by *doing* science in terms of generating and testing hypotheses using evidence (Brewer & Smith, 2011). Similarly, Bravo-Torija and Jimenez-Aleixandre (2018) developed a learning progression for the use of evidence in decision making contexts. At the lowest levels, students are able to extract information from sources in response to prompts. At higher levels, students integrate evidence from multiple sources but only support their own position. At the highest levels, students synthesize evidence from multiple sources by supporting their choice and disconfirming other choices (Bravo-Torija & Jimenez-Aleixandre, 2018).

Some science education studies have investigated beliefs about sources of knowledge in relation to science learning. When elementary school children were asked to justify their scientific knowledge, most sought justifications for knowledge, other than appeals to authority when possible. These students first justified conclusions with data, than other plausible mechanisms, and only looked to authorities when data lacked conclusiveness (Sandoval & Cam, 2011). In a high school context, high school science students cited several sources of knowledge in their science learning including trials and testing, discipline-based theory, class members, the teacher, parents, and other students outside of class. When presented with open-ended tasks, these high school students tended to draw on more sources of knowledge than during close-ended tasks (Venville et al., 2004). College students who consider and question the authority of sources tend to more often justify conclusions with multiple sources (Braten et al., 2014) and maintain that scientific knowledge is tentative (Liu et al., 2011). Furthermore, secondary students who justified knowledge with research-based authorities like scientists held more adaptive beliefs about Internet information (Cheng et al., 2021). Based on these results, some authors advocate for science instruction that explicitly elicits students' epistemological ideas to identify and address concepts that are justified primarily through teachers' or scientists' authority (Hofer, 2020; Sandoval & Cam, 2011).

Epistemological beliefs are important predictors of other desired outcomes in science education. First, epistemological sophistication is associated with approaches to learning science content. In a study of college science majors, students with less sophisticated epistemological beliefs about sources of knowledge were more likely to rely on memorization of content for tests (Liang & Tsai, 2010) rather than engage in deeper learning strategies employed by their more epistemologically-sophisticated peers (Lin et al., 2012). Second, Fulmer (2014) found that undergraduates had more positive views of science when they believed scientific knowledge is derived from authority, a less sophisticated epistemological view. Fulmer (2014) explained this surprising finding in that the students viewed their science faculty as content experts who derived their authority from their secular academic accomplishments. Additionally, undergraduate students who justified their claims using information from multiple sources demonstrated more comprehensive argumentation when confronting a socioscientific issue (SSI) such as climate change (Braten et al., 2014). Finally, epistemological beliefs such as those about sources of knowledge matter because they influence how people learn, search for information, evaluate claims, apply scientific knowledge, and engage in civic duties. (Hofer, 2020). Clearly, epistemological beliefs about sources of knowledge are important for engagement in science learning, attitudes toward science, and argumentation quality.

Sources of Knowledge and Controversial Science

Scientific knowledge can be controversial for a variety of ways – active science that is controversial within the scientific community, societally-denied science that is widely accepted within the scientific community but contested within society, and SSI (Borgerding & Dagistan, 2018). When reasoning about societally-denied science like evolution, learners often appeal to authorities. The authorities may include scientists, teachers, religious leaders, and parents (Borgerding et al., 2017). In one study of college undergraduates, upperclassmen biology majors appealed to authority less than lower classmen biology majors and nonmajors (Borgerding et al., 2017). Yet, when reasoning about SSI, Liu et al. (2011) found that science majors tended to be less critical of science information about an SSI and more often appealed to scientific authority when compared to their nonmajor counterparts. These findings indicate that background knowledge or identity associated with a college science major may be important as college students consider referencing various authorities.

Researchers have investigated how students confronting SSIs consider and evaluate sources of knowledge. Students examining socioscientific issues often recognize that some sources are more credible than others (Stadtler et al., 2016; Yazici et al., 2016). When preservice social studies teachers examined a nuclear power plant safety SSI, participants readily concluded that scientists working on the issue were most trustworthy, while Parliament officials, nuclear power companies, and television news were the least trustworthy sources of knowledge in that order (Yazici et al., 2016). Students most often attend to the credibility of the source by determining if the source is authoritative/expert versus partisan and/or scientific versus non-scientific (Mason et al., 2010). Other students finding sources for evaluating an SSI about stem cell research used the language of the authors, the authors' statuses within their field, and the content of the source for determining source credibility (Witzig et al., 2013). Previous research has shown that students who evaluate the credibility of sources of knowledge for SSI tend to use multiple sources of knowledge (Braten et al., 2014; Mason et al., 2010). When students are confronted with conflicting evidence about an SSI, they tend to rely more on the quality of the source than their own content knowledge (Bromme et al., 2015) and are more likely to question the motivations of the scientists when the sources differed in terms of their implied trustworthiness (Gottschling et al., 2019). Ultimately, students who attend to the credibility of sources of knowledge about SSI outperform their peers on learning goals (Mason et al., 2010). Importantly, the ability to choose more credible sources of knowledge can improve with training. Training that included awareness of expertise and the importance of source competence when choosing a source of knowledge for issues, such as carbon sequestration or protection of endangered zoo animals, increased vocational students' selection of pertinent expert sources and citation of these sources to justify judgements (Stadtler et al., 2016).

When confronted by societally-denied science topics such as evolution or anthropogenic climate change, sources of knowledge can be particularly important for science learners. Climate change education studies have illustrated the importance of authorities and perceived credibility of sources of knowledge. Wodika and Schoof (2017) identified formal education, the media, and family as sources of college students' climate knowledge. When American college undergraduates evaluated an article about climate change, they perceived trustworthiness of the source and the certainty of the message were better predictors of the plausibility of the message than knowledge of anthropogenic climate change (Lombardi et al., 2014). Additionally, in a study of undergraduates who were provided with a list of scientific authorities and had to choose relevant experts for a climate change scenario, participants largely identified scientists with relevant disciplinary expertise, such as earth scientists, even though the participants had relatively little general science knowledge themselves (Bromme & Thomm, 2015).

Evolution is a particularly complicated example of societally-denied science in terms of credible sources of knowledge. College biology students rely on both religious and scientific authorities to justify their rejection or acceptance of evolution (Borgerding et al., 2017). In that study, students with overall low epistemological sophistication were more likely to rely on authorities and less accepting of evolution in general than their higher epistemological peers. Similarly, Metz et al. (2018) found that evolutionists used empirical evidence and scientific consensus as criteria for their evolution acceptance while Creationists relied on religious authority and "knowledge of the heart" as their justification. Clearly, people rely on and evaluate authorities when identifying sources of knowledge for their positions on societally-denied science.

Importantly for evolution education, learners may view evolution differently than other science subjects because of perceptions of conflict with some religious beliefs (Barnes et al., 2020). Sinatra et al. (2003) examined college learners' understandings, acceptance, and epistemological dispositions surrounding controversial topics (animal evolution and human evolution) and noncontroversial topics (photosynthesis and respiration). As their participants' knowledge of photosynthesis and respiration increased, so did their acceptance of these theories. However, increased knowledge of evolution was not correlated with acceptance of theories about animal or human evolution. Importantly, epistemological sophistication and having an open-minded thinking disposition were correlated with human evolution acceptance, but not acceptance of animal evolution or photosynthesis and respiration. These findings demonstrate that learners view human evolution differently, than less controversial science content such as photosynthesis and respiration. Based on these findings, this study sought to identify participants' sources of knowledge for varying controversial and non-controversial science topics including both animal and human evolution in particular.

This paper focuses on how undergraduates in an introductory biology class for non-majors identify sources of knowledge that could be used to answer scientific and non-scientific questions that vary in terms of their potential controversy. In this research, we aimed to answer the following research questions:

1. What sources of knowledge do community college biology students seek, to answer potentially controversial and noncontroversial questions?
2. To what extent do sources of knowledge differ for potentially controversial and non-controversial science questions?
3. Does evolution acceptance predict the sources of knowledge chosen for potentially controversial and noncontroversial science questions?

Methodology

Sample

Community college students (N=28) taking Biology 110 at a community college in the Southeastern United States participated in this research. All students were earning a non-science degree (Business Administration, Hospitality Management, etc.) and took biology as their only science requirement for a two-year degree. Students could choose between two scientific fields (biology and geology) to satisfy their science requirement. Biology 110 covered cell and molecular biology, genetics, evolution, and ecology with evolution being taught as the penultimate unit of the semester. The course was taught by Mr. Gloucester (a pseudonym), who has Bachelor's and Master's degrees in Biology and has taught at the community college level for nine years. Students were asked to work with their self-selected table mates during this activity. Twelve groups were formed, with the smallest group size as two students and the largest group containing four students. Because the card sort activity was designed as a pedagogical component of the intervention, we asked students to work in pairs/groups rather than independently.

Data Sources

Card Sort

As previously mentioned, data reported in this manuscript are part of a larger research project focused on an intervention designed to help facilitate evolution understanding and acceptance as needed by community college biology students with religious worldviews. The intervention included daily mini-lessons delivered in Biology 110 guided by the cultural border crossing and collateral learning theoretical frameworks. The mini-lessons were scripted for Mr. Gloucester, and the first author attended all evolution lectures to ensure that the lessons were implemented with fidelity (Green & Delgado, 2021).

In this part of the research, we collected card sort data. Card sorts ask participants to place things into groups; cards can contain pictures or words. They are often used as an exploratory technique when the aim is to collect information on categories people use (Rugg & McGeorge, 1997). Card sorts have been previously used to collect data on various science education topics such as orientations to science teaching (Friedrichsen & Dana, 2003), perceived risks of biotechnology (Gardner & Jones, 2010), and how students think about size and scale (Chesnutt et al., 2018). Card sorts are useful because information organized into categories is an important part of all learners' knowledge (Rugg & McGeorge, 1997).

The first mini-lesson, implemented on the first day of the evolution unit, was titled "Who do you ask?" and focused on different sources of knowledge (for example a science teacher, the Bible, a family member). The lesson plan included the following background information, providing context to the instructor before the lesson:

> Why is this important? We use different sources of information when answering questions. Jegede says that collateral learners can use more than one source of knowledge while studying science. For example, parallel collateral learners might use two different sources of knowledge in two different places. They might answer questions about the beginning of the universe using a scientific source of knowledge while in Biology class, and a religious source of knowledge while in church. This theoretical framework says that students should be able to use multiple sources of knowledge to answer questions about the world, not only one. We should be encouraging students to leverage different sources of knowledge, rather than talking them into believing in only one (science) (Green & Delgado, 2021, p. 492).

The instructor was asked to read the following script aloud to the students before the activity began. This script was created to set up the card sort activity for the students:

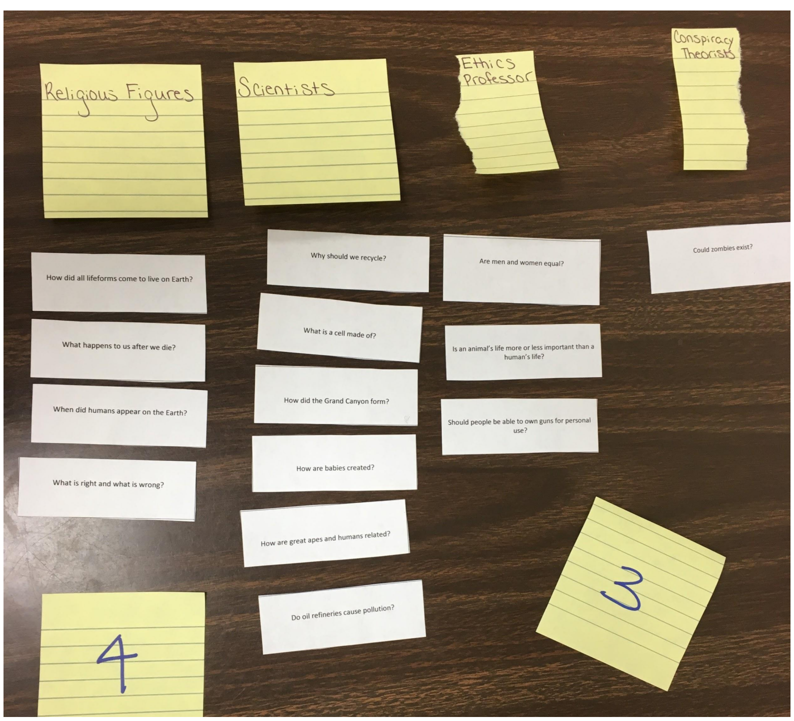
> Some scientific issues are discussed often in places other than science labs and conferences. One of these issues is evolution. You might hear the word "evolution" at school, at a place of worship, or in a doctor's office. If you have questions about evolution, who do you ask?

> In this activity, we'll talk about different sources of knowledge and what questions they answer. For example, if you wanted to know how many planets there are outside of our solar system, who would you ask? [Pause and wait for students to answer. Possible answers might include a scientist, the internet, an astronomer]. What kind of source of knowledge is that? [Pause and wait for students to answer. The intended answer is "scientific".] If you wanted to know what the meaning of life is, who would you ask? [Pause and wait for students to answer. Possible answers might include a philosopher, a religious expert, a friend.] What source of knowledge is that? [Pause and wait for students to answer. Possible answers might include philosophy or religion.]
>
> Think about the different sources of knowledge that you draw from in your own life. I'm going to give you a set of cards. I want you and your table partner to group these cards based on the sources of knowledge you would use to answer each one. You can create as many or as few sources of knowledge as you'd like.

Students were given slips of paper with one question per slip. Some questions were designed to be answered by science, while others were not. In addition, some questions were related to potentially controversial issues (e.g. gun ownership, human origins), while others pertained to noncontroversial topics (e.g. cell composition, zombie existence). For the potentially controversial scientific questions, we used three prompts related to evolution. We classified the questions about evolution as "potentially controversial" because some members of the public may believe that evolution is not the best explanation for the diversity of life on Earth, but there is wide consensus within the scientific community that evolution is a valid theory.

Figure 1

Example of Card Sort Data from One Group



Before the activity began, student groups were asked to place the previously-distributed cards containing their participant number on their desks. Student groups were given post-it notes on which to create sources of knowledge (SoKs) as the researchers wanted students to create their own sources rather than group the questions into prescribed SoKs imposed by the researchers. Student groups were told that they could place a question into more than one source if they felt it was appropriate. Groups arranged the questions into sources of knowledge on their desks. Students were given about 10-15 minutes to complete the activity. After the questions were arranged, a picture of each group's card sort was taken.

Table 1

Questions Given to Student Groups

Question	Can be Answered by Science	Potentially Controversial
What is a cell made of?	X	
How did the Grand Canyon form?	X	
How are babies created?	X	
Could zombies exist?	X	
What happens to us after we die?		X
What is right and what is wrong?		X
Should people be allowed to own guns for personal use?		X
Is an animal's life more or less important than a human's life?		X
Are men and women equal?		X
When did humans appear on Earth?	X	X
Do oil refineries cause pollution?	X	X
Why should we recycle?	X	X
How are great apes and humans related?	X	X
How did all life forms come to live on Earth?	X	X

Quantitative Data Collection (MATE)

We used the Measure of Acceptance of the Theory of Evolution (MATE; Rutledge & Warden, 1999) to collect data regarding students' evolution acceptance. This instrument contains twenty Likert-scale items that can shed light on students' agreement or disagreement with various parts of evolution. Although the instrument was originally designed to assess teachers' acceptance of evolution (Rutledge & Warden, 1999), it has also been successfully used to measure undergraduate students' acceptance of evolution (Borgerding et al., 2017). The MATE is the most widely used evolution acceptance instrument and has been used in over 24 studies since its publication in 1999 (Romine et al., 2017). While other instruments such as the Inventory of Students' Acceptance of Evolution (I-SEA; Nadelson & Southerland, 2012) and Generalized Acceptance of EvolutioN Evaluation (GAENE; Smith et al., 2016) also exist, the MATE was chosen because it is well-validated and accepted (Romine et al., 2017).

Each student in the class took the MATE as a pre-assessment the week prior to the evolution unit and as a post-assessment at the end of the semester. Answers were entered into a Google Sheet and scored according to the scoring guide included with the instrument. Data was identified with a random number previously assigned to the students so learning gains could be measured for the larger study by comparing pre- and post- scores. Because the card sort occurred on the first day of the evolution unit, we used students' pre-instruction MATE scores in our analysis for this paper.

Data Analysis

Data analysis of the card sort data employed a constant comparative method approach (Glaser & Strauss, 1967). First, the authors open-coded the various knowledge sources student groups listed on their post-it notes. During this open coding phase, detailed code notes were taken to characterize the dimensions of each emerging code. Through discussion, the authors used these initial codes and dimensions to collapse the existing codes into four categories to describe the sources of knowledge: scientists, religious experts, God, humanities experts, and possibly dubious experts, as shown in Table 2. This coding scheme was then re-applied to all the data to ensure that all sources of knowledge were consistently categorized. This analysis was used to address our first research question about the sources of knowledge community college biology students seek, to answer potentially controversial and noncontroversial questions.

At this point, information about the status of the question (can be answered by science, can be considered controversial) was used to sort the sources of knowledge categories. In this way, data were sorted to develop axial codes that highlight the conditions/contexts in which the categories occurred and possible relationships between sub-codes. These findings were used to address the second research question regarding the extent to which sources of knowledge differ for potentially controversial and non-controversial science questions.

Finally, to address the third research question targeting the extent to which evolution acceptance predicted the sources of knowledge chosen for potentially controversial and noncontroversial science questions, we merged the MATE evolution acceptance data with category data. We scored the MATE according to Rutledge and Warden's (1999) recommendations to generate numerical scores for each participant. Because students worked in groups for the card-sorting task, we averaged the MATE scores for the members of each group to get a group MATE score and group MATE score range. We then developed a cross-tabulation of average MATE score and categories for each group in order to identify any trends relating evolution acceptance with types of knowledge sources. We were unable to perform any additional statistical analysis due to the small sample size and the fact that the MATE was scored on an individual level while the card sort was performed in pairs.

Results

Source of Knowledge Categories

The first research question was "What sources of knowledge do community college biology students seek, to answer controversial and noncontroversial questions? Student groups created 35 distinct sources of knowledge in this study. An SoK was considered distinct if the difference between it and another SoK was more than simply the difference between singular and plural. For instance, "scientist" and "scientists" would not be distinct sources of knowledge but "science" and "scientists" would be distinct.

Since many SoKs were similar, we grouped them into four categories. Table 2 lists, describes, and exemplifies these categories.

Table 2

Sources of Knowledge Categories

Categories	Code Description	Participant Exemplars
Scientists	Any individual whose professional responsibilities pertain to science	"Scientists," "Biologist," "Environmental Scientist," "Geologist/Ecologist/Toxicologist"
Religious experts and God	Any individual whose professional responsibilities pertain to religion; also God	"God," "Religious Expert," "Priests, Preachers, etc."
Humanities experts	Any individual whose professional responsibilities pertain to human culture or society	"Ethics professor," "Political Scientist," "Law," "Humanities," "Psychologist," "Sociologist," "Political/Ethical experts," "Economist"
Possibly Dubious experts	Lay people and sources with questionable credibility	"Parent," "Activists on both sides," "Internet"

Controversial and Noncontroversial Questions

To answer the second research question, "To what extent do sources of knowledge differ for controversial and non-controversial science questions?", the authors compared the source of knowledge categories for the different types of questions. See Table 3 to explore which questions were placed in which category.

As the data show, different types of questions elicited different sources of knowledge. First, students almost always placed the questions we considered non-controversial and answerable by science questions ("solidly science"), including the questions about cells, the Grand Canyon, recycling, how babies are created, oil refineries, and how humans are related to apes in the scientist SoK category. One group placed the question about babies in the possibly dubious experts category (specifically placing the question in a "parents" SoK). One group placed the question about humans and apes in a religious category and one group thought that question could be answered by humanities experts. We

Table 3

Questions and Participants' Proposed Sources of Knowledge

Question	Question Type	Scientists	Religious experts	Humanities experts	Possibly Dubious experts
What is a cell made of?	S, NC	12	0	0	0
How did the Grand Canyon form?	S, NC	12	0	0	0
How are babies created?	S, NC	11	0	0	1
Could zombies exist?	S, NC	10	0	0	3
What happens to us after we die?	NS, PC	1	6	5	1
What is right and what is wrong?	NS, PC	0	4	7	3
Should people be allowed to own guns for personal use?	NS, PC	0	1	8	4
Is an animal's life more or less important than a human's life?	NS, PC	0	2	8	3
Are men and women equal?	NS, PC	1	2	8	1
When did humans appear on Earth?	S, PC	7	2	2	1
Do oil refineries cause pollution?	S, NC	11	0	1	0
Why should we recycle?	S, NC	11	0	1	0
How are great apes and humans related?	S, PC	10	1	1	0
How did all life forms come to live on Earth?	S, PC	6	5	2	1

Note. (s=science, ns=science, c=controversial, nc=non-controversial, pc=potentially controversial)

placed the question about zombies in this category although three groups out of thirteen thought it could be answered by possibly dubious experts such as "conspiracy theorists."

Another set of questions ("beyond science"), we considered both potentially controversial and beyond the scope of science included the questions about the afterlife, what is right/wrong, gun ownership, animal rights, and gender equality. None of the groups placed these questions in a scientist category, with the exception of one group who placed the gender equality question there. All "beyond science" questions were placed in a religious experts category by at least one group, with what is right/wrong appearing in the religious experts category most frequently. At least one group placed all questions in the possibly dubious experts category, with the question about gun ownership being placed there by four groups.

Most of the mixed results were found with the questions pertaining to evolution, "How did all life forms come to live on Earth?" and "When did humans appear on Earth?" For the lifeforms question, the majority of the groups placed the question in a scientist or religious experts SoK. Two groups placed the question in a humanities SoK, and one group would turn to a possibly dubious expert--in this case, the internet.

Evolution Acceptance and Sources of Knowledge

Our final research question examined whether evolution acceptance predicts the sources of knowledge chosen for controversial and noncontroversial science questions. We used the MATE scores as the measure of acceptance of evolution. The smallest range in MATE scores between group members was 2 points, with the largest difference being 53 and a mean difference of 23.2 points between group members.

Further analysis of the data showed no consistent patterns. For example, Group eight had MATE scores of 75 and 80 (moderate to high acceptance), yet placed four questions in a religious SoK, while Group nine had MATE scores of 81 and 85 (high acceptance) and did not create a religious SoK. Group 11 had a 35-point difference between scores (ranging from high to low acceptance) and placed the question about what happens after humans die in a religious SoK and the question about lifeforms appearing on Earth in a scientific SoK. Group 12 had one very low accepter, one low accepter, one moderate accepter, and one high accepter yet created no religious SoK. After analyzing the data, we did not see any alignment between acceptance of evolution and SoK chosen for science questions.

Discussion

Different Questions Elicited Different Sources of Knowledge

Different questions clearly elicited different sources of knowledge. Participants distinguished between SoKs for non-controversial and potentially controversial science-related questions. The noncontroversial science-related questions primarily elicited SoKs in the scientist category while only a few instances of humanities experts and possibly dubious experts were seen in the data. Participants never sought religious experts for noncontroversial science-related questions. However, all three of the controversial science-related questions elicited religious experts as sources of knowledge. The questions pertaining to humans' first appearance on earth and how all life forms came to live on Earth elicited the most SoKs by far. These findings are consistent with previous literature in which college biology students sought scientific and religious authorities for evolution-related questions (Borgerding et al., 2017; Metz et al., 2018) when compared to less controversial science topics (Sinatra et al., 2003).

Some groups used very few sources of knowledge across all the different types of questions. Two of these groups relied exclusively on either religious experts or scientific experts across the questions. This binary may be very important for students' science learning experiences, especially when learning about biological evolution. In a German study, evolution acceptance was found to be related to students' perception of the conflict between science and religion (Konnemann et al., 2016). In an investigation of Christian university students, many religious students entered college with the perception that religion and biology are in conflict and that the biology community is not sympathetic to religion (Barnes et al., 2017a). These religious students had negative biology learning experiences when their instructors did not acknowledge religion or religious viewpoints in their teaching and emphasized conflicts between religion and biology (Barnes et al., 2017a). For student groups that identify science-religion binaries when expressing sources of knowledge, an instructor can help students understand questions that science can and cannot address by helping them understand the bounded nature of science (Southerland et al., 2012).

Of the three possibly-controversial, evolution-related questions, participants sought far more religious sources of knowledge for the questions addressing humans' first appearance on Earth and how all life forms came to appear on Earth. However, the other possibly-controversial, evolution-related question about how great apes and humans are related mostly elicited scientific sources of knowledge. This difference may reflect college biology learners' distinction between evolutionary origins and evolutionary processes (Smith, 2010). Future card sort research that includes more questions about evolutionary origins and processes could examine this possibility.

Evolution Acceptance Did Not Predict Categories

The range of evolution acceptance did not predict types of SoK created. Since groups were composed of table partners/groups (and seats were not assigned), researchers did not intentionally group students based on evolution acceptance or rejection. When examining the groups' SoKs, it was evident that some groups were composed of students with similar MATE scores while others showed a wide range of scores between group members. Since no patterns emerged linking average MATE score to SoK categories, we wondered how students navigated differences in evolution acceptance when creating their categories. For instance, two groups had similar differences in MATE scores between the members, but one group (Group seven) created a religion SoK and placed four questions in it while the other group (Group eight) did not create a religion SoK. We wondered who posited the idea of a religious source of knowledge in Group seven and whether Group eight members discussed a possible religious SoK. A limitation of the present study is that field notes and audio recordings during the activity were not taken. In future research, audio recordings of student discussions during this type of activity would help elucidate student discourse around sources of knowledge, and examine the extent to which group dynamics are important for identifying sources of knowledge for potentially controversial science subjects.

Understandings About Scientific Expertise Were Diverse

Participants in this study had a range of understandings related to scientific expertise. While the majority of groups used a generic "scientist" source of knowledge, several other groups were aware of specialization within scientific fields. This awareness of specialization signifies greater epistemological sophistication by recognizing that experts have specific training and are at the cutting edges of their fields (Hofer, 2004). The ability to choose more credible sources of knowledge can improve with training (Stadtler et al., 2016). In the context of evolution learning, the ability to identify the most credible experts may be particularly important. Despite the fact that evolution is overwhelmingly supported within the scientific community, the United States public is much less accepting of evolution in public polls (Wiles, 2010). Students seeking information about evolution must navigate their way through various purported scientific documents developed by Creationists and supporters of Intelligent Design. Compared to evolution research documents that advance evolutionary claims supported by empirical evidence, Creationist and Intelligent design documents rely less on empirical support and on a myriad of other justifications including appeals to authority and the absence of evidence, among others (Barnes et al., 2017b). Clearly, students must be able to evaluate the expertise of sources of knowledge regarding evolutionary questions. Students may hold different ideas of what constitutes “expertise” or “expert sources” and may need to operationally define the idea of what an “expert” is.

Conclusion

This study investigated the sources of knowledge sought by community college biology students for various science/non-science and controversial/non-controversial questions. The main contributions of this study are centered around college students’ choices of sources of knowledge. First, college biology students clearly sought different SoKs for science and non-science questions, with science questions largely evoking scientific experts. Second, among the science-related questions, the potentially controversial ones were connected to religious and other SoKs when compared to the noncontroversial questions. Third, these community college students never considered themselves a source of knowledge for any of the questions. Fourth, some students were aware of conflicts between SoKs and recognized a range of expertise among scientific SoKs.

Implications for science educators center around students’ epistemologies. In general, it is important for science educators to be aware of students’ wide-ranging depth of epistemological ideas about science and scientific evidence. Based on these findings, efforts to promote epistemological sophistication, especially in science education, among college students are warranted. Careful, non-threatening discussions about students’ beliefs about evidence, expertise, and reasoning could lead to higher epistemological sophistication. Specifically, efforts should address the status of various evolution experts within the scientific community, the nature and development of scientific expertise, and strategies for assessing the relative credibility of competing sources of knowledge.

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Preparing Elementary Preservice Teachers to Integrate Technology: Examining the Effects of a New Science Course Sequence with Technology Infusion

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ABSTRACT

Elementary teacher preparation programs often separate content and technology courses. This study examined the impact of changing the required science content courses for elementary preservice teachers in a small liberal arts setting. Following the new science course, students participated in a field experience as part of an elementary science pedagogy course that required using technology when delivering content lessons. We compared the students' perceived technological, pedagogical, and content knowledge (TPACK) and confidence teaching with the technology between the two groups. Data was collected using the TPACK survey at the end of their teacher preparation program. The analysis showed a significant difference in students' perceived TPACK between a discipline-specific science course and a multidisciplinary course, except in one dimension, pedagogical knowledge (PK). Overall, candidate confidence in combining content and technology in teaching a classroom lesson was higher with the multidisciplinary course. However, students could not effectively describe specific episodes that indicate high-level, inquiry-based teaching but did describe overall knowledge of technological pedagogical knowledge.

Keywords: infused, pedagogy, preservice teachers, TPACK

Introduction

Preparing elementary preservice teachers to teach science using technology is a complex process. To be effective, candidates need knowledge of essential science concepts and skills, effective pedagogy, and digital tools and resources. Because these domains of expertise do not exist in separate silos, future teachers need opportunities to plan instruction that allows them to consider the most effective pedagogy and technology for teaching specific science concepts and skills.

Teacher preparation programs must consider how best to prepare their teacher candidates with the technological, pedagogical, and content knowledge (TPACK) needed to teach all disciplines, including science. This paper describes our approach to preparing elementary preservice teachers to make meaningful use of technology when teaching science content.

Science Content Preparation

Preparing elementary preservice teachers to teach all of the disciplines of science is complicated. Some colleges introduce future teachers to science content in multidisciplinary courses, but most depend on discipline-specific classes open to students across all majors offered at the college or university. This approach affords an extended amount of time to learn the concepts and skills associated with a single discipline (e.g., biology, chemistry, physics, etc.). Research, however, suggests that elementary preservice teachers continue to lack confidence in the sciences with this approach because the modeling of effective pedagogical practices is limited (Bergman & Morphew, 2015). Without proper modeling and relevant inquiry-based learning, elementary preservice teachers' attitudes towards and confidence in science may ultimately play a role in the amount of time they will devote to science instruction in their future classrooms (Bursal & Paznokas, 2006; National Research Council, 2007). Finding the best approach to prepare elementary preservice teachers with the knowledge and confidence to teach science is one area still being explored by many teacher preparation programs. One trending theme is the creation of multidisciplinary courses. Multidisciplinary science content courses explicitly designed for prospective elementary teachers and taught by trained pedagogues may address some of the identified concerns (Avery & Meyer, 2012; Bergmann & Morphew, 2015; Kirst & Flood, 2017; Knaggs & Sondergeld, 2015; Long 2019; Menon & Sadler, 2016).

Technology Preparation

In addition to ensuring elementary preservice teachers possess adequate science content knowledge, teacher preparation programs must also identify effective ways to help future teachers make meaningful pedagogical use of technology. Various factors, including time, resources, knowledge, and beliefs, impact teachers' pedagogical use of technology (Ottenbreit-Leftwich et al., 2010). The most significant predictor of technology use for preservice teachers is their self-efficacy with technology and beliefs in the value of technology in the classroom (Anderson et al., 2011). Therefore, teacher preparation programs must consider the impact of candidates' technology beliefs and knowledge when designing learning experiences.

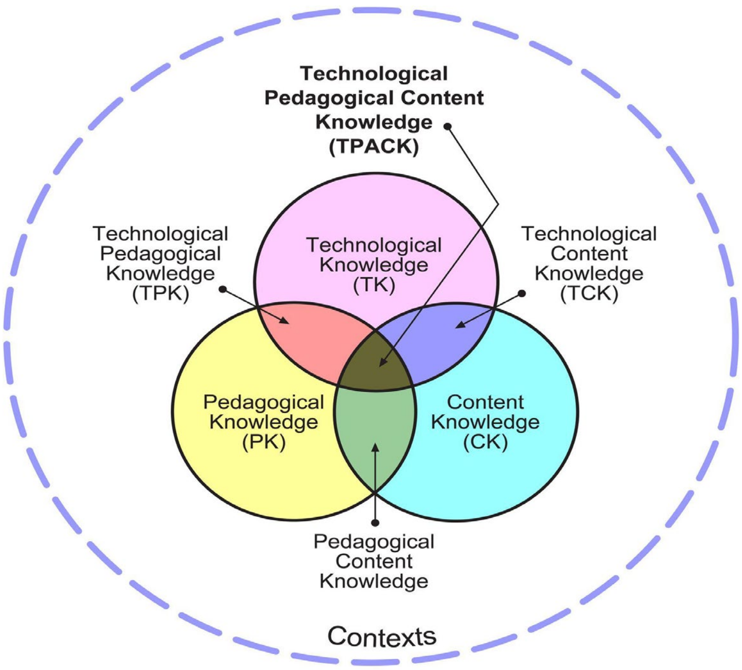
Theoretical Framework

This study and the design of our elementary-level science and pedagogy courses are grounded in the Technological, Pedagogical, and Content Knowledge (TPACK) framework (Kohler & Mishra, 2009; Mishra & Koehler, 2006), see Figure 1. The framework creators argue that technology, pedagogy, and content are interrelated; and that teacher preparation programs must help candidates develop the knowledge and skills needed across all three domains. While this framework is applicable across academic disciplines, we focus specifically on science education.

Preparing elementary preservice teachers who understand the complex interplay of science content, technology, and pedagogy is essential but also a significant challenge for teacher preparation programs. Focusing on any of these components (i.e., science content, pedagogy, or technology) in isolation reveals the breadth and depth of knowledge and skills future elementary science teachers will need. For example, science content knowledge (CK) requires expertise in multiple disciplines, each focused on its own set of disciplinary concepts, methods of inquiry, and discursive practices. Pedagogical knowledge (PK), equally complex, requires an understanding of the subject matter, purposes and values of education, learning and learners, curriculum and planning, classroom management, assessment, resources, and context (Hashweh, 2018; Kurt, 2018; Mishra & Koehler, 2006). Finally, technology knowledge (TK) requires knowledge of and the ability to use a variety of technologies, applications, and corresponding resources (Kurt, 2018; Mishra & Koehler, 2006).

Figure 1

Graphic Representation of Technological, Pedagogical, Content Knowledge (TPACK) Adapted from http://tpack.org/ Website and Used with Permission



Elementary teachers do not, of course, apply the knowledge and skills associated with these domains in isolation. Shulman (1986) developed a framework that enables an examination of the intersection of content and pedagogy. According to Shulman, teachers' pedagogical content knowledge (PCK) includes "an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons" and "knowledge of the strategies most fruitful in reorganizing the understanding of learners" (p. 9-10). In other words, effective teachers must understand the central concepts and skills of their discipline and be able to make that content accessible to their learners. Mishra and Koehler (2006) extended Shulman's framework to include technology. They contend that in addition to possessing knowledge of content and pedagogy, teachers need to be prepared to make effective pedagogical use of technology when teaching their content. Thus, to be effective, teachers need technological content knowledge (TCK), which includes understanding the role of technology in their discipline (e.g., biology, mathematics, history); technological pedagogical knowledge (TPK), or the ability to teach with and about technology; and technological pedagogical content knowledge, the ability to integrate the three domains of technological knowledge, pedagogical knowledge, and content knowledge (TPACK).

The TPACK framework is a valuable tool for examining teacher-preparation programs and has led to significant recommendations for improving prospective teachers' pedagogical uses of technology (DeCoito & Richardson, 2018). This work guided both the design of this study and the preparation of our elementary preservice teachers to teach science with technology.

Designing a New Course Sequence

To improve elementary preservice teachers' science content knowledge, pedagogical skills, and technology preparation, the elementary science pedagogy course was revised, and a new multidisciplinary science content course was developed. The new science content course, created specifically for future elementary teachers, replaced two previously required discipline-specific introductory science courses (e.g., biology, chemistry, physics, etc.). The new course was designed specifically to ensure elementary candidates 1) develop the science content knowledge needed to teach required academic standards, 2) experience effective pedagogical practices, 3) learn to make meaningful use of technology in their lessons, and 4) develop confidence in and enthusiasm for teaching science. The instructor for the multidisciplinary science course has expertise in both pedagogy and content with advanced degrees in both areas.

The multidisciplinary science content course includes a module in life science, physical science, earth science, and space science. Each module addresses state standards for licensure and includes state standards-based lessons they would teach in elementary classrooms. For example, lessons in life science included life cycles of plants and animals or in earth science lessons on the water cycle. Within each session of the course, technology was infused, such as coding, robotics, 3D printing, and virtual simulations. For example, when learning about the roles of organisms (producers, consumers, and decomposers), students coded a program showing the transfer of energy in the ecosystem. Another example when learning the water cycle, students coded a robotic device to navigate through the water cycle explaining the actions of water at each step. Each class session featured hands-on, cooperative investigations and lessons that candidates could use in their future classrooms.

In addition to developing a new multidisciplinary science course, the elementary science pedagogy class was also modified to enhance the elementary preservice teachers' ability to plan and teach science content using appropriate technology in a field experience. In the field experience, students were paired with cooperating teachers in first grade through fifth grade with licensed elementary cooperating teachers. The students worked with cooperating teachers to identify science standards and develop a technology-infused unit that was implemented during the field experience. The field placement was approximately two weeks, and each unit included science lessons that aligned to state standards that integrated coding and robotics. For example, in a first-grade lesson, students learned about hearing, tasting, and seeing, which was correlated to the Kibo robot. The Kibo robot has different sensor blocks that can be programmed to see the light (eye) and hear a sound (ear). In second-grade lessons, the Dash robot was coded by students to find the correct habitat for a specific animal by using cards and a map on the ground with various habitats. The robot and tasks were chosen based on the standards and the grade level taught. Previous field experiences did not require integrating technology to teach content, and the content was selected by the cooperating teacher. During the two-week field experience, students reflected on their practices with the instructor. Students were also required to videotape the lesson for further reflection.

Purpose of the Study

The purpose of this study was to investigate the impact of a new multidisciplinary science content course and technology-infused field experience on elementary preservice teachers' perceived technological, pedagogical, and content knowledge (TPACK); and their overall confidence in teaching with technology. The research question guiding this study is: What impact do the elementary multidisciplinary science content course and field experience with technology have on elementary preservice teachers' perceived knowledge and confidence in teaching science content with technology?

Methods

Participants

The study utilized a quasi-experimental design based on the course students enrolled in for content preparation. This method was chosen because the course sequence students enrolled was not random; therefore, we could not utilize a true experiment. Participants included 127 of the 136 elementary preservice teachers enrolled in either general discipline-specific science (DS) courses or the new multidisciplinary science (MS) content course over six semesters. The sampling was purposive to include all elementary education candidates who voluntarily participated at the end of the licensure program. Data sets were analyzed by the science course sequence completed rather than by the cohort. Fifty-nine participants completed the DS course and field experience without a technology requirement, and 68 participants completed the MS course and technology-infused field experience. For comparative reasons, the nine students who took science courses outside the institution were not included in the analysis.

Data Collection

Upon completing the licensure program, study participants' perceived technological, pedagogical, content knowledge was assessed using the Survey of Preservice Teachers' Knowledge of Teaching and Technology. The survey was developed and demonstrated an internal consistency reliability (coefficient alpha) ranging from .75 to .92 for the seven TPACK subscales (Schmidt et al., 2009). The survey consists of 54 Likert-scaled statements about Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK) Pedagogical Content Knowledge (PCK), and Technological Pedagogical Content Knowledge (TPACK). Response categories are "strongly agree," "agree," "uncertain," disagree," and "strongly disagree." Additionally, open-ended questions that asked candidates to describe their confidence and ability to integrate technology and episodes where they integrated technology in effective ways were also included. Participation in the study was voluntary and anonymous. Students accessed the survey online using an electronic device (computer, tablet, or phone).

Data Analysis

A mixed-methods approach was used to evaluate the outcomes of the two different course sequences. A mixed-method approach can provide a more comprehensive picture of the data compared to a single design (Morse, 2010). Quantitative and qualitative data were collected in a survey. Quantitative analyses included descriptive statistics, t-tests, and Levene's test to assess the equality of variances for the two groups. Likert-scale items were initially scored based on guidelines provided by Schmidt et al. (2009) and were exported into Excel and the Statistical Package for the Social Sciences (SPSS), where means and standard deviations were calculated for each TPACK domain and as a whole. Data sets were not analyzed for the content-specific questions related to math, social studies, and language arts since this was not the focus of the course. Open-ended responses describing the confidence in teaching with technology for participants were coded into four categories, highly confident, confident, fairly confident, and not confident. Open-ended responses describing specific episodes where elementary preservice teachers themselves effectively combined content, technologies, and teaching approaches in a classroom lesson were read repeatedly to generate a list of episodes that demonstrated specific uses of technology with content and pedagogy.

Results

Quantitative Data

Descriptive statistics were calculated to perform an independent t-test to compare the means of the general discipline-specific (DS) course vs. multidisciplinary (MS) course. The means for each area of the TPACK were then calculated, including Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and Technological Pedagogical Content Knowledge (TPACK). For the purpose of this study the Content Knowledge (CK), Technological Content Knowledge (TCK), and Pedagogical Content Knowledge (PCK) were only analyzed for science. Levene's Test for equality of variances indicated in all cases that equal variances were assumed, TK ($F = 2.34, p = .156$), PK ($F = .418, p = .519$), CK ($F = 1.09$, $p = .297$), TPK ($F = .985, p = .323$), PCK ($F =. 018, p = .895$), and TPACK ($F = .507, p = .478$). The mean TK, CK (Science), PCK(Science), TPK, TPK(Science), PCK (Science), and overall TPACK all showed a significant difference from the old course sequence to the new course sequence. The PK was the only measure that was not significant, see Table 1. The greatest change in means from the DS (3.87) course to the MS (4.22) was with content knowledge in science.

Table 1

Descriptive Data and Results of t-test of Discipline-Specific (DS) Course vs. Multidisciplinary Science (MS) Course

Factor	**Mean DS** (N=59)	**SD**	**Mean MS** (N=68)	**SD**	**t**	**Sig. (2-tailed)**
TK	3.79	0.46	4.12	0.53	-3.77	.000*
PK	4.33	0.39	4.43	0.38	-1.57	.119
CK Science	3.87	0.58	4.22	0.42	-3.90	.000*
TPK	4.22	0.46	4.40	0.39	-2.37	.019*
TCK Science	4.00	0.64	4.40	0.52	-3.84	.000*
PCK Science	3.95	0.62	4.22	0.45	-2.82	.006*
TPACK	3.97	0.45	4.21	0.48	-2.84	.005*

Qualitative Data

For this study, we analyzed two open-ended questions from the survey. First, participants in the survey were asked to describe their confidence and ability to combine content and technology in teaching a classroom lesson. Responses were coded as 1-not confident, 2-somewhat confident, 3-confident, and 4-very confident. Researchers coded the responses independently with agreement on 86% of the responses. Through discussion, 100% agreement was achieved. Five responses were eliminated because they did not address the prompt and could not be rated. A comparison of participants' confidence by percentage is presented in Table 2. Results indicated a high and very high level of confidence in participants regardless of whether they took the discipline-specific science course (DS) (79%) or multidisciplinary science course (89%), but a shift in the percentage of very confident rose from 31% in the DS to 49% in the MS.

Table 2

Comparison of Confidence by Percentage in DS vs. MS

	DS (n=52)	**MS** (n=63)
Not Confident	4%	0%
Somewhat Confident	17%	11%
Confident	48%	40%
Very Confident	31%	49%

Analysis of responses to open-ended prompts in which participants described specific times they effectively combined content, technologies, and teaching approaches in a classroom, indicated a relatively limited understanding of TPACK in both groups (DS and MS). Many participants described the use of presentation tools, apps, quiz tools, games, video-recording, and content-specific software. Overall, almost no participants demonstrated the ability to describe how they integrated the use of technology, pedagogy, and science content in meaningful ways. For example, they did not provide examples where they were coding or using robotics. Most instances of technology integration were to enhance lessons, such as using a presentation tool rather than transform the learning in new ways by coding, using robotics, and interacting or collaborating globally.

Discussion

The complexity of preparing elementary preservice teachers with the required science and technology knowledge can challenge teacher preparation programs. Our decision to create a multidisciplinary science content course and modify a field experience to include a technology-based teaching experience appears to positively impact candidates' perceived technological, pedagogical, and content knowledge. Specifically, candidates who participated in the new multidisciplinary science content course and technology-embedded field experience completed the program with higher perceived CK, TK, PCK, TPK, PCK, and TPACK. Pedagogical knowledge (PK) is the only domain in which participants did not show a statistically significant increase, but the overall mean was the highest mean in both groups compared to the other TPACK domains. One significant finding was that the greatest change in mean was found with the participants' perceived science content knowledge (CK Science). This course design shows promise in the multidisciplinary approach compared to the discipline-specific approach. This is similar to results reported by Knaggs and Sondergeld (2015), where students enrolled in a multidisciplinary science content course before a science pedagogy course, expressed gains in content knowledge and pedagogical knowledge that would help them to become effective science teachers.

The results also indicate that participants' confidence in their ability to integrate technology into instruction increased. While candidates' confidence in their technology integration skills was high for all participants, an increase of 18% of candidates who enrolled in the multidisciplinary course indicated being very confident, compared to the discipline-specific course sequence. The increased confidence may be attributed to the programmatic changes, including creating a multidisciplinary science content course taught by a professor with advanced training in science and pedagogy, and modifications to the elementary science field experience to include opportunities for candidates to teach with technology. These results are consistent with other research that indicate observing, designing, and teaching technology-based lessons were instrumental in developing TPACK (Ertmer & Ottenbreit-Leftwich, 2010; Buss et al.,, 2018).

Although confidence does not automatically ensure effective technology integration, research suggests that technological self-efficacy is a factor. According to Bandura (1997), individuals' self-efficacy "influences the courses of action people choose to pursue, how much effort they put forth in given endeavors, how long they will persevere in the face of obstacles and failures, their resilience to adversity, … and the level of accomplishments they realize" (p. 3). Educational technology researchers have utilized Bandura's work when exploring factors that impact preservice teachers' pedagogical uses of technology. Specifically, self-efficacy has repeatedly been identified as a key determinant of novice educators' use of technology in the classroom (Bauer & Kenton, 2005; Ertmer & Ottenbreit-Leftwich, 2010). While participants' TPACK confidence was high, the evidence suggests most were not yet able to identify examples of meaningful ways that they, or their cooperating teachers, used technology to expand elementary students' knowledge of significant science concepts or skills. Participants' limited ability to identify meaningful uses of technology occurred even though the science content professor regularly modeled how to use productivity applications, coding, 3-D printing, and digital simulations to foster scientific thinking and understanding. Buss et al. (2017) also found that most teacher candidates in their study planned to use technology in routine, non-transformative ways, leading to the conclusion that the pedagogical uses of technology may follow a developmental trajectory. These findings are similar to Mouza et al. (2013), who found that preservice teachers recognize the value of technology but have limited knowledge of how to use technology in ways that deepen content knowledge. Not only do elementary education candidates need opportunities to plan and teach inquiry-based science lessons that include technology, but they also need time to reflect on how technology supports the teaching of science through inquiry compared to other traditional uses of technology, such as showing a video or PowerPoint to present content (Polly & Binns, 2018).

Limitations

One limitation of the current study is that self-report scales were used to measure participants' TPACK and confidence in teaching with technology. Respondents may overstate their confidence because they think it is desirable, particularly when the researcher is also the course instructor. In addition, the method of data collection may have impacted participants' responses. The survey was administered during the last official programmatic meeting of the semester. Limited time to prepare written responses and the excitement of being finished with the program may have negatively impacted the care candidates took in answering open-ended questions. In future studies, interviewing preservice teachers may generate responses with more depth and might produce more robust data. A third limitation of our study is that because we did not gather data before and after student teaching, we do not know how this signature experience impacted participants' perceived TPACK and technological self-efficacy. Finally, caution should be exercised in forming generalizations based on the results of this study due to the small sample size.

Future Recommendations and Next Steps

The initial results of this study have promising implications for teacher preparation programs that are interested in integrating technology within science content and pedagogy courses and requiring a field placement that includes the use of technology. While we are hopeful about the positive impact of our model on preservice teachers' perceived TPACK and technological self-efficacy, we see areas for additional programmatic modifications that may enhance candidates' ability to identify and deliver meaningful technology-infused elementary science lessons. Moving forward, we plan to introduce teacher candidates to the TPACK framework in science content and pedagogy courses. Research suggests that structuring learning opportunities that allow them to reflect on and analyze the complex interplay of technological, pedagogical, and content knowledge may enhance their ability to deliver science lessons that show evidence of understanding a more sophisticated TPACK (Ertmer & Ottenbreit-Leftwich, 2010).

Additionally, we think training cooperating teachers to model, support, and help facilitate opportunities for technology inclusion to improve elementary preservice teachers' technology integration in science content teaching may prove helpful. All teacher candidates in our study demonstrated the ability to plan and teach lessons on coding and robotics in area elementary schools during a pre-student teaching field experience. These lessons, developed with the support of the pedagogy instructor, evidenced strong TPACK. By comparison, technology integration during student teaching remained basic using apps, quiz tools, and presentation software. While various factors may explain the difference, we wonder if cooperating teachers received TPACK training, would candidates be given the support needed to use digital tools in more meaningful ways.

Lastly, to evaluate the success of the teacher preparation program in TPACK, we need to observe and assess graduates of our program to determine if the preparation was adequate and if TPACK practices are occurring in their current practice. Understanding how teacher candidates' perceived TPACK and self-efficacy impact their long-term teaching practices is key to evaluating the effectiveness of our program modifications.

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Understanding the Role of Science-Specific Literacy Strategies in Supporting Science Teaching and Student Learning: A Case Study of Preservice Elementary Teachers in a Science Methods Course that Integrated a Disciplinary Literacy Framework

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ABSTRACT

The shift to student engagement in scientific and engineering practices to learn science provides opportunities for science learning and language learning to occur in tandem. These opportunities also pose new challenges for elementary pre-service teachers (PSTs) since literacy methods courses have been presented separately from science methods courses. We integrated a disciplinary literacy framework in a science methods course to help elementary PSTs understand the synergistic connections between literacy and science teaching. The purpose of this study was to examine elementary PSTs' understanding of the use of science-specific literacy strategies to support science teaching and learning through three points of observation. Findings from three data sources indicated that PSTs showed a developing understanding of the role of disciplinary literacy in supporting student engagement in science practices and learning disciplinary core ideas. Implications for future uses of a disciplinary literacy framework for teaching and learning science and elementary PSTs' science preparation are presented.

Keywords: science methods course, elementary pre-service teachers, disciplinary literacy, science-specific literacy, teacher preparation, lesson planning

Introduction

The Next Generation Science Standards (NGSS) provide three dimensions to cultivate K-12 students' scientific habits of mind, develop their capability to engage in scientific inquiry, and teach them how to reason in a scientific context (National Research Council [NRC], 2012; NGSS Lead States, 2013). The NGSS call for sense-making through engaging students in science and engineering practices (SEPs) and learning disciplinary core ideas and crosscutting concepts (NGSS Lead States, 2013). SEPs involve making sense of the world (Schwarz et al., 2017) and require students to shift between everyday language and specialized language in science (Lee et al., 2013; NRC, 2012; Schwarz et al., 2017). Participation in language-intensive SEPs relies on science-specific literacy skills such as using technical vocabulary of science (Fang, 2004), comprehending scientific texts (Alvermann & Wilson, 2011; Sinatra & Broughton, 2011), and writing scientific explanations (Norris & Phillips, 2003). To support students' engagement in these practices, teachers need to understand how language and literacy practices support students in constructing and communicating meaning in science (Lee et al., 2013).

Elementary teachers typically teach science as part of an integrated language arts block. However, teacher education program structures often isolate literacy and science preparation (Pearson et al., 2010). Many elementary pre-service teachers (PSTs) take several literacy methods courses and a separate science methods course (Wallace & Coffey, 2019). This is not an ideal teacher preparation structure for facilitating PSTs' integration of science and literacy. To address this issue, elementary PSTs need to learn how to bridge science and literacy. They need to support students' use of science-specific language to participate in SEPs (Howes et al., 2009; Lemke, 1990). However, research showed that even though elementary teachers understood the importance of engaging students in scientific practices, they needed support in engaging their students in those practices (Bismack et al., 2014).

Disciplinary literacy is different from general literacy. It focuses on the language and literacy practices that members of academic disciplines use to produce and construct knowledge within each community (Zygouris-Coe, 2015; Rainey et al., 2017; Shanahan & Shanahan, 2008). This perspective could help elementary teachers understand the connections between science-specific literacy and science teaching. For example, this perspective could show how science-specific literacy instructional tools can scaffold students' participation in SEPs and help them make sense of science (Lee et al., 2013; Wright & Gotwals, 2017). In this study, a disciplinary literacy perspective was used to guide PSTs' lesson planning and reflection practices in an elementary science methods course.

Lesson plans are an essential part of teaching and in most teacher preparation programs. They are a means of gauging PSTs' pedagogical content knowledge (i.e., integration of science, pedagogy, student characteristics, and learning environment) (Cerbin & Kopp, 2006; Richards & Rogers, 2014; Shulman, 1986). Lesson planning has also has been documented as a significant area for examining PSTs' understanding of content and pedagogical strategies (Clark & Dunn, 1991; Clark & Peterson, 1986). Reflecting on the roles literacy plays in supporting, rather than competing, with science instruction is also critical for elementary teachers (Grysko & Zygouris-Coe, 2020). The purpose of this study was to examine elementary PSTs' understanding of the use of science-specific literacy strategies to support science teaching and learning through three points of observation within a disciplinary literacy integrated elementary science methods course. Specifically, our research questions (RQ) are as follows:

- RQ1: What specialized literacy practices of science do PSTs know at the beginning of the semester as demonstrated in their belief paper?
- RQ2: How did PSTs incorporate science-specific literacy strategies in their group lesson plans to support science teaching and learning?
- RQ3: What understanding do PSTs demonstrate in their reflection paper about the roles of the science-specific literacy strategies in supporting science teaching and learning?

Conceptual Framework

Two conceptual frameworks were used in this study. The frameworks guided an elementary science methods course design to develop PSTs' understanding of teaching science and literacy in tandem.

Engaging Students in Language Intensive SEPs

Research suggests that science teaching must reflect the natural inquiry of children's learning (Bransford et al., 2000) and promote students' engagement in SEPs (Sinatra et al., 2015). These SEPs include: (a) asking questions, (b) developing and using models, (c) planning and conducting investigations, (d) analyzing and interpreting data, (e) using mathematical thinking, (f) constructing explanations, (g) developing evidence-based arguments, and (h) obtaining, evaluating, and communicating information. The NGSS emphasize guidance of science teachers' teaching practices and are essential for several reasons (NGSS Lead States, 2013; NRC, 2012). First, engaging in these practices allows students to understand how scientific knowledge develops and applies to their local context. Using these practices also helps them appreciate the diverse approaches used to create this knowledge (NRC, 2012). Second, being involved in these practices helps students understand science's crosscutting concepts and disciplinary core ideas (NGSS Lead States, 2013). Third, it helps students' science knowledge become more integrated, instead of viewing science as isolated fact-based knowledge. Fourth, engaging in science or engineering can evoke students' curiosity and motivate their further learning (NRC, 2012). This conceptual perspective guided the design of interventions in an elementary science methods course to develop PSTs' understanding of SEPs. The eight SEPs were also used to analyze PSTs' understanding of science teaching and student learning in their lesson plans and reflection papers.

The SEPs offer rich opportunities and substantial demands for language learning while advancing science learning for all students (Lee et al., 2013). Engagement in these practices is language-intensive and requires specialized literacy skills, such as reading scientific texts and writing scientific explanations. A disciplinary literacy perspective offers science-specific pathways to teachers and students.

Disciplinary Literacy

Disciplinary literacy refers to reading, writing, thinking, and reasoning within academic fields (Moje, 2007; Shanahan & Shanahan, 2008). Science is not just a body of knowledge; it is also a way of knowing. As members of an elementary science classroom community, all students should learn about the nature of science, the structure of scientific knowledge, and how knowledge is developed and communicated (NRC, 2012). Through a disciplinary literacy lens, elementary students learn how to read the texts of science, use the norms and conventions of science, form scientific explanations, and engage in scientific investigations (Zygouris-Coe, 2015; Moje, 2007; Schleppegrell, 2004, 2007; Shanahan & Shanahan, 2008, 2012, 2014). In this study, we integrated a disciplinary literacy perspective in a science methods course. We engaged PSTs in using science-specific literacy strategies that reflect how science experts use language and literacy to do the following: build and use models; make sense of science concepts; construct scientific explanations; and develop, evaluate, and communicate knowledge. We also used this framework to analyze PSTs' lesson plans for identifying science-specific literacy strategies for science teaching and reflections on the roles of the science-specific literacy strategies in supporting science teaching and student learning.

Literature Review

Disciplinary Literacy in Science Teaching

Integrating literacy in science teaching and learning is not a new phenomenon (Krajcik & Sutherland, 2010; Lemke, 1990; Osborne, 2002; Townsend et al., 2018; Wellington & Osborne, 2001; Yore et al., 2003). Elementary teachers spend considerably less time on science instruction than on mathematics or language arts (Bassok et al., 2016; Duke, 2000, 2019). In many cases literacy strategies have been used in science teaching to engage students in the process of attending to text ideas, monitoring their understanding of concepts, and making connections between new content and prior knowledge (McKeown et al., 2009; Palinscar & Brown, 1984; Pressley et al., 1992).

What is new is the call for students to receive explicit instruction in science-specific literacy practices (NGSS Lead States, 2013; NRC, 2012). New educational standards call for a need to re-conceptualize literacy in science instruction for improving all students' preparation for both the academic and the literacy demands of science (Zygouris-Coe, 2012; Lee et al., 2013). Reading, writing, reasoning, and communicating are authentic components of learning and doing science. In the discipline of science, students need to develop literacy skills in science relevant ways to build their understanding of disciplinary core ideas, engage in SEPs, and apply crosscutting concepts (Fang & Wei, 2010; Krajcik & Sutherland, 2010; NGSS, 2013; Pearson et al., 2010). Disciplinary literacy offers a different instructional and learning framework in the content areas. In science, a disciplinary literacy approach will help teachers develop students' science and literacy knowledge and skills in tandem (Shanahan & Shanahan, 2008). For example, while students learn how to construct scientific explanations, they will also learn about scientific discourse and develop scientific knowledge (Osborne, 2010). However, few empirical studies addressed how to prepare elementary teachers to teach science by integrating disciplinary literacy in science teaching.

Teacher Preparation for Supporting All Students' Science and Literacy Learning

The NGSS emphasize the need to support students' science and literacy learning in tandem and the elementary teachers' roles in teaching both content areas (NGSS Lead States, 2013). To meet this objective, some language arts and science teacher educators have investigated how methods courses can help elementary PSTs learn to integrate science and literacy in meaningful ways and optimize instructional time for teaching both areas. Researchers have found the following: (1) encouraging PSTs' to use language arts methods in science teaching contributes to their recognition of language as a tool for science learning and seeing the possibility to include science teaching as part of a language arts curriculum (Akerson & Flanigan, 2000); (2) introducing PSTs to an interdisciplinary model in a scientific classroom has the potential to improve PSTs' confidence to implement an inquiry-based science teaching approach (Lewis et al., 2014); and (3) matching similar cognitive skills for both literacy and science learning through planning a science lesson helps PSTs understand the connections between scientific practices and the associated reading comprehension skills (Wallace & Coffey, 2019).

Akerson and Flanigan (2000) explored how a language arts methods course helped elementary PSTs improve their science teaching using language arts methods. Analysis of 23 PSTs' written journal entries revealed that they came to recognize language as a tool for teaching science content. They felt more confident in their abilities to deliver effective science instruction. Over half of PSTs chose to plan and conduct a science lesson during their in-class presentations in the language arts methods course. Two language arts tools, Know-Want to Know-Learned (KWL) graphic organizer and journals, were modeled in the methods course and commonly adopted by PSTs while they taught science lessons. However, PSTs also reported some difficulties with meeting science objectives using the methods they gained through the language arts methods course. The science methods instructor was not agreeable to coordinating efforts for instruction. These authors proposed the need for collaboration between literacy and science methods course faculty to help elementary PSTs address both discipline standards.

In another study, Lewis et al. (2014) explored how using an interdisciplinary model within a five-week summer elementary science methods course improved PSTs' knowledge and self-efficacy toward teaching science. The interdisciplinary model was focused on scientific classroom discourse to connect science and language arts. The academic language development strategies, such as using science notebooks, were also explicitly highlighted in the course. Analysis of 16 participants' post-course questionnaires, their final papers about their beliefs of science teaching, and transcripts from focus group interviews revealed that PSTs came to view interdisciplinary instruction as an effective way to create connections between science and literacy. PSTs began to see the potential integration of literacy tools, such as using science notebooks, as a more effective teaching approach. All 16 PSTs recognized the importance of adopting an inquiry-based approach to teaching science. Inquiry-based science lesson planning was a major component in the science methods course. Most of the PSTs worked with a partner to design a science lesson using the engage, explore, explain, elaborate, and evaluate (5E) instructional model (Bybee & Fuchs, 2006). However, this study did not use the analysis of the PSTs' lesson plans to disclose what literacy tools or strategies were incorporated into their science lesson. Also, this study did not discuss specific connections they made between science teaching and the use of literacy tools.

Most recently, Wallace and Coffey (2019) investigated elementary PSTs' use of an integrated science and literacy instructional model in their science methods course to design a lesson plan by providing a template focused on making meaning for hands-on science activities along with appropriate fiction or nonfiction texts. For example, while elementary students engage in a hands-on activity focused on making inferences by observing fossils, PSTs might choose a reading passage describing fossils and their environment to direct students to explain how the fossils might have been formed. Analysis of 35 integrated lesson plans written or co-written by 45 PSTs revealed that most participants demonstrated proficiency in incorporating strategies to promote reading comprehension and sense-making in science by matching similar "scientific thinking skills" and "reading skills" within a science lesson. PSTs were able to show their understanding of connecting the scientific practice with the associated reading comprehension skills from the text. This could potentially strengthen both science learning and reading comprehension of elementary students.

The reviewed studies focus on integrating general literacy strategies in science to augment elementary students' understanding of science concepts and science practices. These general literacy strategies include those that can be used across all content areas (e.g., KWL graphic organizers, notebook, and organization of ideas from texts). However, Shanahan and Shanahan (2008) argued that general literacy strategies are not enough for preparing students to meet the specialized demands of a discipline such as science. The above review of the literature supports the need for research investigating the preparation of elementary PSTs through collaboration between science and literacy teacher educators. It also demonstrates a need to integrate a disciplinary literacy framework to help elementary PSTs understand the roles of science-specific literacy strategies to support elementary students' science learning through lesson planning and reflection. The current study was designed to address these needs.

Methodology

A qualitative exploratory case study research design (Creswell, 1998) was used to examine our three research questions. This case study helped build an in-depth and contextualized understanding (Yin, 2003) of elementary PSTs' learning about using science-specific literacy strategies to support science teaching and student learning. This occurred through collecting, describing, and interpreting (Yin, 2006) three data sources from PSTs' individual and group work within a disciplinary literacy integrated elementary science methods course. The data collection process followed the learning activities PSTs engaged in within the science methods course (Koro-Ljungberg et al., 2009; Tellis, 1997).

Context

Interdisciplinary Collaboration

This study took place at a large metropolitan university in the Southeastern United States, in a state that has not adopted the NGSS. During the 15-week spring semester of 2018, 31 elementary education PSTs (8 juniors and 23 seniors) participated in a science methods course before starting their senior clinical internships in elementary classrooms. The course instructors, who are also researchers of this study, included two faculty members from science education and literacy education with their respective two doctoral students who were teaching assistants. A two-faculty member collaboration resulted from professional discussions and a common interest in the role of literacy in science teaching and learning. Faculty collaboration was based on a voluntary commitment and was not part of a faculty workload. Two faculty members met for 12 weeks before the beginning of the course, shared readings, pedagogical ideas, and research plans. The interdisciplinary faculty collaboration resulted in a plan of action for a science methods course that included presentations and informal co-teaching by the literacy faculty and a literacy doctoral student. Another outcome of the collaboration included changes made on the original science methods course syllabus, lesson plan assignment, rubric for the lesson plan, belief paper, and reflections.

Science Methods Course

In the elementary education program, the science methods course was the only course focusing on teaching science. It was designed to prepare PSTs to incorporate the state science teaching standards and implement them in elementary classroom settings.

Instructors started this course by eliciting PSTs' background knowledge of literacy in science at the beginning of the semester. Then PSTs were engaged in different experiences to help them understand the roles of the science-specific literacy strategies in supporting science teaching and student learning. After introducing science standards in the state and general lesson planning procedures, most course time was devoted to adopting a disciplinary literacy approach to science teaching guided by our second conceptual perspective starting from the fourth week of the course (see Table 1). The co-teaching conducted by both the science and literacy teacher educators took place for 12 weeks. The significant content implemented through co-teaching included (1) an overview of literacy and challenges related to students' literacy needs in science; (2) an introduction of disciplinary literacy in science (Zygouris-Coe, 2015); (3) engagement with scientific texts (McKeown et al., 2009) and a presentation of reading tools (Zygouris-Coe, 2015) and science vocabulary; and (4) engagement in three model science lessons.

Three model lessons were structured by the 5E instructional model (Bybee & Fuchs, 2006) and were designed to situate PSTs as elementary students. PSTs were engaged in SEPs to support their science and literacy learning based on specific state science standards. The two NGSS dimensions, disciplinary core ideas and science practices, were addressed in the three model lessons. The NGSS dimension, crosscutting concepts, was not covered because the state science standards did not incorporate them. Simultaneously, science-specific literacy strategies were integrated into these lessons to support students in making sense of science concepts and participating in science practices. For example, in a physical science lesson, PSTs investigated the physical properties of Oobleck (a non-Newtonian fluid) during the exploration phase. Then they exchanged scientific arguments on the state of the matter by using the pieces of evidence they collected. The Claim-Evidence-Reasoning (CER) framework (McNeill & Krajcik, 2011) was introduced to support their practice of argumentation. Another life science lesson (Hall et al., 2017) focused on how to develop and use scientific models to explain the process of photosynthesis and cell respiration. Specific sentence frames and a review of vocabularies (such as chloroplast) helped PSTs write and tell their scientific explanations. In an earth science lesson, the instructor used science talk to engage PSTs in communicating their ideas about water erosion effects on land. PSTs were also guided to use a graphic organizer to compare similarities and differences of some science-specific concepts (i.e., weathering, erosion, deposition).

Table 1

Relative Activities and Curriculum Materials in the Science Methods Course

Activity	Curriculum Materials
Discuss teaching standards	The purpose of science teaching and guided questions - CCSS, NGSS, state standards, and school district planning
Lesson planning, write objectives based on state standards.	Planning to teach science, lesson plan template, and criteria
Discuss science practices and 5E instructional model, teach science through a disciplinary literacy lens	Inquiry and science teaching, NGSS (SEPs), science text ("Issue Overview: Fracking") from Newsela
Experience and reflect on a physical science lesson focusing on *scientific argument*	Science lesson 1, scientific argument using CER (McNeill & Krajcik, 2011)
Experience and reflect on a life science lesson focusing on the *explanatory model*	Science lesson 2, cell modeling
Experience and reflect on an earth science lesson focusing on *vocabulary instruction* and communicating like scientists	Science lesson 3, erosion
Make explicit connections to supporting all students learning science and literacy in tandem.	Lesson plan template and rubric
Design an inquiry-based science lesson	NGSSS standards, lesson plan template and rubric
Reflect on the lesson planning process	Reflection framework

Data Sources

For this study, we focused on the analysis of three data sources (belief papers, lesson plans, and reflection papers) from three learning activities PSTs engaged in within the science methods course. First, an individual belief paper from each PST was collected. This assignment was guided by five questions related to PST's prior knowledge of science instruction. Only responses to one question (see data analysis section) in PSTs' belief papers were chosen to answer our first research question. Second, the key assignment of the science methods course was a lesson plan. PSTs were asked to use a 5E instructional model (Bybee & Fuchs, 2006) to plan an inquiry-based science lesson to support elementary students' science learning. Eight groups of three or four PSTs worked on this assignment since the second week of the semester and each group submitted one lesson plan at the end of the semester. Each lesson plan included eight components, such as the following: state science standards and objectives; detailed procedures structured by a 5E instructional model (Bybee & Fuchs, 2006); SEPs; a materials list; and safety precautions. One component in the lesson plan rubric was to ask PSTs to include a variety of practices that support students' science-specific literacy development. PSTs were not limited to any specific strategies in their lesson plan and could incorporate science-specific literacy strategies in any phases of their lesson based on their understanding of the roles of science-specific literacy in science teaching and learning. The lesson plan was a culminating assignment that showed how groups of PSTs constructed meaning of how science teaching and disciplinary literacy could be implemented in tandem. Third, PSTs were asked to write a reflection paper at the end of the semester. The reflection paper was guided by five questions focusing on participants' individual thoughts related to the planning and learning process. For this study, only responses to one question (see data analysis section) in PSTs' written reflection papers were chosen to answer our third research question.

Data Analysis

To answer R1, PSTs' responses to a question in their individual belief paper, "What specialized literacy practices of science have you learned to promote students' science and literacy learning? Please provide a brief explanation", were analyzed. An inductive analytical approach (Miles & Huberman, 1994) allowed codes to emerge from the data. During the initial coding process, responses to the question of the belief and reflection papers were read, and the following question was considered: "What is the major idea brought out in this sentence or paragraph?" (Strauss & Corbin, 1998, p. 120). An initial code was assigned to segments of the text based on the answer to this question. Initial codes were then grouped into categories grounded on similarities in their properties and dimensions. For example, the initial codes of using graphic organizers and discussing vocabulary were grouped under "Examples of literacy strategies" (see examples in Table 2). Initial themes were then identified due to consistency in the data among participants. These themes indicated PSTs' understanding of the specialized literacy practices of science at the beginning of the semester.

Table 2

Sample of the Coding System for PSTs' Belief Paper

Category	Subcategories	Codes	Quotes
Examples of literacy strategies	Graphic organizers	KWL chart	"I have observed this in the classroom, where the students made a KWL chart with the teacher."
	Discussing vocabulary	Word analysis in class	"Word analysis and discussing vocabulary could be used in a science classroom."

To answer RQ3, a similar approach was used to analyze PSTs responses to a question in the written reflection paper, "How do science literacy strategies facilitate the process of inquiry and the development of students' scientific knowledge?" Examples of categories, codes, and quotes are presented in Table 3 below. Specific themes with examples are described within the findings section in detail.

Table 3

Sample of the Coding System for PSTs' Reflection Paper

Categories	Subcategory	Codes	Quotes
Explanation of how science-specific literacy strategies support science learning	Scaffold	Vocabulary and Concepts/misconceptions	"in an inquiry-based lesson plan the teacher starts with a question, students can discuss the topic/answer the question to the best of their knowledge. Using questioning as a scaffold, students will use science specific vocabulary and determine misconceptions."
		SEPs	"They support inquiry and problem solving by allowing students to be engaged enough to ask questions, make predictions, find answers, and make inferences based on their findings."

To address RQ2, PSTs' lesson plans were analyzed using a constant comparative approach (Glaser & Strauss, 2017). The constant comparative method involves dividing the data into discrete "incidents" and coding them into categories. The initial coding scheme consisted of three categories (disciplinary core ideas, SEPs, and crosscutting concepts) to align with the three dimensions of science teaching in the NGSS. While analyzing PSTs' lesson plans, there were no literacy or strategies identified related to the development of students' crosscutting concepts. This was not surprising, since crosscutting concepts were not part of the state science standards. Thus, the crosscutting concepts category was excluded from the final coding scheme. Table 4 presents the final coding scheme for the types of science-specific literacy strategies PSTs incorporated in their lesson plans to support elementary students' science and literacy learning in tandem.

During the data analysis process, the first and second author coded data independently and achieved initial inter-rater reliability greater than 85%, and after discussion, reached 98% agreement.

Table 4

Coding System for Types of Science-Specific Literacy Strategies PSTs Incorporated in Their Lesson Plans

Categories	Codes	Examples
SEPs	Engaging students in science-specific writing supported by evidence	Using content-specific language to write a paragraph explaining erosion and its' effects
	Engaging students in explanation using the CER framework	Requiring students to construct an explanation to explain why particular objects sink and others float
	Providing sentence frames for scaffolding students' science writing	Provide sentence frames based on the CER framework to help students construct a written scientific explanation
	Helping students record and organize information/data	Having students record their observations in a science notebook
	Guiding students in using multiple sources of information	Using the internet and texts to research the functions of different organs
	Communicating scientific information	Having students explain their findings to the teacher and their peers
Disciplinary Core Ideas (DCIs)	Using text to build background knowledge to stimulate interest, introduce vocabulary, etc.	Having students use nonfiction text to research one of the human organs
	Teaching science-specific vocabulary	Explicitly teach terms related to the classification of rocks (e.g., sedimentary, igneous, and metamorphic)
	Developing concept knowledge by exploring relationships between vocabulary	Leading a discussion on the relationships between the following vocabulary words: seasons, sun, Earth, equator, and revolution.

Findings

Overall, findings indicated that through participation in an integrated disciplinary literacy science methods course co-designed and co-taught by science and literacy teacher educators, elementary PSTs began to develop their understanding of literacy in science teaching and student learning. First, at the beginning of the semester, while most PSTs had never heard about science-specific literacy strategies, they demonstrated their understanding of general literacy practices in science. Second, PSTs incorporated science-specific literacy strategies within their inquiry-based lesson plans to facilitate students' development of disciplinary core ideas and engagement in SEPs. Third, in their written reflection paper, PSTs showed more developed knowledge than their belief papers on the role of science-specific literacy in science teaching and student learning within four categories.

Table 5

PSTs' Understanding of Science-Specific Literacy as Demonstrated in Their Belief Paper

Category	Subcategory	Codes	Quotes (Samples)	Themes
Examples of literacy strategies	Graphic organizers discussing vocabulary	KWL	"I have observed this in the classroom, where the students made a KWL chart with the teacher."	PSTs mentioned general literacy strategies
	Reading different types of texts	Vocabulary	"Word analysis and discussing vocabulary Could be used in science classroom."	
		Read storybooks, fiction, nonfiction, trade book	"The teacher first read a book about butterflies and listed the stages of the butterfly. The students were also given a worksheet to fill out and label each stage."	
Conceptualization of specialized literacy practices of science	Connection to science	Never heard of disciplinary literacy	"I have never learned a specialized literacy practice of science to promote science and learning. This has not been a discussion in any of my courses."	Some conceptualized literacy as scientific methods while others could not position literacy in science teaching and learning.
		Scientific methods	"By making their observations, asking questions, making predictions, searching for information to test those predictions, and summarize their findings, this makes the Scientific Method a highly effective literacy practice used in science."	
	Relationship between literacy and science learning	Reciprocal relationship	"Science and literacy go hand in hand. To complete the experiments requested students need to be able to read the instruction and explain what they are observing."	Only 2 PSTs referred to the reciprocal relationship of science and literacy learning explicitly while one student viewed literacy and science as two separate subjects.
		Two subjects	"I love science but literacy was not my favorite topic to learn. I am looking forward to learning how teachers get their students to enjoy the two subjects."	

RQ1. What Specialized Literacy Practices of Science do PSTs Know at the Beginning of the Semester as Demonstrated in Their Belief Paper?

Most of PSTs had never heard about a science-specific literacy approach (i.e., disciplinary literacy). PSTs had different experiences with, and general prior understanding of the specialized literacy demands of science and how they relate to students' science and literacy learning. The themes under two categories were described below.

Examples of Literacy Strategies

Most PSTs mentioned some general literacy tools when they talk about literacy strategies being used in science classrooms. These examples include graphic organizers (e.g., KWL), discussing vocabulary in class, reading different types of texts (e.g., storybooks, fiction, nonfiction, trade book). See the belief paper excerpts in Table 5.

Conceptualization of Literacy in Science

Very few students explicitly talked about how they viewed the relationship between science and literacy in general. As shown in Table 5, only two PSTs referred to the reciprocal relationship between science and literacy learning, while one PST viewed literacy and science as two separate subjects. Two PSTs used "hand in hand" to describe the importance of literacy in science practices. For example, one of them mentioned that, "To complete the experiments requested students need to be able to read the instructions and explain what they are observing." However, one PST viewed literacy and science as almost two competing subjects. A statement was made in this PST's belief paper that "I, as a student, love science but literacy was not my favorite topic to learn. I am looking forward to learning how teachers get their students to enjoy the two subjects."

Some PSTs made connections between literacy and scientific methods and practices in science. For example, one PST wrote in the belief paper that:

> . . . a specialized literacy practice of science in the classroom I know of is the Scientific Method. By making their observations, asking questions, making predictions, searching for information to test those predictions, and summarizing their findings, this makes the Scientific Method a highly effective literacy practice used in science.

R2: How Did PSTs Incorporate Science-specific Literacy Strategies in Their Group Lesson Plans to Support Science Teaching and Learning?

Analysis of PSTs' lesson plans revealed that all eight groups incorporated various science-specific literacy strategies to support two dimensions of science teaching and learning in the NGSS (see Tables 6 and 7). These two dimensions were disciplinary core ideas and engagement in SEPs.

Table 6

Science-specific Literacy Strategies Incorporated to Support Students' Development of Disciplinary Core-ideas

Group	Type of Strategy	5E Phase	Excerpt from PST Group Lesson Plan
1	Teaching science-specific vocabulary	Explain	"To define wind and water erosion, students will be shown a PowerPoint presentation directed by the teacher defining content specific vocabulary and describing the differences between weather and erosion."
2	Teaching science-specific vocabulary	Engage	"Introduce flashcards (word on front, picture on back) for the following key terms: season, sun, Earth, equator, and revolution."
3	Developing concept knowledge by exploring relationships between vocabulary	Explore	"Allow students to work together to observe and distinguish the three types of rocks in their own way. In each students' science notebook, they will make a chart that they will use to sort each rock."
4	Developing concept knowledge by exploring relationships between vocabulary	Evaluation	"Students will have an end of the lesson assignment that will include riddles for their friends or family about body parts. A human body riddle book in which they create one question for each organ or body part specifying the functions and characteristics."
5	Teaching science-specific vocabulary	Engage	"The class will discuss what they already know about the organs in the human body and what they want to know using the science-specific terms (brain, heart, lungs, stomach, skeleton, and muscles)."
6	Developing concept knowledge by exploring relationships between vocabulary	Elaborate	"Students will create their own riddle flip book that includes the 6 major body parts (brain, heart, lungs, stomach, muscles, and skeleton)."
7	Using text to build background knowledge, stimulate interest, and introduce vocabulary	Engage	"Read the story *What Floats in a Moat* by Lynne Berry. During the reading students are to keep note of the objects that sank or floated in the story."
8	Developing concept knowledge by exploring relationships between vocabulary	Elaborate	"Students will write three sentences per topic for the assignment portion of this activity. The first topic will consist of a proper understanding recognizing that solids have a definite shape and that liquids and gases take the shape of their container."

Note: Find a more comprehensive table https://drive.google.com/file/d/13O3WaPDE-FPTG7LVWD8PSrMRJs_XFGj8/view?usp=sharing

First, to support students' development of disciplinary core ideas, PSTs incorporated three science-specific literacy strategies. These strategies included: (1) using science text to build background knowledge, stimulate interest, introduce vocabulary, etc.; (2) teaching science-specific vocabulary; and (3) exploring relationships between vocabulary to help students make sense of science concepts. Each group chose different strategies and incorporated them in different phases of the 5E instructional model from the list for different purposes. While three groups (group 4, 6, and 7) incorporated all three science-specific literacy strategies in their lesson plan, one group (group 5) only incorporated the second strategy focusing on teaching scientific vocabulary. Other groups incorporated two science-specific literacy strategies in their lesson plan.

For example, Group six included a read-aloud of the expository science text, *Me and My Amazing Body* by Joan Sweeney and Annette Cable (1999), to introduce students to various body parts and their basic functions (excerpts found in Tables 6 and 7). PSTs of this group planned that students would indicate the functions of organs to learn science-specific vocabulary. Their lesson plan also incorporated students creating riddle books to develop relationships between organs (science-specific vocabulary). Group five included one science-specific strategy, teaching science-specific vocabulary. In their lesson plan, students would engage in building a KWL chart to begin learning about parts of the body (science-specific vocabulary).

Second, six science-specific literacy strategies were identified in PSTs' lesson plans that showed how they planned to support students' engagement in SEPs. These science-specific literacy strategies included the following: (1) helping students record and organize info/data during an investigation, (2) communicating scientific information, (3) engaging students in science-specific writing supported by evidence, (4) guiding students in using multiple sources of information, (5) engaging students in scientific explanation using the CER framework, and (6) providing sentence frames for scaffolding students' science writing. Table 5 displays the specific types of science-specific literacy strategies found in each coding category per participant group. While one group (group four) did not use these strategies to engage students in SEPs in their lesson plan, other groups incorporated at least two science-specific literacy strategies. Most groups incorporated science-specific literacy strategies to support recording and organizing information/data and communicating scientific information. However, some groups provided more scaffolding, such as the CER framework or sentence frames. For example, in the Evaluation phase of their lesson plan, group seven included an opportunity for students to construct a scientific explanation, explaining why particular objects sink or float using the CER framework.

Out of the three dimensions of science teaching and learning, PSTs mainly incorporated science-specific literacy strategies to support students' engagement in science sense-making and science practices. PSTs did not include any science-specific literacy strategies focusing on the development of students' crosscutting concepts. This is not surprising given that the state has not adopted the NGSS and crosscutting concepts are not included in science standards.

RQ3: What Understanding do PSTs Demonstrate in Their Reflection Paper About the Roles of the Science-specific Literacy Strategies in Supporting Science Teaching and Learning?

In their reflection paper at the end of the semester, PSTs showed a more advanced knowledge of the role of science-specific literacy in science teaching and learning than understanding demonstrated in their belief papers. They showed their understanding in the following four categories: Explanation of how science-specific literacy strategies support science teaching and learning, Examples of science-specific literacy strategies to support science learning, Comparing science-specific literacy strategies to general literacy strategies, and the Relationship between literacy and science

Table 7

Science-Specific Literacy Strategies Incorporated to Support Students' Engagement in SEPs

Group	Type of Strategy	5E Phase	Excerpt from PST Group Lesson Plan
1	Communicating scientific info	Evaluation	"Students will turn to a shoulder partner and quickly discuss with each other what they learned about wind erosion and what it does."
2	Engaging students in explanation using the CER framework	Elaborate	"Students will complete a C-E-R framework on which location will make the best destination for their specified time of year."
3	Helping students record and organize info/data	Explore	In each students' science notebook, they will make a chart that they will use to sort each rock. They will have to write down common characteristics of the different rocks."
4	No strategies identified		
5	Guiding students in using multiple sources of information	Explore	"Students will work in groups to research each body part using the resources provided to them."
6	Providing sentence frames for scaffolding students' science writing	Explain	"Students will individually record in their science notebooks the function of each major organ using the following sentence structure: The ____ function is______."
7	Helping students record and organize info/data	Engage	"Pass out the Sink or Float table with the seven experimental objects listed. Explain to students that they will be filling out the first blank column with their predictions of what objects will sink or float. Display the items for the students to see and to record their answer."
8	Engaging students in explanation using the CER framework	Explain	"Claim: Write a sentence that states if a cup holds more or less or the same amount of liquid than cup ____. Cup __ holds ____(more or less or the same amount)."

Note: Find a more comprehensive table https://drive.google.com/file/d/13O3WaPDE-FPTG7LVWD8PSrMRJs_XFGj8/view?usp=sharing

Most PSTs provided explanations about how science-specific literacy strategies support the process of inquiry and the development of students' scientific knowledge. Specifically, PSTs identified three areas that science-specific literacy have been used in science teaching and learning. These areas include the following: learning scientific vocabulary, learning science concepts, and engagement in practices of science. Three excerpts below demonstrate PSTs' understanding of the role of science-specific literacy strategies in supporting science teaching and learning in the areas mentioned above, respectively:

> PST 1: These strategies motivate students to think and engage in inquiry-based, discovery science. They support inquiry and problem solving by allowing students to be engaged enough to ask questions, make predictions, find answers, and make inferences based on their findings.
> PST 2: Science is about more than just exploring facts. It is about exploring, going through the process of inquiry, and how students are able to uncover facts and theories. None of these

> steps would be possible without the development of scientific literacy. As a final thought, scientific literacy can also help students develop knowledge in ways outside of inquiry or experimentation. Students often will obtain scientific information through reading. If students are unable to read like a scientist, not able to comprehend science-specific texts, or not understanding tier-three vocabulary associated with the subject, it will be impossible for them to gain any new knowledge from a nonfiction text related to the subject area of science.
> PST 3: In an inquiry-based lesson plan the teacher starts with a question, students can discuss the topic/answer the question to the best of their knowledge. Using questioning as a scaffold, students will use science specific vocabulary and determine misconceptions.

PSTs' provided more examples of science-specific literacy strategies to support students' vocabulary learning, conceptual understanding, and engagement in SEPs (e.g., CER, science nonfiction texts, vocabulary strategies). Examples from PSTs' reflection paper are presented in Table 8.

Some PSTs believed there were no differences in literacy strategies across the subject areas. For example, one PST mentioned that "science literacy strategies for teaching are the same as other literacy strategies because they both involve comprehending and becoming more knowledgeable in a certain subject area." Others believed that science-specific literacy strategies differ from other literacy strategies "because they focus on science concepts, and vocabulary, and help students learn how to think like scientists." Other examples are shown in Table 8.

Most PSTs viewed the roles that literacy, especially science-specific literacy, plays in science teaching and learning. One PST who initially viewed science and literacy as separate subjects started to increase their understanding of the specialized literacy demands of science. In the reflection paper, the following statement was documented to represent this perspective, "Students need to be actively reading their textbook to learn science; the science is not only learned from the experiments they learn about." However, PSTs did not explicitly specify how inquiry-based science teaching supported students' development of their literacy and language proficiency.

Table 8

PSTs' Understanding About the Roles of the Science-Specific Literacy Strategies in Supporting Science Teaching and Student Learning in Their Reflection Paper

Category	Codes	Quotes (samples)	Theme
Explanation of how science-specific literacy strategies support science learning	Vocabulary	"In an inquiry-based lesson plan the teacher starts with a question . . . "	More PSTs provided explanations about how science-specific literacy strategies support the process of inquiry, and the development of students' scientific vocabulary, making sense of concepts, and engagement in SEPs.
	Concepts	"Using questioning as a scaffold, students will use science specific vocabulary and determine misconceptions."	
	SEPs	"They support inquiry and problem solving by allowing students to be engaged enough to ask questions, make predictions, find answers, and make inferences based on their findings."	
Examples of Science-specific literacy strategies to support science learning	C-E-R science nonfiction texts Using diagrams to compare and contrast concepts Vocabulary strategies		PSTs' provided more examples of science-specific literacy strategies to support students' vocabulary learning, conceptual understanding, and engagement in SEPs
Compare science-specific literacy strategies to general literacy strategies	No difference	"Science literacy strategies for teaching are the same as other literacy strategies."	Some believed there were no differences in literacy strategies across the subject areas. Others believed that science-specific literacy strategies differ from other literacy strategies
	Difference	"Because they focus on science concepts, and vocabulary, and help students learn how to think like scientists." "The difference between science literacy strategies is that they are presented in another form or way that enhances that specific subject of learning ability."	
Relationship between literacy and science	Hand-in-hand	"They are Hand-in-Hand. Inquiry becomes a way to engage students in learning vocabulary; learning vocabulary makes science learning easier and helps further inquiry."	There were differences in the ways PSTs conceptualized the relationship between science-specific literacy and science teaching and learning.

Discussion

The purpose of this study was to examine elementary PSTs' understanding of the use of science-specific literacy strategies to support science teaching and learning through three points of observation**.** This was in the context of a disciplinary literacy integrated elementary science methods course. Our findings indicate that elementary PSTs benefited from the lesson planning process by integrating disciplinary literacy in the elementary science methods course. Major findings from this study are discussed in this section.

First, this study provided empirical evidence of PSTs' understanding of the roles of literacy in science when they entered a science methods course. Even though most PSTs mentioned that they had never heard about science-specific literacy, their understanding of specialized literacy practices of science was demonstrated based on their different prior learning experiences (e.g., service-learning and literacy methods courses). PSTs were able to list some general literacy tools used in science teaching, such as KWL, reading fiction, or nonfiction text. These examples reflected PSTs' perceptions of the literacy demands of science and connections to students' science learning. This finding echoes some challenges of the traditional elementary teacher education programs, in which the science methods course was separated from literacy methods courses (Grysko & Zygouris-Coe, 2020; Pearson et al., 2010) and how literacy has been presented to teachers (Moje et al., 2010). PSTs lack opportunities to learn how to read, write, speak, and think in ways that reflect how knowledge is developed in science. For example, very few PSTs in their belief papers made connections between literacy and scientific methods and practices. One PST explicitly viewed literacy and science as separate subjects which could compete with each other for instruction.

Second, an encouraging finding of this study is that PSTs worked within groups and incorporated at least two science-specific literacy strategies in each inquiry-based lesson plan to support two dimensions (disciplinary core ideas and SEPs) of science learning. Although PSTs incorporated these science-specific literacy strategies in different phases of the 5E instructional model for different purposes, and some groups incorporated more strategies than others, the major roles of these strategies, as demonstrated in the lesson plans, were consistent. These roles include engagement in SEPs and sense-making of disciplinary core ideas (NGSS Lead States, 2013). For example, one group incorporated a read-aloud of an expository science text to teach body parts and functions. Another group planned to use the CER framework to scaffold students in constructing scientific explanations. This finding is different from other studies (Akerson & Flanigan, 2000; Lewis et al., 2014; Wallace & Coffey, 2019) that focused more on general literacy strategies' integration in science. Therefore, it enriches this research line by adding analysis of science-specific strategies in the lesson plans of PSTs to demonstrate how PSTs perceive the roles of science-specific literacy strategies in supporting elementary students' sense-making of disciplinary core ideas and engagement in SEPs. Integrating a disciplinary literacy framework in a science methods course through a collaboration of science and literacy education faculty made it possible for PSTs to start paying more attention to science-specific literacy strategies, instead of general literacy strategies for supporting elementary students' science learning. This is especially important because it provided empirical evidence of the outcomes of the collaboration between instructors of science and literacy methods courses to meet science standards as recommended (Akerson & Flanigan, 2000).

Third, an important finding from this study is that PSTs demonstrated their developing understanding of the role of science-specific literacy in science teaching and learning through their written reflection paper at the end of their science methods course. PSTs were able to specify three areas (i.e., vocabulary, learning science concepts, and engagement in science practices) that science-specific literacy supports in science teaching and student learning. Different examples (e.g., CER framework) were used to explain how they could be used for different purposes. It is important to note that although the role of literacy in science teaching and student learning has been documented in the literature (Krajcik & Sutherland, 2010; Sutherland, 2008), many studies on preparing elementary PSTs for integrating literacy in science teaching focus on general literacy strategies. These studies either see the possibility of including science teaching as part of a language arts curriculum (Akerson & Flanigan, 2000) or optimizing instructional time for elementary teachers to teach both areas (Lewis et al., 2014; Wallace & Coffey, 2019). Our current finding extended this research line by focusing on preparing elementary PSTs to explicitly reflect on comparing science-specific literacy strategies and general literacy strategies. The fact that PSTs made these critical connections in their reflections is notable because they demonstrated their conceptualizations of the role of science-specific literacy strategies as tools for supporting students' engagement in SEPs and learning disciplinary core ideas (NGSS Lead States, 2013). This is different than viewing them as stand-alone, literacy activities (Moje et al., 2010).

Furthermore, this finding is also formative regarding what science educators need to address in teacher preparation courses to develop better PSTs' knowledge of science and science-specific literacy strategies. For example, the findings indicated that PSTs just started identifying the roles of science-specific literacy strategies in science teaching and student learning. At the same time, they did not have enough opportunities to reflect on how science learning and inquiry-based science teaching serve as opportunities and contexts for elementary students to develop their science-specific literacy proficiency, such as ". . . the ability to read and comprehend a wide range of science texts, knowledge of the specialized vocabulary of science, and habits of mind that are inherent to learning and doing science" (Grysko & Zygouris-Coe, 2020, p. 497). This study provided empirical evidence to identify the areas teacher educators need to continue to work on through university coursework and future research to promote teaching science and science-specific literacy in tandem.

Limitations

Case study designs allow for limited generalizations because of the restricted sample size and bounded context of the study (Creswell, 2013). More research needs to be conducted to examine PSTs' understanding in other elementary teacher education program contexts. Two limitations of the study are presented before discussing the implications of the study. First, this study used a purposive, convenience sample in a state that did not adopt the NGSS, so different PSTs populations may be unaccounted for in this study. Second, the reflection paper was guided by the questions that researchers were interested in, and this might have led the participants to answer questions towards a researcher-oriented perspective. Despite these limitations, this study carries implications for the potential design of science methods course and future research (Cervetti et al., 2015).

Implications

This case study presented initial results from an interdisciplinary collaboration between science and literacy teacher educators who co-designed and co-taught an elementary science methods course. Science and literacy teacher educators should continue to seek more ways to collaborate and reform literacy and science methods courses. Such collaborations would better prepare elementary PSTs to teach science and meet the new science standards (NGSS Lead States, 2013). This also could begin the development of resources to prepare PSTs in several ways. First, a disciplinary literacy framework needs to be further integrated into the science methods course curriculum to deepen PSTs' understanding of science and literacy knowledge in tandem. For example, a disciplinary literacy framework could be integrated with the crosscutting concepts in science since this connection was missing in the current study. Second, reflections on using literacy for science teaching could be more meaningful if PSTs are provided opportunities to implement their lesson plans in elementary classroom settings. At the same time, in order to encourage elementary teachers to teach science and science-specific literacy in tandem, PSTs should be guided to reflect on if and how inquiry-based science teaching contributes to developing elementary students' proficiency in science-specific literacy. Third, instructors of science methods courses need professional development that facilitates collaboration with disciplinary literacy experts to co-construct new knowledge about 21st-century elementary teachers' needs in science and literacy.

Follow up research is needed to explore and examine the following areas: (1) how science and literacy educators can continue to support elementary PSTs consistently after science methods courses and in other learning contexts (i.e., pre-service teacher clinical internships), and (2) how to explicitly connect university courses to teaching practices in classrooms (Janzen, 2008). Besides science methods courses, it is necessary to monitor PSTs' progress during their clinical internship experiences through their first year of teaching to investigate and support their instructional and pedagogical needs.

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Advocacy Interrupted: Exploring K-12 STEM Teacher Leaders' Conceptions of STEM Education Advocacy Before and During COVID-19

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ABSTRACT

This phenomenographical study examined 10 American science, technology, engineering, and mathematics (STEM) teacher leaders' (TL) conceptions of and activities in STEM education advocacy before and during the coronavirus disease 2019 (COVID-19) pandemic. Data collection consisted of semi-structured interviews conducted via online conferencing before the onset of the pandemic and responses to an online questionnaire completed during the pandemic. The outcome space emerging from the participants' conceptions of STEM education advocacy were: (1) identity, (2) communication, and (3) movement. Communication was a priority of advocacy activities before COVID-19 interruptions, whereas movement was thematically transformed due to participants' experiences (challenges and successes) in transferring their advocacy activities to online modalities. This study addresses gaps in STEM teacher and teacher advocacy literature by qualifying TLs' conceptions of and activities in education advocacy.

Keywords: COVID-19, phenomenography, STEMMaTe, STEM teacher leader, STEM teacher advocacy, teacher leadership

Introduction

To stymie the spread of the coronavirus disease 2019 (COVID-19) during the first quarter of 2020, public and private K-12 schools ceased face-to-face classes and K-12 teachers rapidly transitioned to fully remote (primarily online) instruction (Kaden, 2020). The lion's share of attention has been focused on student outcomes due to this shift in instruction and how students are differentially navigating this sudden change. Other changes may be impacting students, such as their teachers' conceptions of how able they are to advocate for their students, fellow teachers, and local communities. "Teacher advocacy [is] both a practice of teacher leadership, as well as teaching and leading for social justice," performed through activities that ensure teachers and students have adequate, accessible, and equitable resources both in and out of school (Bradley-Levine, 2018, p. 47). In particular, teacher advocacy in the science, technology, engineering, and mathematics (STEM) disciplines is vitally important to ensure students receive the equipment and supplies needed for generative experiences (National Research Council [NRC], 2012), provide their fellow teachers the professional development (PD) and support needed to provide rich K-12 STEM experiences (Fulton & Britton, 2011), engage their communities by facilitating family-centered STEM activities, and promote social justice in STEM (Sondel et al., 2017). Because of the technological resources needed to access online learning platforms, the pandemic has disproportionately impacted vulnerable, under-resourced students (Armitage & Nellums, 2020). Therefore, it is important to concurrently examine how the pandemic has augmented K-12 STEM teachers' conceptions of planning and engagement in advocacy work, to improve equity and access to STEM education when it is most threatened. Thus, we explored how STEM teacher leaders (TL) conceptualized STEM education advocacy before and during the COVID-19 pandemic. This study was guided by the following research question: *how have STEM TLs' conceptions of advocacy (through their advocacy activities) changed since the onset of COVID-19?*

Purpose and Theoretical Framework

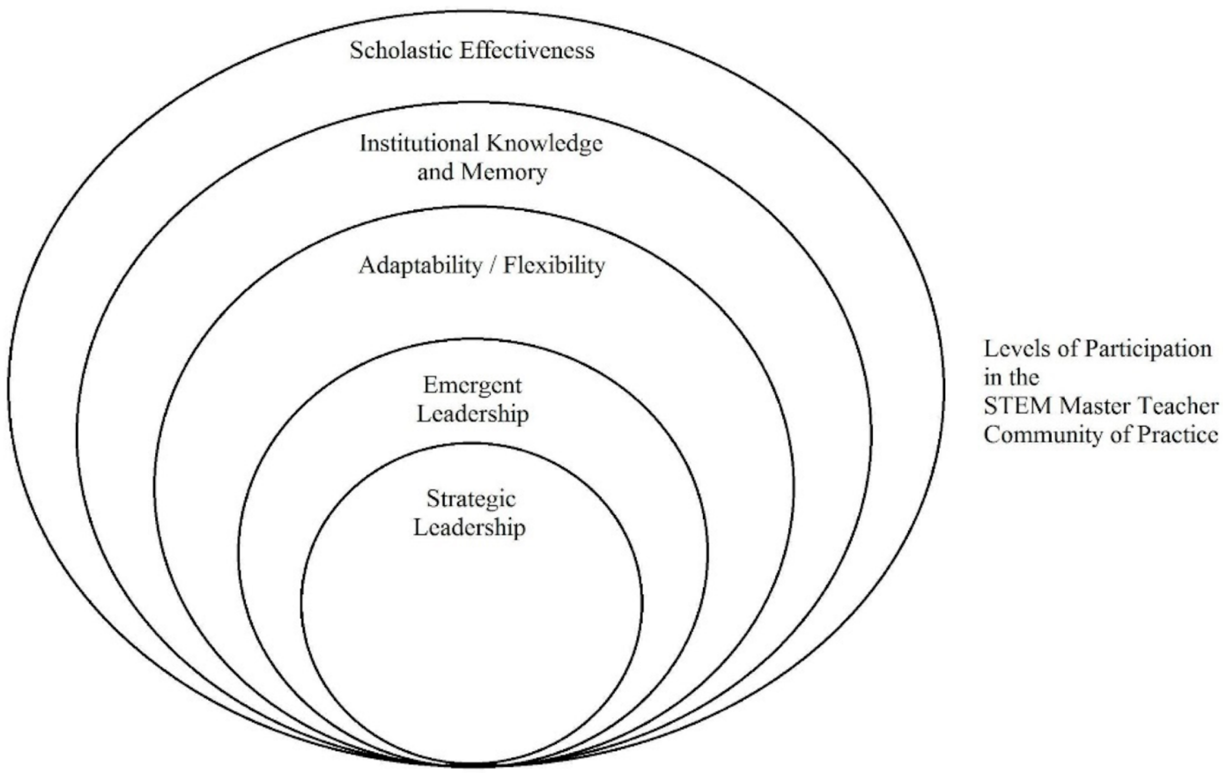
In this study, we sought to describe conceptions of K-12 STEM education advocacy among 10 community-vetted and advocacy-trained TLs both before and during the COVID-19 pandemic. We examined how the pandemic augmented thinking (conceptions) and outcomes (advocacy) among these STEM education teacher-advocates. We focused on the type of "teacher leadership [that] occurs within and outside classrooms to influence school-wide instructional practice" that impacts students (Cooper at al., 2016, p. 87). These STEM TLs were trained in policy advocacy work through the National Science Foundation's STEM Teacher Ambassador (STA) program (NSF, 2019). The program consists of learning modules and experiences in basic STEM education policy knowledge, crafting effective policy briefs, speaking to local and national media, and using social media (Twitter) as a digital advocacy space.

This study applies the *STEM Master Teacher (STEMMaTe)* framework of teacher-leadership development in advocacy (Hite & Milbourne, 2018) to explore how STEM TLs progress in their participation in advocacy-based leadership. STEM teachers progress through five stages of generative developmental experiences with respective communities of practice, which is reflective of Lave and Wenger's (1991) legitimate peripheral participation (LPP) concept. Lave and Wenger (1991, p. 29) defined LPP as providing "a way to speak about the relations between newcomers and old-timers, about the activities, identities, artifacts, and communities of knowledge and practices. It concerns the process by which newcomers become part of a community of practice." Thus, LPP can be explored as the process in which novices within a new domain engage in ample and appropriate opportunities to develop necessary knowledge, skill, and disposition of that domain (i.e., expertise). This process occurs within legitimate experiences assisted by experts. LPP experiences for the novice in the framework of teacher leadership in policy (STEMMaTe) describes LPP related to the individual's development first within STEM teaching by developing their scholastic effectiveness in content knowledge and pedagogical expertise and their understanding of how their local school and district functions (institutional knowledge and memory, Figure 1). Within these opportunities, STEM TLs gain knowledge, skills and dispositions from instructional leadership to strategic leadership through high-impact policy and advocacy activities among experts in those arenas.

The STEMMaTe model asserts that development as an advocate requires opportunities for acquiring experiences within each of the five sequential domains. *Scholastic effectiveness* requires a solid knowledge of STEM teaching. For example, appropriate LPP at the scholastic effectiveness level would be high-quality classroom teaching guided by a mentor teacher. *Institutional knowledge and memory* is the ability to (recognize) practice and policy issues within STEM education outside their own professional context (Hite et al., 2020). Appropriate LPP at this level could be sourced from participation on district or school committees with administrators to garner a greater understanding of the school's policies and politics. *Adaptability and flexibility* refer to gaining experience and knowledge of policy development and implementation to become an effective policy agent (Good et al., 2017). With these new experiences, TLs may begin to problematize issues in STEM education and learn the 'culture' of policy spaces, so they can understand issues within a policy context. Adaptability and flexibility are known for specific PD, training and programs that bring effective teachers and emergent leaders to novel contexts in which they are able to obtain new knowledge and skills beyond scholastic effectiveness. Examples include participating in a Research Experiences for Teachers (RET) program, Albert Einstein Distinguished Educator Fellowship Program, or CDC Science Ambassador Fellowship. Leadership opportunities comprise *emergent leadership*, leading to full engagement (*strategic leadership*), in leadership work that influences or creates STEM education policy from local to international levels. Emergent leadership might include assisting with implementation of an RET program; strategic leadership would include concept and design of the RET program.

Figure 1

The STEMMaTe Model of STEM Teacher Growth in Policy-Advocacy and Leadership



Note. Reproduced with permission from Hite & Milbourne, 2018 (CC by 4.0)

The STEMMaTe framework is useful to this study as it both justifies the examination of STEM TLs who have vetted LPP experiences that mirror the STEMMaTe model and how COVID-19 interruptions created new needs for LPP to reengage in the modified advocacy landscapes. Working and advocating in virtual versus physical environments warrants a new phase of adaptability and flexibility to lead online versus in person. This *adaptive expertise* (NRC, 2000) enables people to "remain flexible and adaptive to new situations" (p. 33). Termed within a dichotomy of expertise as artisan and virtuoso, individuals with virtuosity are able to identify the knowledge and skills needed in a new environment. In this case, STEM TLs who are able to garner the knowledge, skills, and disposition need to re-engage with leading in the now-changed policy advocacy spaces for STEM education. In studying STEM TLs, we may understand how their advocacy-based leadership, as viewed through their conceptions of STEM advocacy and subsequent advocacy activities, are impacted by sudden changes due to COVID-19. Using the STEMMaTe model, we can examine how changes to their situated expertise may have pushed them back into the adaptability and flexibility level of the framework. This is based upon how they perceived themselves as advocates or changed their advocacy activities entirely due to the larger societal interruptions from the pandemic (e.g., needing to learn how to engage in remote teaching and learning, learning how to advocate for different types of resources). Moreover, this framework helps to ensure that what participants are reporting vis-a-vis changes in their advocacy activities are not due to a lack of understanding of STEM teaching (i.e., scholastic effectiveness), how schools operate (i.e. institutional knowledge and memory), or a lack of experience working in policy spaces (i.e. emergent or strategic leadership). Rather, we can study changes in participants' conceptions of STEM education advocacy and their activities due to the pandemic. Engaging in adaptability and flexibility to garner the knowledge and skills needed to re-conceptualize and re-engage in policy-leadership activities provides vital insight to how these STEM TLs are differentially advocating for their colleagues and students.

Literature Review

Much of the literature on teacher advocacy focuses on general teacher leadership (e.g., Bradley-Levine, 2018; Nguyen et al., 2020; Pantic, 2017; Wenner & Campbell, 2017) or teacher advocacy in specific contexts, such as teacher advocates for English language learners (e.g., Dubetz & de Jong, 2011; Haneda & Alexander, 2015) and teacher advocates in special education (e.g., Burke et al., 2016; West & Shepherd, 2016). While there are extant studies on conceptions of STEM education by STEM teachers (e.g., Dare et al., 2019; Radloff & Guzey, 2016), we have not found studies that explore how STEM TLs conceptualize specifically STEM education *advocacy*. Such a study would provide insight to the ways in which STEM teachers practice and enact advocacy, a critical aspect of STEM teacher leadership (Bradley-Levine, 2018). We sought to address these gaps in both the STEM teacher and teacher leadership literature, by qualifying how this sampled group of STEM TLs conceptualized STEM education advocacy before and during the pandemic. Such insights are also crucial at a time when the COVID-19 pandemic, in the U.S., has stymied face-to-face education, creating both obstacles and opportunities in STEM education as well as its advocacy. Herein we review recent literature on STEM education, teacher leadership, and teacher's activities in policy advocacy, through the currently known (empirical) impacts of COVID-19 on American K-12 STEM education.

STEM Education, Teacher Leadership, and Teacher Policy Advocacy

Before discussing *how* K-12 STEM teachers advocate for K-12 STEM education, it is important to first understand *why* STEM education advocacy is necessary. On a broader scale, research in the field has suggested several reasons why STEM education is beneficial for economic prosperity (Langdon et al., 2011; Xie et al., 2015) and global competitiveness (Breiner et al., 2012) by providing content-savvy graduates to fill the growing number of positions in emerging STEM jobs and careers (Hira, 2019; Noonan, 2017) and by fostering students' problem-solving and critical thinking skills both in STEM and real-life (Brophy et al., 2008). It would follow logically if teacher advocacy is seen as "a practice of activism external to the school and a practice of educational leadership" (Bradley-Levine, 2018, p. 47), then advocating for STEM education, especially by instructionally proficient STEM teachers like STEM TLs (Hess, 2015), is vitally important and beneficial for students short-term and for society long-term.

While many states and districts have recognized the importance of a high-quality and equitable STEM education, there is a lack of consensus in the decentralized American school system as to how STEM is applied in schools (Brown et al., 2011; Chalmers et al., 2017; Hite & Milbourne, 2021; Reimann, 2020). Largely, the key stakeholders that STEM education policies would impact—students and teachers—are absent in the policymaking process (Pennington, 2013). Yet, study after study has evidenced the importance of the teacher voice in crafting effective and efficient education-focused policies and the impacts of school effects (e.g., negative administrators or colleagues) on teachers' abilities to promote policies with fidelity (Fairman & Mackenzie, 2015; Olsen & Buchanan, 2019; Sunderman et al., 2004). One study showcased that specifically involving special education teachers in the evaluation of special education policy provided insight to what actually occurs within special education classrooms (Bourke et al., 2004). Benefits included teachers helping to clarify academic language and curricula specific to special education classrooms, as well as special education teachers gaining new skills in policy through their participation in the policymaking process. This situation is not unique to special education teachers, however, as similar results were evidenced in a study of bilingual teachers (Dubetz & de Jong, 2011).

These studies suggest that teachers lack opportunities for experiences in the policymaking process (required for knowledge and skill development) as well as engaging in activities related to policy advocacy (Cohen, 2008; Dever, 2006) as LPP. Bond (2019) amplified this notion by stating that teacher advocates of any discipline need these specific experiences in policy leadership, especially those actively engaged in advocacy. This need is significant because teacher advocates who gain this experience may lend an influential voice in policy decisions that affect students and fellow teachers. Similarly, a case can be made for STEM TLs who wish to advocate for STEM education. For STEM specifically, many policymakers lack backgrounds in education (Dever, 2006), therefore, involving STEM TLs in the decision- and policy-making process, showcasing their instructional and educational expertise, as well as leadership skills (per STEMMaTe) is a vital act of advocacy that would contribute to student success (Pennington, 2013; Wayman, 2005).

Cooper et al. (2016) describe teacher leadership as a dichotomy of the actions that occur within and outside of schools, both of which affect schooling outcomes. This study furthers that notion by utilizing what Wenner and Campbell (2018) referred to as 'thick' and 'thin' teacher leadership. Thick leadership is described as teachers' leadership activities that extend beyond school walls (e.g. policy advocacy via conversation with STEM education policymakers), whereas thin leadership refers to leadership activities at the school level (e.g. math department chairperson modeling implementation of STEM integration in the math classroom). While the latter form of leadership is typically mastered in *instructional knowledge and memory*, opportunities for LPP in policy advocacy are vital for STEM teachers to be effective as advocates. There are extant STEM educator policy training programs (i.e., STA) that provide LPP opportunities for STEM TLs to engage and be trained in policy advocacy.

COVID-19 Impact on STEM Education

The COVID-19 pandemic suddenly and dramatically changed K-12 education in the U.S. by abruptly shifting face-to-face instruction to virtual formats (Kaden, 2020). Two notable studies have reported projected effects of the pandemic on STEM education: one study forecasts a decrease in pass percentage rates among secondary students in science and mathematics due to the lack of technology resources available to students at home (Sintema, 2020). The second projects that school closures and shifts to distance teaching and learning will facilitate a significant decrease in K-12 student academic performance, specifically in mathematics (Kuhfeld et al., 2020). Most notably, a consensus study report from the National Academies Press predicts the STEM education equity gap to widen profoundly, especially for disadvantaged populations such as Black and Hispanic minority groups, due to the abrupt change in instructional delivery (Bond et al., 2020).

In regard to institutional challenges, a report from the Albert Shanker Institute stated that "the revenue that funds public K-12 schools--almost 90 percent of which comes from state and local sources--will see large decreases," due to the economic recession as a result of COVID-19 (Baker & Di Carlo, 2020, p. 1). Baker and Di Carlo further explained that many states are still recovering from the last recession in late 2007. Thus, budget cuts that have been set in place endanger school initiatives and programs, including those involving STEM. It is then important for STEM TLs to keep abreast of these pandemic-induced education obstacles in student academic losses, widening equity gaps, and ongoing budget costs, to leverage their knowledge and skills of STEM education and advocacy practices in sustaining effective STEM education curriculum and programming during the pandemic. Further, without the tight constraints school environments exert that inhibit teacher leadership (Fairman & Mackenzie, 2015), it is unknown to what degree STEM TLs are advocating (more or less) without hindrance, or how they are advocating (new or adapted advocacy activities).

Per the STEMMaTe model, LPP at each of the five levels relate to face-to-face means of obtaining LPP, such as school, district, and programmatic supports. In STEM, this has meant many schools and districts closed or went online for emergent leaders, shifting or reducing their support networks. For those STEM leaders who were engaging in LPP for adaptability and flexibility, STEM educator policy leadership programs went online (e.g., the AEF) or on hiatus (e.g., RET programs with deferred NSF grants). Emergent and strategic STEM teacher leaders had previously exercised their policy leadership in communities with stakeholders and one another in-person, such as designing and delivering professional development experiences for other STEM teachers at practitioner conferences. Due to the pandemic, much of this PD was either cancelled or migrated to webinars.

At each of the five STEMMaTe levels, LPP supports for policy leadership development among STEM teachers were impacted by the interruptions caused by COVID-19. Per Lave and Wenger (1991), a lack of LPP opportunities fosters a dearth of social interactions to comprehend, develop and refine the knowledge, skills, and dispositions to affirm and extend activities within a chosen domain, such as policy-advocacy activities for STEM education among STEM teachers. Therefore, it is unknown how STEM TLs understood, obtained, leveraged, abstained from, or provided LPP in the fewer and socially different online modality of policy leadership LPP during the pandemic. Maintaining effective and equitable STEM education programming may be explored through STEM TLs' conceptions of and activities in STEM education advocacy prior and during the COVID-19 pandemic.

Methods

This study employed phenomenography, defined as a qualitative research approach that "aims at description, analysis, and understanding of experiences" (Marton, 1981, p. 180). Phenomenography is often confused with, and erroneously compared directly to, phenomenology as both relate to phenomenon-based research (Cibangu & Hepworth, 2016; Hasselgren & Beach, 1997). A critical difference is how these qualitative approaches problematize the purpose or the intention of the study, which in this case was to understand and describe the phenomenon of STEM advocacy as conceptualized by STEM teacher advocates, rather than lived experiences (of phenomenology). Instead, phenomenography allows for the description of a phenomenon as it is *conceptualized* by a group of participants (Alsop & Tompsett, 2006), which is why Han and Ellis (2019) have ascribed phenomenography as an ideal methodology for STEM education research.

Therefore, in phenomenography, descriptions of experiences of a phenomenon (engaging in STEM advocacy activities) as provided by participants (STEM TLs who are engaged in advocacy) are grouped together to form what is known as *categories of description* (Marton, 1986). These categories are established through a robust analysis of the relationships between and variations among participants' *utterances*, their descriptions of experiences, which serve as this method's units of analysis. Notably, utterances can be whole sentences, segments of sentences, or a cluster of sentences that are placed into a specific category after multiple rounds of coding. Final categories of description are commonly structured hierarchically, to provide explicit descriptions of how categories differ. Collectively, these categories comprise the *outcome space* of categories established from utterances of sampled participants (Marton & Pong, 2005). Given the understudied phenomena related to conceptions of and activities in STEM advocacy among STEM TLs, and the novel effects of the pandemic in the sphere of education, phenomenography provided the means to ascertain variations among and relationships between elicited conceptions uttered by STEM TLs on advocacy at two levels (Marton & Pang, 2008):

through STEM education advocates as processed by the researcher (*first-order perspective*) and as described by utterances reflective of the experiences of STEM education advocates (*second-order perspective*) (Marton, 1986). This, in part, is what made phenomenography the most appropriate methodological approach for this study: STEM advocacy was occurring before and during an unprecedented time, completely altering the thick and thin leadership in which STEM TL advocacy would normally take place and perhaps the purpose (e.g., greater focus on procuring technology resources) of their advocacy activities.

Participants

Purposeful sampling is customary for phenomenographical research due to its strictly empirical and inductive nature in analysis (Åkerlind, 2005). In order to capture conceptions of STEM advocacy, we recruited STEM TLs specifically trained and experienced in advocacy. Based on the STEMMaTe model, these sampled individuals constitute teachers at the emergent leadership phase, participating in leadership (advocating) for STEM education. The LPP experiences of these participants occurred in the NSF's STA (2019) program, jointly facilitated by the National Science Teaching Association (NSTA) and the National Council of Teachers of Mathematics (NCTM). An important criterion for participation in the STA program was that teachers had to be past recipients of the Presidential Award of Excellence in Mathematics and Science Teaching (PAEMST), a national-level award for K-12 STEM teachers who have demonstrated excellence in STEM classroom teaching and leadership. Programmatic criteria provide vetting of the scholastic effectiveness and institutional knowledge and memory (Figure 1) to effectively participate in the LPP experiences (adaptability and flexibility) within the STA program to become an effective STEM education advocate.

In the two years of the program's existence, a total of 20 STEM teacher advocates (10 per year) completed the advocacy training fellowship. The STA program consisted of learning modules and experiences (LPP) in basic STEM education policy knowledge, crafting effective policy briefs, speaking to local and national media, and using social media (Twitter) as a digital advocacy space. Fifty percent (10/20) of all STA alumni participated in this study; they comprise a diverse demographic in terms of gender, grade level taught (and STEM discipline, if they taught at the secondary level), and number of years of teaching experience (Table 1). It is important to note that while this study had a small sample size, the focus of phenomenographic research and analysis is driven by the presentation of variations of conceptions described by participants, not by the number of participants itself (Mullet et al., 2018). Thus, both the sampling and sample are appropriate for a phenomenographic study (Bruce et al., 2004; Mullet et al., 2018; Trigwell, 2006).

Data Sources and Collection

Interviews and a follow-up questionnaire provided the data on how these 10 STA alumni conceptualized and problematized STEM education, and how their advocacy priorities and/or activities have shifted as a result of COVID-19. Data collection for this study occurred in two phases: (1) pre-COVID-19 in the summer of 2019 and (2) during COVID-19 in the spring of 2020. While the original intent of this study was to analyze and describe STEM teacher advocates' conceptions of STEM advocacy in a more general manner, the onset of COVID-19 allowed us to not only analyze their conceptions of STEM advocacy, but also to do so within a pandemic. Given the abrupt shift in moving teaching and learning to hybrid or fully-online teaching modalities was a novel situation for math and science teachers (Bloom et al., 2020), that may too have had impacts on these specific STEM TLs' conceptions of advocacy and resultant activities.

Table 1

Study Participants

Pseudonym	Sex	Grade Level Band (and STEM Discipline)	No. of Years of STEM Educator Experience	Notes
Jane	F	Elementary	21	
Ben	M	Elementary	27	District STEM teacher
Dave	M	Middle School Science	33	
Lou	F	High School Science	31	Held teacher educator role concurrently
Mark	M	Middle School Math	13	
Lisa	F	Elementary	35	Retired at the time of interview
Mary	F	Elementary	22	State curriculum coordinator for science
Anne	F	High School Math	26	Held administrative role concurrently
Paul	M	High School Science	20	
Beth	F	High School Math	28	Held administrative role concurrently

Individual semi-structured interviews were conducted as an extension of a previous study on how alumni of the STA program conceptualized and engaged in STEM TL advocacy (Velasco et al., 2021) during July and August of 2019. Audio data was transcribed using qualitative analysis transcription software (Otter, 2020). Interviews were video-recorded via Zoom (2016) and lasted no longer than one hour. Interview questions focused on participants' conceptions of and experiences in STEM advocacy, such as: How have you come to understand what advocating for STEM education entails? How has your experience as an STA influenced your role as an advocate for STEM education in your classroom? What are you doing now for STEM education, regarding advocacy, after the STA program? How has your teaching changed since STA as an education advocate?

Phase two of the data collection process occurred during the COVID-19 pandemic (April 2020) and at a time when most K-12 schools and universities across the U.S. had fully transitioned to online or hybrid instructional platforms (Tull et al., 2020). During this phase, a five-item open-ended questionnaire (Edwards, 2007) was developed based upon the most cogent responses from the interview data. Items asked participants to reflect and describe: the extent to which they have advocated, or plan to advocate, for STEM education during the COVID-19 pandemic; how their thinking (conceptualization) or advocacy (activities) for STEM education have changed since the onset of the COVID-19 pandemic, including how they network with other TL advocates; how they think their advocacy for STEM education will change after the end of the COVID-19 pandemic. A Google Form with an online link was directly emailed to all 10 participants during the first week of April 2020. All participants were able to fully complete the questionnaire within two weeks.

Analysis

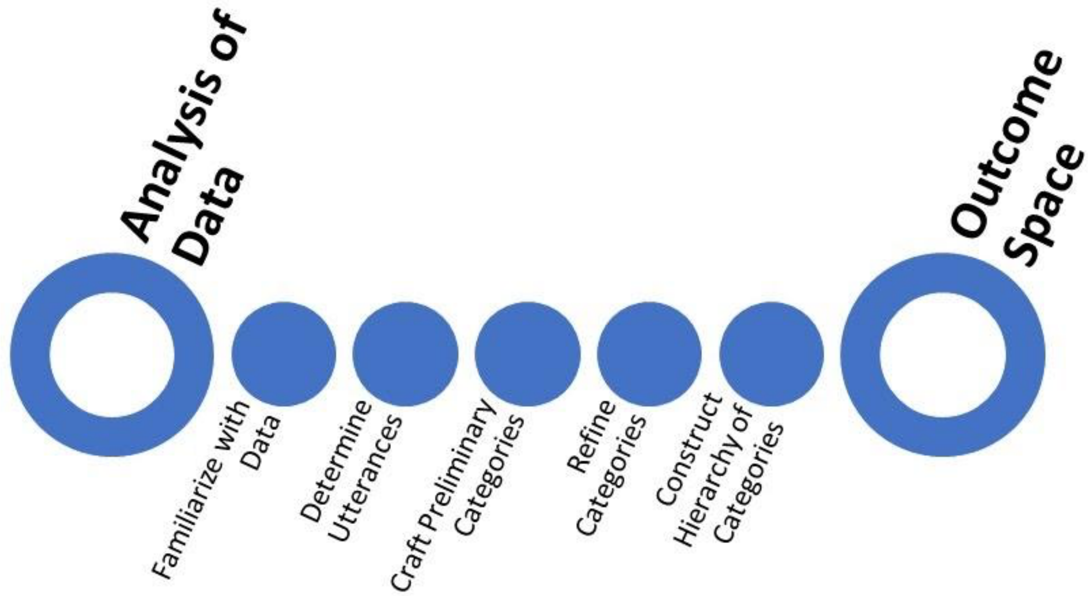
The analytic approach to phenomenography is both empirical and inductive (Marton, 1986), focusing on description of participants' conceptions of a phenomenon underscored by how said phenomena is actively experienced by the participant. While there is no specific prescribed technique in the analytical process of phenomenography (Ashworth & Lucas, 2000), we utilized the five-step formula offered by Sandberg (1997) for both sets of data collected (before and during COVID-19; Figure 2). First, we familiarized ourselves with the 10 previously de-identified transcripts by reviewing the data, correcting software-based errors, and establishing the audit trail. Second, we inductively identified and selected utterances from the transcripts by making sure to focus primarily on the utterance as its own unit of analysis, independent of the participant. We first conducted this second step of the analysis separately to ensure an unbiased selection of utterances, then compared and discussed notes to come to an agreement in final use of utterance as data. A third senior researcher was consulted to help resolve disagreements. Third in the analytical process, we conducted preliminary categorizations of the utterances, where utterances were grouped based on similarities and collective meanings across the set of data, unbounded by linking specific utterances to participants. Fourth, we refined categories by shifting utterances to expand and/or collapse categories until we reached consensus on the final categories of description. This refining process is vital to reduce categories of meaning into developing the outcome space because "these categories of description are the logically related [yet] qualitatively distinct ways of experiencing the phenomenon" (Åkerlind, 2005 as cited in Daniel, 2021, p. 4). Last, we reviewed the outcome space (i.e., the collection of categories of description) and explicitly described differences among categories, but also their relationship to the phenomena of study. Per Han and Ellis (2019) the phenomenographic outcome space "contains two essential elements: descriptions of each category and selections of illustrative statements accompanying each category" (p. 6). Thus, once categories of the outcome space are established, readers are given an understanding of how many illustrative statements were made by participants to substantiate the categorical descriptions. Han and Ellis (2019) elaborated that "the outcome space can also be arranged chronically (temporal ordering), which denote the evolution of the participants' experience" (p. 6). Given that the research inquiry is punctuated by COVID-19 interruptions, marking the shift from face-to-face to online LPP for learning and exercising expertise in STEM education policy advocacy, bifurcating the data is logical to understand how this shift impacted participants' experiences or activities in STEM education policy advocacy.

Researchers' Positionality

Both authors were former K-12 STEM TLs who have had experience in STEM policy advocacy training and are current STEM education researchers at large research institutions in the Midwestern and Southern regions of the U.S. Both researchers leveraged their classroom and policy knowledge, advocacy training, and scholarly experiences to develop the interview protocol and questionnaire used in the study. The first author is an alumnus of the second (and final) STA cohort, collecting all data from participants given this relationship to the program and participants. The second author has had deep involvement in K-12 STEM TL advocacy and prior scholarship in this space.

Figure 2

The Five Step Phenomenographic Progress



Note. Adapted from Sandberg (1997).

Trustworthiness

To maintain the degree of confidence and rigor of analysis employed in this phenomenographical approach to research, we strove to meet the four criteria of trustworthiness offered by Lincoln and Guba (1985). Credibility of the data was established since the participants of this study were community-vetted STEM teacher advocates, per the theoretical frame of the STEMMaTe model, who shared and provided thick descriptions of their advocacy experiences after being trained in advocacy. Dependability measures were taken as we kept an audit trail of participants' transcription data. Both researchers worked collaboratively to code all data of the present study, discuss the data over multiple time periods, and construct final categories of description to account for confirmability of data. For transferability purposes, we provided a detailed description of the study's context (conceptions of STEM advocacy), setting (pre-COVID-19 and during), and participants (STEM teacher advocates).

Results

We reviewed a total of 224 pages of transcribed data from all 10 interviews and an additional 21 pages extracted from the questionnaire responses. For our initial analysis, we identified and selected 304 relevant utterances from the interview data and 73 relevant utterances from the questionnaire data for a total of 377 units of analysis for the data pool. We began with the utterances in the transcribed data collected pre-pandemic, grouping similar utterances inductively, producing a total of 44 preliminary categories. We completed the same process for questionnaire data and found that utterances in this data set fit into 16 of the preliminary categories derived from the transcript data. This process of categorical refinement (i.e., from 44 to 16) is integral to the development of the phenomenographic outcome space. Data from questionnaires were highlighted in a different color to distinguish them from interview data; these preliminary categories are summarized in Table 2.

Table 2

Preliminary Categories in Alphabetical Order

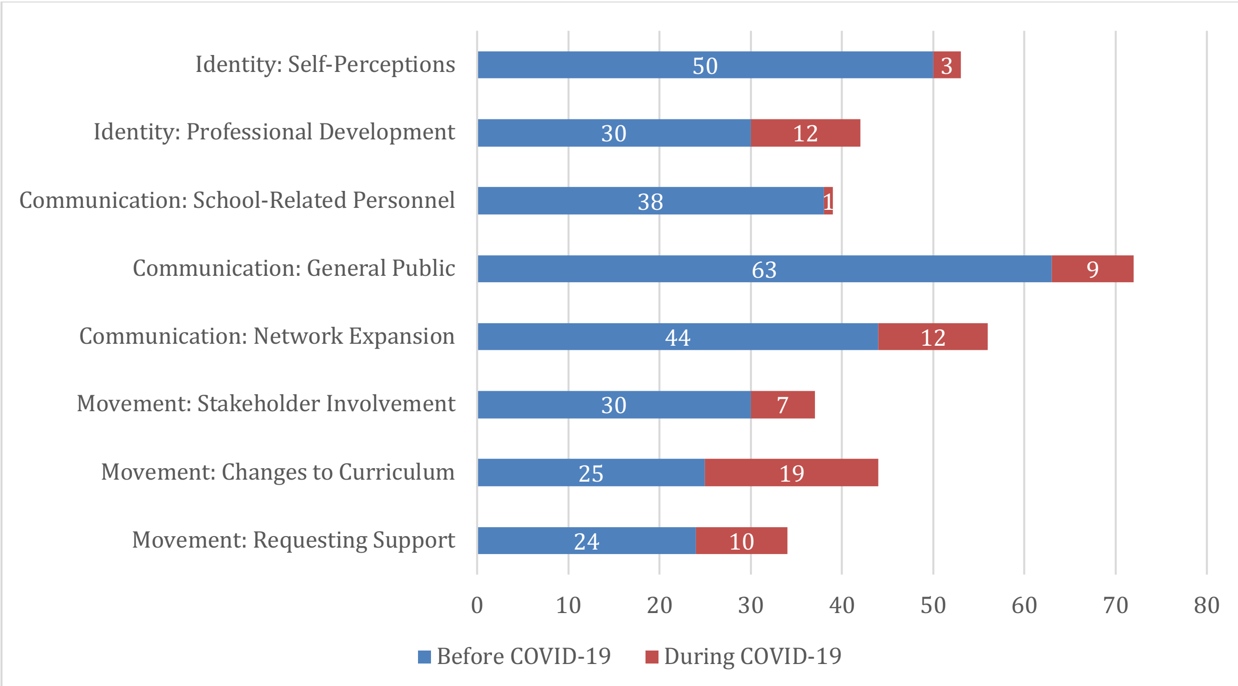
Advocacy as a passion	Involvement with STEM education community*
Advocacy training	Making connections with other STEM teachers
Advocate identity*	More advocacy needed*
Advocating for funds for STEM*	Political awareness
Advocacy as a calling	Presentations at professional organizations
Applying for grants and awards	Providing support
Being a STEM person	Push for math
Constantly learning for professional growth	Responding to questions about STEM
Conversations with government officials*	Responding to STEM opportunities
Convincing other STEM TL to advocate	Speaking with the school board*
Creating school STEM programs	Spreading awareness: what advocacy looks like*
Curriculum changes*	STEM activity in the community*
Deciding on how funds should be spent for STEM	STEM advocacy using social media*
Disseminating STEM info. to stakeholders*	STEM awareness
Engaging with a broader audience	STEM in a problem-based learning environment
Helping pre-service teachers	STEM night for parents
Highlighting STEM in casual conversation	Talking with administrators
Incorporate STEM into teaching	Talking with district supervisors or leaders
Increasing in STEM knowledge*	Teaching other teachers to become advocates
Increasing networks*	Teaching style is constantly changing
Integration of STEM into other disciplines*	Teaching workshops to other teachers*
Inviting STEM professionals to class	Writing an op-ed*

*Preliminary categories that include utterances from survey data.

Upon further examination, we then reassigned, regrouped, and rearranged utterances to different categories and eliminated categories. For example, the preliminary categories 'advocacy is a passion,' 'advocate identity,' 'advocacy as a calling,' and 'being a STEM person,' all shared common utterances that referenced STEM TLs' perceptions of their identities as STEM teachers and advocates. Thus, the utterances in these preliminary categories were regrouped to form the 'Self-perceptions' subcategory. Further refinement of categories led to a final set of three overarching categories, each containing a set of subcategories: (1) *identity*, (2) *communication,* and (3) *movement* (Table 3). Findings indicated that STEM TLs' conceptions of advocacy were tied to their STEM teacher and advocate identities. In order to advocate for STEM, one must be knowledgeable and skilled in their discipline and advocacy. Furthermore, STEM TLs' conceptions of advocacy were manifested in some form of communication. STEM TLs made references to conversations with education leaders, voicing the importance of STEM with the general public, or collaborating with professional networks. Finally, STEM TLs' conceptions of advocacy went beyond voicing concerns and were more action-oriented (hence the category, 'movement'), resulting in training or creating a document. Figure 3 illustrates the frequencies of utterances per subcategory before and during the COVID-19 pandemic.

Figure 3

Frequency of Utterances Per Subcategory in Outcome Space



Findings reveal that prior to the COVID-19 pandemic, STEM TLs' conceptions of STEM education advocacy were largely in the form of constant communication. During the pandemic, participants primarily conceptualized STEM education advocacy as immediate movement (i.e. advocacy that requires action beyond communication). The sections that follow further explicate the thick descriptions within each of the three overarching categories and their subcategories formed in the outcome space. In addition to these descriptions supported by direct quotations from participants, we report the sum number of utterances as well as the final number of utterances assigned from both the interview and questionnaire. We report percentages of increase to illuminate how data changed in the categories of description from the time before the onset of pandemic to the time questionnaire data was collected.

Category 1: Identity

Ninety-five descriptions of identity were uttered in STEM TLs' conceptions of STEM education advocacy, comprising the least amount of data in the outcome space. Eighty utterances were extracted from interviews conducted pre-pandemic and 15 utterances were added from questionnaires answered during the pandemic, indicating an 18.8% increase in utterance frequency. Within this category of identity, sampled STEM TLs' conceptions of STEM education advocacy were dependent upon their self-perceived roles and their reception of received PD.

Self-perceptions

According to sampled STEM TLs, STEM education advocacy was a result of self-identifying as a STEM educator and an advocate. Many utterances related to respondents' exemplary teaching of a STEM discipline (i.e. science or math), and from that expertise, they felt compelled to be advocates

Table 3

Overarching Categories, Subcategories, and Utterance Examples Prior to and During COVID-19 Pandemic

Subcategory	Examples of Utterances Pre-Pandemic	Examples of Utterances During Pandemic
	Category 1: Identity	
	Description: STEM teacher leaders' conceptions of advocacy were tied to their STEM teacher and advocate identities. In order to advocate for STEM, one must be knowledgeable and skilled in their discipline and advocacy.	
A. Self-perceptions	Jane: "I was advocate for it in my district, and in my school, pretty much limited to that level, it was I didn't do a lot of calling legislators I didn't do a lot of you know, that type of advocacy, writing articles or anything like that, I just was just active and doing it in my classroom and at the school level, and kind of leading it that way." Ben: "I've always been kind of a STEM person." Mark: "The research on advocacy is my proudest moment."	Mary: "It has shown me that my work is essential. We have got to do better so that we have a more informed public who can understand basic health issues, understand math and science models, and grapple with data and basic stats. Our future as a nation depends on it. I'm even more fired up." Dave: "I feel STEM ed may be less of a priority in the short term due to extreme budget cuts happening to local education agencies everywhere, but in the long term, I think interest may increase as we will need STEM educated citizens to solve these complex world problems." Anne: "COVID-19 has made me think about how to continue to push for STEM as we enter the online world."
B. Professional development	Dave: "The [STEM teacher ambassador] training was focused on the state level, how to navigate state politics, which was very helpful." Beth: "I wanted to learn more about STEM, kind of on the ground roots and also figure out how to do more collaboration between our science and math staff at the high school."	Jane: "I think the pandemic will bring a greater respect for STEM and educators in general which will hopefully allow us to do more for our students." Lou: "STEM knowledge is so important to dispel the many myths and misunderstandings."

Category 2: Communication

Description: STEM teacher leaders' conceptions of advocacy were manifested in some form of communication, be it conversations with education leaders, voicing the importance of STEM with the general public, or collaborating with professional networks.

A. School-related personnel	Lisa: "I'm serving on a board right now, where we're bringing the new standards into schools. And I know that they're coming with some resistance, because it's not that easy, you know, give this test, teach these facts." Anne: "I'm trying to get the other teachers to buy in, because some of them don't even understand [STEM]." Lou: "[Administrators] pretend like they want our opinions, but they already have theirs."	Dave: "My work—advocating for NGSS—continues during COVID and is actually doing well. Tomorrow, our state board of education is having its first ever live Zoom that will, in part, discuss the standards revision process."
B. General public	Ben: "I think I have a bigger platform now because now when I meet people, I don't just share my ideas. I share my ideas and say, I'm a STEM ambassador. And, you know, it's a platform." Anne: "Whenever you get a chance and sometimes I can run into people where you're not planning to run into and you have an opportunity or an opportunity presented [to talk about STEM]. Paul: "I've been a moderator before, so I felt like I was I am I've got some skills in that area, some background in that area. And then but also, you know, I'm very excited for what everybody else is bringing to the table."	Mark: "For the past couple of months, I've tweeted a few topics on STEM education to help educators with some STEM-at-home ideas, such as reading news articles." Lou: "I have posted instructional ideas via Facebook and Twitter. I have tried to explain COVID things and posted videos and tutorials." Jane: "In addition I have created a Facebook page called Science Sleuths dedicated to science instruction and a platform for students to share their experiments and investigations."
C. Network expansion	Paul: "So, I have not yet reached out to the new representative or so that's also something that I've learned is like some of these relationships that you maybe want to try to build." Beth: "My purpose of that is to then provide it to the governor as more think piece. We need to be better and stabilize." Anne: "Further the dissemination of the information and, and how advocacy is important to get more teachers and politicians and in general just everybody realizing how important [STEM] is in education and how and why it is so important."	Mary: "I hope to partner with my state leaders to provide quality science experiences for my colleagues in my state. We are working on if that can happen." Dave: "There will now be connections and networks to ramp up my advocacy to a global level." Lisa: "I am reaching out to my network to support them with resources, helping with ideas for trainings, and offering classes myself in STEM."

Category 3: Movement		
Description: STEM teacher leaders' conceptions of advocacy went beyond voicing concerns and were more action-oriented, resulting in training or creating a document.		
A. Stakeholder involvement	Anne: "The classroom sharing with the teachers, because a lot of the teachers don't understand, you know, the elementary because they're not really trained in science." Mark: "That's at least where I see myself like in the future and take advocacy another level that goes beyond the classroom in terms of being more active."	Beth: "I've also recruited teachers for the upcoming science committee. Unfortunately, our district does not have a STEM committee. I have also worked with our counseling department to set schedule for next year to include Tech Pathways course." Mary: "I'll include family and communities more. STEM is a social endeavor. No better place to start than the home and community." Lisa: "As a STEM advocate, I found myself "coaching" others through the process to brainstorm, create solutions, and design a plan that retains the best of STEM."
B. Changes to curriculum	Paul: "I've had a leadership role in transitioning the district to [my state's] new science standards, which are modeled after the next generation science standards." Ben: "I think teaching in a STEM platform in a problem-based learning environment. I created our STEM program." Dave: "So I am teaching in a way that is 180 degrees different than I think how I've taught prior to this, I mean teaching more for divergent thinking, instead of teaching to the test, more for project-based learning, problem solving, authentic learning real world application, whereas before it was test focused."	Mary: "I worked with my district task force of teachers to create 6 weeks of home learning K-5 science lessons that were true to our vision of phenomenon-based, three-dimensional learning. These lessons included on and offline resources/activities and families were encouraged to participate in the learning." Paul: "I have led my district in preparing distance learning opportunities for our high school science classes." Anne: "I am also continuing to help develop/teach online science in summer school for this coming session. I make sure activities are selected that represent STEM and inquiry processes." Beth: "And of course I taught my only foundations of algebra and geometry class via Canvas and Zoom where I integrated technology to support the class."
C. Requesting support	Lisa: "But our task was to go and share about STEM education and getting more funding for that." Jane: "I would think the thing I would need to do that I haven't done and really put off is writing articles and op-eds."	Ben: "Fighting to keep as much of it [budgets] intact as possible." Mark: "It's made me more lethargic and anxious thinking what the future would hold... during this time that has made me think, it's going to get better and life will go on and we shouldn't stop advocating for STEM education, but that it is okay if we need to take a pause for a moment."

within and for the profession. For instance, Ben (all participant names are pseudonyms), an elementary STEM teacher TL described, "I would say I've always been an advocate. I think I've always been since early on. I'm an advocate for STEM, because I'm a STEM teacher." Lisa, a retired elementary teacher with over 35 years of educator experience, echoed the same sentiment,: "So I feel like just being a science teacher, [advocacy] was just a natural part of who I am and who I was. I always think of it as fighting for what's right, fighting for what's good." Where STEM TLs identified as STEM teacher advocates, there was also a passion for advocacy and in certain instances, advocacy was a calling. Mary, a former elementary teacher and currently her state's science curriculum coordinator explained about advocacy, "I have a passion, and I'm putting in the work. I felt if no one else is doing it, then I'll do it because our kids deserve the time, they deserve the learning."

Respondents' passions and calls to advocacy did not wane during the pandemic. Mary expressed how the pandemic has given a greater purpose to her advocacy activities, "My work is essential. We have to do better so that we have a more informed public who can understand basic health issues, understand math and science models, and grapple with data and basic stats. I'm even more fired up!" There were also pandemic challenges in advocating for STEM education, such as the shift to online learning. For example, Lisa vented, "I have become an advocate for hands-on learning. It is frustrating when I hear teachers saying, 'I can't do hands-on when it's online.'" Middle school math teacher Mark shared how quarantining posed challenges to his advocacy: "Because I have been in self-isolation for most of this time during the pandemic, it has been quite difficult to advocate for STEM education in some capacity."

Professional Development

The majority of utterances that increased over time (between the data sets) in the category of identity were in relation to STEM TLs' descriptions of a continual need for PD; so teachers could learn more about STEM education and receive training for advocacy work. Prior to the pandemic, participants felt that STEM education meant continuous learning of STEM in general. For example, high school science teacher Paul indicated, "I want to learn more about STEM and some of the ins and outs of it, from a policy standpoint or even from a historical standpoint." Beth, a high school math teacher and administrator, also elaborated, "I wanted to learn more about STEM, kind of on the ground roots. What our nation needs are highly competent people in the areas of science, technology, engineering, and math, and we're falling behind." To further illustrate the importance of explicit educative experiences in advocacy, middle school science teacher Dave spoke to experiences and training he received in the STA program, describing that "their [advocacy] training was focused on the state level, how to navigate state politics, which was very helpful."

During the pandemic, STEM TLs acknowledged that advocating for STEM education would help mitigate misconceptions and misunderstanding associated with the COVID-19 global crisis. Lou, a high school science teacher and teacher educator, articulated, "I feel that [advocacy] gives us a voice to promote STEM as something that will help bring this pandemic under control. STEM knowledge is so important to dispel the many myths and misunderstandings." Participants discussed what the pandemic meant for the future of STEM education initiatives and policies. As Mary observed, "I saw that during this time many used this health crisis to manipulate STEM initiatives. I think we as a community need to be concise and make sure we are champions for equitable STEM learning for ALL rather than novel activities disconnected from authentic learning or what is cute on Instagram. And we need to be clearer on what STEM is and what STEM isn't."

Category 2: Communication

The category of communication consisted of 167 utterances, marking the largest amount of data in the outcome space. However, this category had the smallest percentage increase of utterances at 15.2% with 145 utterances coming from pre-pandemic data and 22 during pandemic data. Similar utterances assigned in preliminary categories were grouped together into subcategories. Specifically, STEM TLs had conceptualized STEM education advocacy as conversations with school-related personnel about STEM, informing the general public about the importance of STEM, and calling upon or being recruited by external organizations to expand their STEM education networks.

School-related Personnel

Respondents' described STEM education advocacy as being more successful when co-workers are educated and involved. Anne, a math teacher and school administrator mentioned, "I'm trying to get other teachers to buy in, [but finding trouble] because some of them don't even understand it." Dave shared the same sentiments in regard to spearheading his own state's STEM advocacy program, expressing that advocacy "would be an awesome thing to continue and to get more teachers involved with." For elementary teacher Jane, effective advocacy means involving school administration, "My response to the definition [of advocacy] was different. I felt like advocacy was where I was with teachers, with principals, with administrators." She suggested that her administration's involvement led to her school district reaching out to her as a STEM TL, "My district gave me more attention for being an ambassador, and for being a presidential awardee." Paul articulated a similar experience having been recruited by his school board to be a part of his district's STEM advisory board, "I am part of my district's STEM advisory board. This is a new role for me. I don't think I would have been invited had I not been named [as] a STEM advocate." Other participants commented on how they leveraged their networks to extend their advocacy beyond the school's walls, as STEM TLs referenced contacting district leaders to enact change. As an example, Lou declared, "If I really believe something, and I have some strong views, I'm talking to my superintendent, I'm emailing, I'm talking to my principal now." However, STEM TLs cautioned that this approach was not always effective. Ben indicated that, in trying to incorporate a more integrative STEM curriculum at his middle school, persistence was also necessary, "And I kept pushing. It's the same old thing, like people don't want to be bothered, like, change is different." Beth described another example of disappointment by stating, "I was able to insert things like, 'Well, I think we need to do this because it will prepare kids for these types of careers.' But, a lot of my suggestions fell on deaf ears." Other than a statement provided by Dave regarding meeting with his school board via Zoom (Table 3), notably no other utterances from the questionnaire data collected during the pandemic were assigned to this subcategory.

General Public

Another conceptualization of STEM education advocacy among respondents was promoting and communicating the significance and importance of STEM education to the general community. For example, Dave uses his TL voice to advocate to the community about STEM education's importance to a thriving economy, "I try to convince people that STEM is all about competing globally, for jobs, for the economy." Ben described experiences that aided him in elevating his voice and more effectively communicating the importance of STEM education, "I think the STEM ambassadors was a platform to bring [STEM] to a bigger audience, to talk about it to a bigger audience." Leveraging social media was also referenced by STEM TLs as a means to advocate for and communicate STEM education to the general public. Reflecting upon her experiences of using social media for advocacy (prior to the pandemic), Jane shared that, "I did become a lot more active on

Twitter, connecting and retweeting, you know, just trying to get [STEM] out there, to the people that I connect with or that follow me." Mary indicated that social media was her avenue to have her voice heard: "I very quickly found out that Twitter was a great space for not just learning, but networking and sharing my voice in a way that I felt could also improve the things I had to say." However, some STEM TLs indicated that they were apprehensive about sharing advocacy on social media. Paul talked about his trepidation, yet shared nonetheless that he uses social media to promote his STEM interests, "I am very cautious about what I put on social media still. I seem to advocate NASA. I love NASA. And so, I find it easiest to retweet, or like and mention, respond to amazing things NASA is doing." Lou added her thoughts on the need for more training before STEM TLs use social media for advocacy: "I still don't use it. There could be more training on how to really utilize and expand your reach if you do choose to use social media."

The following utterances on social media represent the data added to this subcategory from questionnaire responses collected during the pandemic. Shifts to hybrid and virtual learning prompted STEM TLs to leverage the internet and social media to advocate for STEM. For instance, Dave shared that "Zoom and [Microsoft] Teams have been great resources for advocacy." And from Mark, "I have been retweeting STEM resources that I find to be helpful or particularly useful for parents to help their kids at home." However, Mark also noted obstacles for students without access to technology and/or the internet, "I definitely want to be more active in advocating for STEM using social media, but I also have to think about ways to reach populations that do not have social media. I think reaching out to communities and seeing what their needs are based on this pandemic and being able to relate the notion of STEM and what STEM is all about is very important." Further, technology can be a lifeline for teachers and students. As Lisa described, "I worry about the isolation of the students and their teachers. Education is such a collaboration and we need each other. Using Zoom type platforms to create interactions has been increasingly important."

Network Expansion

STEM TLs' conceptions of STEM education advocacy entailed communicating with external STEM organizations, government officials and lawmakers to expand their own professional networks in education policy. Speaking on STEM organizations, Lisa ascribed success in advocacy to working diplomatically with those who may exhibit opposition, "A big thing that was a revelation for me was making yourself available to some of those key players in the STEM world, so that they know you're on their side, even though they might kind of potentially be against you to work with them, to continue to build that relationship and that common understanding."

In regard to government officials and lawmakers, Dave shared that advocating for changes in STEM education policy begins with his state-level policymakers, "I feel like [advocacy] is getting a conversation going in [my state], to rethink what schools could be as far as STEM education." Further, respondents also felt an important part of their advocacy conversations with policymakers was to keep them abreast of the reality of K-12 STEM in today's classrooms. An example of this sentiment was shared by Lisa, "Advocacy is talking to your senators and representatives to share that this is from the classroom, this is from the heart of the classroom. They're in this fantasy world of what STEM education is." In order to have those often tough conversations, STEM TLs stressed the importance of establishing a professional relationship first with their local and state policymakers. Paul shared, "I have not yet reached out to the new representative. That's also something that I've learned is like some of these relationships that you maybe want to try to build." Ben shared he made a point to develop a professional relationship with one of his state's lawmakers, "I live 30 minutes from our state capitol. So, I think that [proximity] has really helped the cause, because a lot of these lawmakers, policymakers, and their staffers, live in my community. So, the relationship has already started." Establishing and maintaining relationships afforded the STEM TLs new and different opportunities, even at the national level, to advocate for STEM education. Jane recalled, "I feel like my name is more out there at the national level than it is in my own state or district."

With the exception of one utterance making reference to partnering with other state leaders, all utterances collected during the pandemic were assigned to this subcategory of increasing networks. Having shifted to virtual modalities for teaching and working from home, Jane put it explicitly, "Increased time at home during the pandemic has given me the opportunity to further build my network." All other utterances shared in terms of network expansion described how the shift to virtual work benefited their STEM education advocacy. Support from now virtual networks helped connect STEM TLs with resources. Mary shared, "I used [my networks] for guidance and support. We were overwhelmingly provided with resources. My networks helped. It was humbling how we were there for each other." Lisa stated, "I feel I am discovering ways to use the virtual classroom as a powerful way to reach teachers across the country in addition to the area teachers. I think this could really extend the outreach of my STEM training."

Category 3: Movement

The final category of movement had the lowest number of utterances from the transcribed interview data collected, with 79 utterances. However, questionnaire data collected early into the pandemic added 36 more utterances to this category, bringing the total number of utterances to 115, which is the second highest number of utterances among the three categories. These additional utterances increased 45.6%, marking this category with the largest increase among the three overarching categories in the outcome space. In terms of movement, this category describes STEM TLs conceptions of STEM education advocacy involving actions beyond communication. These actions included garnering community stakeholder involvement, carrying out changes to curriculum, and requesting funding for STEM education by crafting letters and memos.

Stakeholder Involvement

As described by STEM TLs, training was a common conceptualization in terms of involving stakeholders for movement in STEM education advocacy. STEM TLs felt it was important to train other teachers how to integrate STEM into their curriculum or advocate for better STEM education policies. Ben said, "I have been teaching workshops to other teachers on how to do hands-on science labs, instead of just reading something from a book." And Lou wishes to train all teachers in education policy, not just TLs such to "get them involved in legislation, and let them know about it. Train them to share their ideas in conferences, so they can build their network outside of their school." Anne's advocacy activities focused on parents in her community, "We had a STEM night and did activities with the parents and their kids and saw how engaged they were." From that experience, Anne described she next wanted to similarly engage pre-service teachers, focusing on training "future teachers how to be an advocate for STEM." Mark's advocacy activities progressed beyond the school because he "wants to take advocacy to another level that goes beyond the classroom. I want to be more active and have districts work with local universities."

Conceptions of STEM education advocacy during the pandemic involving stakeholders included continuing work mainly with teacher groups, but in a virtual setting. Lisa shared, "I have been working with teacher groups…on making their online more interactive and more hands-on." With her teacher colleagues, Lou was able to share STEM activities that can be done at home, "I have given other content area teachers ideas for remote learning that also include STEM (e.g., kite making, hydro dipping, disc golf)." For Beth, it seemed to have been business as usual: "I've also recruited teachers for the upcoming science committee. Unfortunately, our district does not have a STEM committee…[so] I have also worked with our counseling department to set a schedule for next year to include a Tech Pathways course." Initial or small-scale advocacy experiences at the local level led to increasingly larger scale advocacy activities to serve a larger and/or wider audience of STEM education stakeholders.

Changes to Curriculum

Of all subcategories in the outcome space, the most utterances from questionnaires referred to curriculum changes. When STEM TLs advocated for STEM education, there was a focus on making needed changes to K-12 STEM curriculum. These changes were mostly targeted at the classroom level, as Anne stated, "I incorporated more of what's going on with STEM and into that course." Beth, discussed how it was important to better integrate STEM, especially in math courses, "I was a proponent of revamping that [STEM] course and turning it into a financial algebra course." For Mary, it was elementary engineering, "But literally it is sharing, what is engineering? Can we integrate technology and then here are some activities that we can do? And so, when I was in the classroom, that's pretty much what I focused on." As for Lou, doing STEM education advocacy work during the pandemic afforded her the opportunity to integrate STEM with art, "I have been the voice for STEM and the NGSS with the Innovation Collaborative which seeks to promote STEAM. This has involved helping with their position statement and STEAM integration activities development." Therefore, STEM advocacy meant advocates had to take bold steps in establishing new initiatives at the school and/or district levels. Ben announced that he had single-handedly "created our STEM program." Other utterances were for curriculum change at the state level as they perceived helping states' standards transition to national (the NGSS) standards, was important advocacy work. Paul expressed, "for the past few years specifically, I've had a leadership role in transitioning the district to [my state's] new science standards, which are modeled after the next generation science standards."

The most prominent theme among desired changes to curriculum were due to the abrupt shift to virtual learning and learning from home. For example, Jane replied, "This has caused me to think how to deliver hands-on instruction through a virtual platform." Lisa experienced pushback in delivering PD online, whereas Anne described how her new foray into online advocacy has reaped benefits for an online STEM curriculum, "I am working with my school system (Teaching and Learning Department) in creating online STEM related activities. I am incorporating STEM activities into my own lessons within the online world. I am also continuing to help develop/teach online science in summer school for this coming session. I make sure activities are selected that represent STEM and inquiry processes. I will have developed a better collection of online activities/modeling investigations that can still be used as we re-enter school settings. I will continue to push for more inquiry and STEM activities that integrate cross-disciplinary activities. Online experiences can augment classroom activities and discussions."

Requesting Support

Finally, STEM TLs' conceptions of STEM education advocacy encompassed formally requesting funding or monetary support for STEM programs and curriculum creation and sustainment. This subcategory is distinguished from communication because certain steps were taken to advocate for funding explicitly, such as writing an op-ed or an email to a lawmaker or lobbying them directly, instead of talking with another individual or organizing body. As an example, Ben took the necessary steps to apply for a grant such that he "got a…$10,000 grant to start an after-school STEM program." Mary was recruited as her state's science curriculum coordinator due to her advocacy activities, "They selected me because I wrote grants [and] I went for fellowships." A few STEM TLs described that writing memos and op-eds were important from an advocate standpoint, but doing so was the task that was always set aside. Jane, just like a few other STEM TLs, shared, "I would think the thing I would need to do that I haven't done and really put off is writing articles and op-eds." Paul felt that he was unsure about what to write about, "Through the course of the year, there were a number of topics that I thought I kind of wanted to maybe blog about or write about. I wasn't ever convinced that it was big enough or hefty enough to write about. And then I definitely never carved out the time to think it through and do it."

Dave mentioned that STA advocacy training initially "helped a lot, you know, like helping me figure out how to write [op-eds]. I felt like the first one or two that I did, they helped a lot" giving him the LPP experience so he could "figure it out and just can do it [on my own]." Little was mentioned in regard to this subcategory from questionnaire data collected during the pandemic as funding priorities shifted. Beth stressed that she had her hands full with other tasks that took priority during the pandemic, "There were so many logistical tasks to complete the last eight weeks so advocacy was not at the forefront." However, one sampled STEM TL mentioned that during the pandemic, moving was needed to ensure that funding for STEM programs would continue. Ben shared that he had been "Fighting to keep as much of our budgets intact as possible. I've been lobbying within my district for funding for STEM, as with COVID causing a drop in [my state's] revenue. Our budget and my program are being slashed."

Discussion

The purpose of this study was to describe STEM TLs' conceptions of STEM advocacy before the onset of COVID-19 and to what extent these conceptions changed during the early months of the pandemic as LPP shifted from largely in-person interactions to solely online. The driving research question for the study was: *How have STEM TLs' conceptions of advocacy and their advocacy activities changed with the onset of COVID-19 interruptions?* To address this research question, we employed a phenomenographical approach, underpinned by the STEMMaTe conceptual framework (Hite & Milbourne, 2018; Hite et al., 2020) of STEM TL in advocacy, with STEM TLs who had participated in an LPP program for STEM education advocacy and have participated in advocacy activities for STEM education. Table 4 correlates our findings to the STEMMaTe conceptual framework. Overall, our study suggests a considerable shift in priorities in STEM TLs' conceptualizations of and activities in advocacy related to the onset educational interruptions caused by the COVID-19 pandemic. Whereas communication was a priority of advocacy before the onset of the pandemic, movement was a dominating theme at the start of the pandemic, affirming prior research that teacher advocates are "often spurred to action after experiencing a crisis" (Bond, 2019, p. 86). We discuss each of the three themes in the outcome space (i.e., identity, communication, and movement) in detail by first presenting implications of STEM TLs' conceptions of STEM education advocacy prior to the pandemic, then provide a discussion regarding the implications of a conceptual shift during the pandemic, framing these discussions within the STEMMaTe conceptual framework. Finally, we conclude with a discussion on limitations and areas for future research.

Table 4

STEM TLs' Conceptions of Advocacy as it Relates to the STEMMaTe Framework

Category	Level of Participation
1. Identity	Scholastic Effectiveness Institutional Knowledge and Memory Adaptability/Flexibility
2. Communication	Emergent Leadership
3. Movement	Strategic Leadership

Reaffirming STEM and Advocate Identity

In the STEMMaTe model, the levels of *scholastic effectiveness*, *institutional knowledge and memory*, and *adaptability and flexibility* are identity-forming areas (Hite & Milbourne, 2018). It was vital for STEM TLs to secure opportunities for LPP (*scholastic effectiveness*) as they navigated changes (*institutional knowledge and memory*) in STEM advocate identity (category 1). This undertaking was evidenced by utterances in the subcategories of self-perceptions and continued PD (*institutional knowledge and memory*). Prior to the pandemic, STEM TLs had sourced their STEM TL advocate identities from their expertise in grade-level STEM content and pedagogy with a heightened interest in publicly promoting STEM. Their desire to provide a more interdisciplinary STEM experience for their students coupled with their understanding of the overall significance of STEM supports findings from literature on STEM teacher identity being the result of the intersection between professional traits and personal beliefs (El Nagdi et al., 2018). This grounding of their STEM teacher identity provides STEM TLs the cognitive foundation to apply their advocacy by assessing their foundational professional expertise, as evidenced in several utterances (Table 3). Furthermore, STEM TLs who had an interest in advocating for STEM education sought additional opportunities for LPP in advocacy, so they could become adaptable and flexible in refining their advocate identity (Servage, 2009).

From LPP sought during the pandemic, STEM TLs learned more about how they could advocate for STEM education effectively and creatively in an online environment, given that most U.S. school districts shifted to online learning. These amplifying experiences suggest a building of advocacy-based self-efficacy, such that positive advocacy experiences led to persistence in advocacy regardless of context (Velasco, 2020) and despite pandemic-facilitated challenges. Recognizing their own obstacles and challenges (professional and/or personal) during the pandemic caused respondents to self-assess how they would continue to advocate for STEM education in an online environment. A tenet of identity formation is that it is dynamic, requiring one to continually evaluate and assess their profession within a given situation (El Nagdi et al., 2018). Given the stress upon teachers due to the pandemic (MacIntyre et al., 2020), it was understandable that some STEM TLs did not resume or adapt their advocacy activities as quickly as others when instruction shifted online. Even so, they did indicate interest (through plans or ideas for advocacy), showcasing their resiliency in adapting and being flexible in the new advocacy landscape.

Communication for STEM Awareness and Network Connections

Before the pandemic, STEM TLs prioritized communication with stakeholders to bring STEM awareness and its importance in education as well as to build and strengthen network connections. This sense of prioritization (*emergent leadership*) is typified by policy messaging and stakeholder engagement, taking on the responsibility to be the voice for STEM students and teachers impacted by these policies. Other studies have supported this notion of teacher advocates being the voice for the voiceless (Burke et al., 2013; Dubetz & de Jong, 2011; Pennington, 2013). To achieve this, STEM TLs conceptualized STEM education advocacy as engaging in discussion with relevant STEM education stakeholders, such as fellow teachers, administrators, district leaders, and parents. Involving education personnel and stakeholders in conversation, conceptions of STEM education become more enlightened and aligned with the needs of the students and the community (Harris & Jones, 2019). As emergent leaders, many STEM TLs emphasized the importance of cultivating positive professional relationships with STEM organizations and policymakers, whether or not they share similar views (Bond, 2019). Diplomatic conversations allow STEM TLs to leverage their experiences and expertise to effectively advocate for STEM education in schools and districts.

An interesting finding from the study was that while communication was conceptualized as a priority in terms of STEM education advocacy, STEM TLs shared little in regard to communication with stakeholders during the pandemic. Still, many expressed the importance of accurate messaging, honing in on the importance of trusted media sources (Donovan, 2020). STEM TLs nonetheless had direct communication with their current networks to discuss strategies on virtual STEM instruction, especially for teachers. In addition to emails and video conferences, social media (specifically Twitter) emerged as an advocacy tactic to communicate information during the rapid transition to virtual learning during the pandemic (Cruickshank & Carley, 2020). STEM TLs described that the hashtag feature in Twitter was ideal to obtain information and attention. Given the ubiquity of Twitter, STEM TLs used tweets to share STEM resources publicly. In essence, while there wasn't as much direct communication between STEM TLs and stakeholders during the pandemic as before, communication technologies and social media afforded a communication space to voice messages indirectly.

Increased Movement in the Time of Crisis

STEM TLs conceptualized STEM education advocacy in terms of movement (*strategic leadership*), in which STEM TLs engage in the most robust advocacy activities and at scale. STEM education advocacy involved training other teachers, both STEM and non-STEM. To achieve their conceptualization, STEM TLs designed and led PD opportunities (LPP) for other teachers by modeling ways to integrate STEM activities into the classroom, providing strategies in closing the equity gap, or training other STEM teachers in advocacy. Fittingly, training other teachers in advocacy work is a signature activity of teacher advocates (Bradley-Levine, 2018; Pennington, 2013; Weiner & Lamb, 2020).

One last and significant finding is how movement was conceptualized by STEM TLs as the greatest priority in advocating for STEM education during the pandemic. A majority of these utterances were specifically in reference to needed changes in STEM curriculum. This finding was especially significant as the pandemic brought about the abrupt shift to virtual learning—a shift for which most educators were not prepared (MacIntyre et al., 2020). While STEM TLs spoke to the notion that they too were unprepared for this shift, they rallied quickly to develop strategies and materials to help students, teachers, and administrators transition to virtual learning. Because of the swiftness of the shift, many of the resources that STEM TLs provided were pulled from various resources from their teaching experiences and networks with other STEM TLs. Yet, because of the limited resources in online STEM instructional delivery, some STEM TLs took the initiative to create and demonstrate how STEM can be delivered in an online setting. Some STEM TLs were moved to write op-eds and letters to policymakers, requesting financial support to make virtual learning possible for all students. These STEM TLs took it upon themselves to advocate on behalf of their schools and/or districts for virtual learning to take place, namely computer devices and widespread internet access. This movement affirms reports on the effectiveness of crafting messages to policymakers to magnify the issue and relay the seriousness (Bond, 2019; Bradley-Levine, 2018). It is indeed possible for STEM TLs to engage in policy by leveraging emails and other tools to craft messages to policymakers to sustain the quality of STEM education throughout the pandemic.

Conclusion

Data from this study revealed significant findings in STEM TLs' conceptualizations of STEM education advocacy related to interruptions in their advocacy activities due to the COVID-19 pandemic. There was a considerable shift in STEM TLs' conceptualizations of advocacy related to a social shift from in-person to online LPP supporting activities caused by the COVID-19 pandemic. Communication was a priority of advocacy activities before the onset of COVID-19, whereas movement emerged as a dominating theme during the pandemic, primarily due to the transition to and domination of virtual social interactions. This shift from voice- to action-oriented advocacy implies a need for STEM TL preparedness in a time of crisis in terms of providing instructional resources and support for students and fellow teachers. From these findings, we recommend that STEM TLs be adequately prepared for engaging with digital technology as a new domain of knowledge, skills and dispositions and provided LPP with experts for adaptability and flexibility per the STEMMaTe model. With targeted and robust LPP, these STEM teacher leaders may engage in advocacy for and activities in assisting STEM teachers for readiness in online instruction and social interactions. We suggest that STEM TLs be provided advocacy-based PD that helps strengthen skills in finding and allocating resources for teachers and students. Although the pandemic is waning, we are confident that LPP experiences and social interaction will be permanently changed (i.e., less reliance on in-person interaction in favor of hybrid experiences or remain online). For example, some practitioner conferences are currently considering hybrid or online-only activities, for the practicality that online PD delivery offers after the pandemic ends. Given that online interaction will likely only scale up, it is important to understand how STEM TLs adapted to and overcame these challenges. Through this exploration of STEM TLs conceptions of STEM education advocacy before and during the pandemic, we have learned that immediate movement is necessary to sustain equitable STEM education for all students in a time of crisis. Vitally important were keeping communication lines open, as well as continual self-assessment of one's STEM advocate identity. STEM TLs are vital in developing online STEM curriculum learning models (Aliyyah et al., 2020), supporting other teachers through STEM materials and/or demonstrations (MacIntyre et al., 2020), and crafting messages to policymakers that communicate school/district needs (Bond, 2019).

Limitations and Recommendations for Future Research

Limitations relate to the change in data collection modality (interviews prior to and questionnaires during the pandemic). Because of the numerous challenges that the participants were juggling during the pandemic, we took steps to ensure that questionnaire data was aligned to the other data set and was a more efficient, and still robust, means to capture participants' thoughts. Second, we purposively selected STEM TLs for this study who received formal training in STEM teacher advocacy and expert advice on how to carry out advocacy practices. Hence, the experiences shared here may not be reflective of all STEM TLs, especially those who have not had formal advocacy training experiences, or even for those who have had similar training in policy-advocacy programs. Thus, further studies are warranted in examining these groups of STEM TLs and their conceptions of STEM education advocacy. Finally, the second data time point was in April 2020, at the beginning of the COVID-19 pandemic; a third data collection is warranted to explore conceptions about how continued pandemic impacts have influenced conceptions of and activities in STEM education advocacy.

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Attracting Underrepresented Pre-College Students to STEM Disciplines

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ABSTRACT

We present our nascent *STEM Access and Training for Underserved Students* (STATUS), a model to attract Latinx students first to attend college and second to enter the STEM fields. The program consists of a series of hands-on investigative activities in physiology, neuroscience, biophysics, genetics, exercise physiology, biomechanics, environmental science, and psychology aimed primarily at instilling students with a sense of belonging and the excitement of discovery. Each two-hour session consisted of a mini-lecture, familiarization with data acquisition systems, the development of a research question and hypothesis, data collection and analysis, and a brief report. Each week students submitted a reflection on the activities and we used these responses to emphasize self-efficacy. One novel aspect of STATUS is the development of *College Knowledge*, a set of conversational sessions with family members to provide information and resources regarding college admissions, financial aid, campus life, academic requirements, career options, and sources of support. Both students and parents provided enthusiastically positive feedback about their experiences; more importantly, all STATUS participants entered college.

Keywords: pre-college, STEM, preparation, support

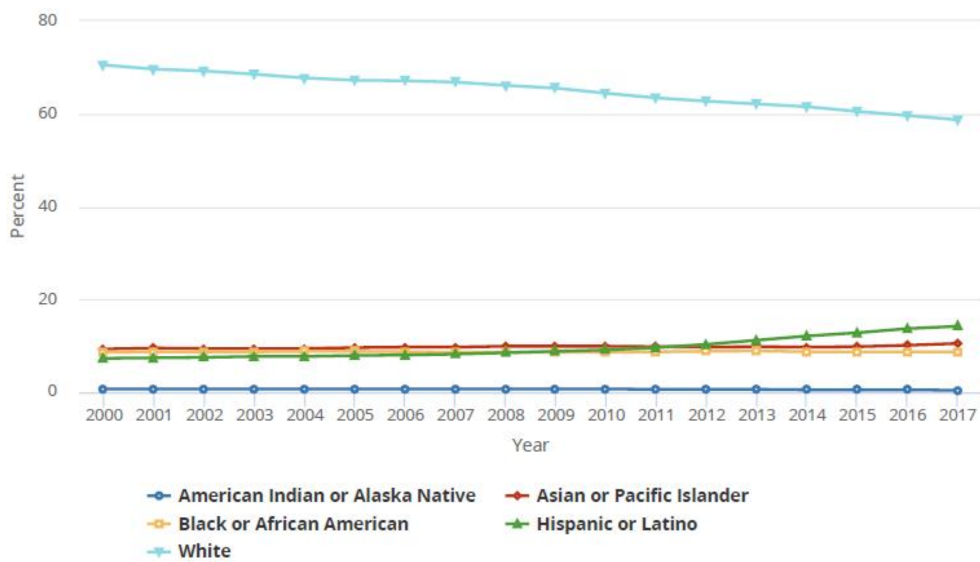
Introduction

There have been numerous efforts dedicated to increasing the number of underrepresented minorities in science, technology, engineering, and mathematics (STEM) fields (i.e., Museus et al., 2011; Contreras, 2011), with emphasis on teacher preparation (i.e., Hayden et al., 2011) or helping aspiring teachers learn about and incorporate culturally relevant experiences in science pedagogy (McCollough, 2020). Others have focused on identifying obstacles to STEM education for underrepresented students through listening to underserved STEM students as to their experiences (i.e., Kricorian et al., 2020), and propose strategies to overcome them (i.e., Flores, 2011). Yet there remains considerable work to be done, particularly in regards to identifying reliable indicators that, once properly mobilized, not only increase enrollment to college, but strengthen persistence of underserved students enrolled in STEM coursework. Further, while much emphasis has been placed on supporting STEM majors in college, less attention is devoted to secondary STEM education. A widely used intervention has involved the development and implementation of pre-college programs designed to engage underserved students early and often; the main idea being that pre-exposure to college-level science content provides a preview of sorts that, in turn, serves to simultaneously de-mystify and encourage students to pursue STEM pathways. However, evidence has shown that often such efforts may produce a somewhat counterintuitive result, inadvertently contributing to a continuing underrepresentation of minority students in STEM fields (data available from National Science Board (2018a).

This, despite the increase in numbers of underrepresented minority students enrolled as full-time undergraduates and the percentage of freshmen declaring their interest in STEM fields; according to the National Science Board (2018b), Science and Engineering Indicators show that in the year 2000, the ratio of white to non-white students (identified as black, Hispanic, Asian or Pacific Islanders, and American Indian or Alaska Native) was 2.70 to 1 (70% white, 25.9% non-white); by 2010 the ratio had decreased to 2.27 to 1 (64.4% white and 28.3% non-white) and by 2018 the ratio was 1.73 to 1 (58.7% white and 33.8% for non-white). See Figure 1 for this information. Furthermore, even though the number of science and engineering degrees awarded each year has been steadily increasing, 398,602 in 2000, 505,435 in 2010, and 684,557 in 2017, (see National Science Board (2019) report Tables S2-6 and S2-7 for the same years 2000 vs. 2017), the percent change for non-white students was minimal (see Figure 2).

Figure 1

Science and Engineering Undergraduate Degrees Awarded from 2000-2017 by Race and Ethnicity

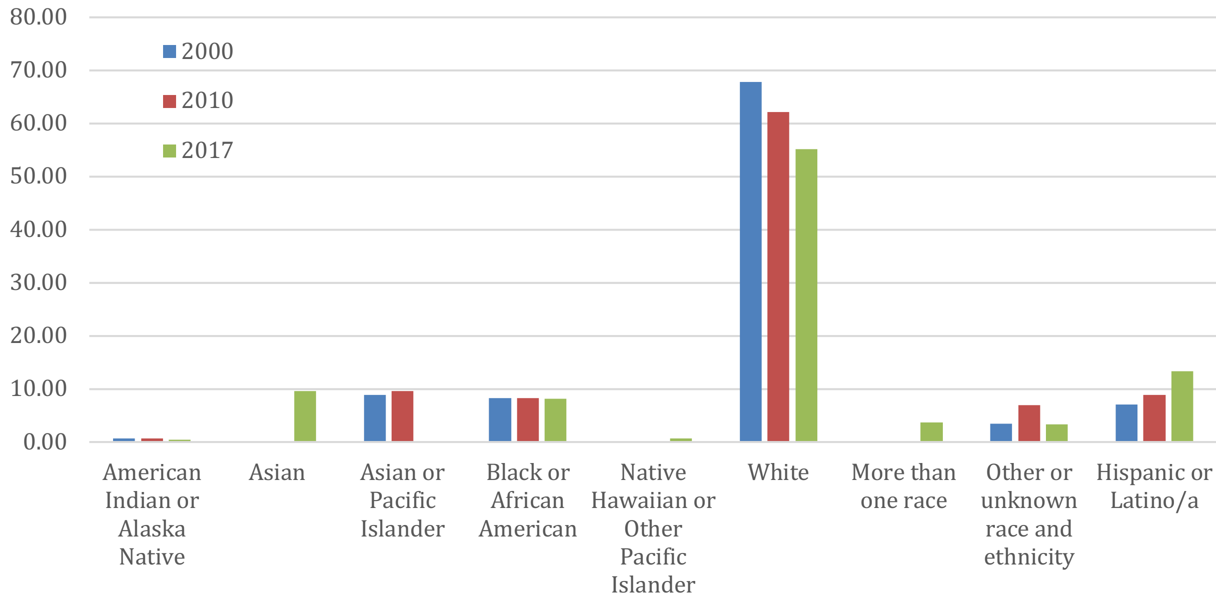


Note: Adapted from National Science Board (2018) report NSB-2019-7.

The percentage of first-year undergraduate students who indicated interest in the STEM fields increased by 9.3% for Asian American/Asian students, 8% for white students, 10.6% for Hispanic/Latinx students, 3.2% for African American/Black students, and decreased slightly by 3.9% for American Indian/Alaska Native students. Yet, according to the same indicators for the same years, no progress was made in increasing the numbers of students who graduated with degrees in STEM areas (Asian Americans/Pacific Islanders increased from 9.3% to 9.8%, African American/Blacks increased from 8.6% to 8.9%, Hispanics/Latinx increased from 7.3% to 11.2%, American Indian/Alaska Natives decreased from 0.7% to 0.6%, and Whites decreased from 70.5% to 62.1%. Summary data is presented in Figure 3. Despite the undeniable progress underrepresented minorities have made in obtaining doctorate degrees over the same period (African American/Blacks: 763 in 2000 and 1434 in 2013; Hispanics/Latinx 735 in 2000 and 1569 in 2013; and American Indian/Alaska Natives: 78 in 2000 and 114 in 2013), these numbers and a multitude of reports bring attention to the needs of our nation in terms of national security, industry, and social programs. At the same time these figures highlight issues such as the recent controversy over high-tech workers and the demand for H1-B visas (e.g., Saltzman et al., 2013).

Figure 2

Science and Engineering Undergraduate Degrees Awarded from 2000-2017 by Race and Ethnicity, as a Percentage of All Science and Engineering Degrees Awarded

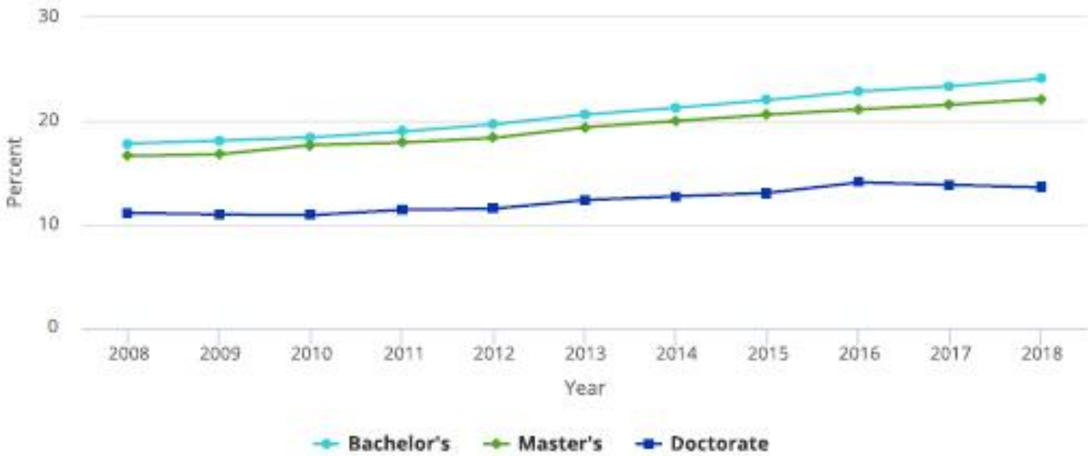


Note: Adapted from National Science Board (2018b) report NSB-2019-7.

A more focused view of this issue reveals further disparities as pertaining to Hispanic/Latinx students. According to the Pew Hispanic Center's 2009 National Survey of Latinos (Pew Research Center, 2013), only 11% of Latinos hold a bachelor's degree or higher, and the reasons for the low enrollment in college are telling: more that 70% need to support their families, and under 50% highlight other reasons (i.e., do not need more education, cannot afford school, do not like school, or limited English ability). The most recent data from the U.S. Census in 2009, for those aged 25 or older, also reflect that reality: Hispanics reported the lowest rates of education of all groups, as only 61% had completed high school or higher, and only 13% had received a bachelor's degree. Thus, the data reflect persistent inequality regarding opportunities to engage in STEM careers for underrepresented minorities, and especially so for Hispanic/Latinx origin (see for example the work of Sylvia Hurtado at the Higher Education Research Institute (HERI) at UCLA, https://heri.ucla.edu/).

Figure 3

Science and Engineering Degrees Earned by Underrepresented Minorities, as a Percentage of Degree Type.



Note: Adapted from National Science Board (2018) report NSF-21321.

Recent data from the National Center for Higher Education Management Systems (2016) reveal that just 20.5% of 9th graders will complete their degree within six years of entering college. These numbers are startlingly lower in our state, Oregon (16.2%). About half of all students who enter college graduate within six years (55.5%), with Oregon just slightly above the national average (56.5%). Alarming as these numbers may be, the data reflect an even more disturbing picture for underserved populations, where the graduation gap between White and Hispanic students is 12-21% (Brownell & Swaner, 2010). Furthermore, first-generation students often self-report as "considerably overwhelmed," and thus are at particular risk of not finishing their college degree; only about 25% nationally succeed in this goal (Chen, 2005). Finally – and directly relevant to the current report – students from underserved populations who complete an undergraduate education tend *not* to pursue degrees in STEM-based fields (Crisp et al., 2009). Several approaches have been introduced to bridge this gap, including better high school science and math instructors, improved facilities, curricula to help alleviate struggles in introductory STEM courses, introductory college science courses with active learning pedagogies, and the development of strategies to attract low-income and underrepresented minorities to college campuses (such as the National Science Foundation's S-STEM program (2002). More direct interventions targeting underserved students' home and community environments as mechanisms for increasing underserved students' likelihood for success in college are relatively recent (i.e., Institute of Medicine, 2011; Rayle & Chung, 2008). Addressing how students can be successful when in college is one thing (see Kezar & Holcombe, 2017a); getting them ready to enter college and face the rigor of introductory science courses is quite another. The challenge is best described by Armstrong and Zaback (2014) in their report to the Appalachian Regional Commission, when they state that 52.7% of Hispanic students and 63.59% of African American students enter remedial courses (as opposed to 49.93% for White students), but only 28% of Hispanic students complete all required remedial courses, as opposed to 31% for African American students, and 52.4% for White students. Similarly, Jimenez et al. (2016) report remedial education enrollment nationally at 56% for Black students, 45% for Latinx students and 35% for White students. The *Condition of STEM 2016* report (ACT, 2016) is promising in that 49% of all tested students are interested in STEM careers, but that only 13% of Hispanic students, 5% of African Americans, and 32% of White students met the ACT STEM readiness benchmark score. Further highlighting the problem of how unprepared students from our own community are to enter college, Jimenez et al. (2016) list Oregon as a solid third highest in percentage of first-time students who enroll in remedial courses as a fraction of total enrollment at 78%, trailing Florida (93%) and Nevada (85%) but well ahead of the next state (New Mexico at 58%). The picture that emerges clearly is that most of these underprepared students are underrepresented minorities and are not ready to face the demands of college, much more the rigors of training in STEM fields. The negative implications for their chances to complete undergraduate studies (or at all) cannot be overstated. These statistics have alarmed educators and administrators at several institutions, who are earnestly developing programs to address this issue of equality in preparedness (e.g., Purdue University, n.d.).

Are there Solutions?

Several initiatives have been launched to address the underrepresentation of minority students in STEM fields, led by Howard Hughes Medical Institute's initiative on Inclusive Excellence in STEM (HHMI, n.d.) Most of these initiatives have focused on retention and STEM careers for undergraduate students. In a recent report, Kezar and Gehrke (2015) call for the development of *Communities of Transformation* designed to provide comprehensive support for all stakeholders involved in STEM education, which also applies to Latinx students. Most of these initiatives are very recent, and little to no data exist regarding their efficacy. When confronted by these facts, so eloquently articulated by David Asai and Cynthia Bauerle (2016), we were compelled to take action at our institution: What could we do in our own community to better prepare Hispanic/Latinx students for a) attending college, and b) entering STEM fields? While these questions have spurred comprehensive (and successful) efforts at several institutions (i.e., Lieberman, 2016), at the time we found it difficult to identify specific institutional initiatives to help Latinx students enter STEM fields in college. Here we describe our initiative, STEM Access and Training for Underserved Students (STATUS), a pilot project guided by the Institute of Medicine (2011) report on *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*, and especially their recommendation regarding Access and Motivation for postsecondary education, which is worthy of including without change: "Improve access to all postsecondary education and technical training and increase underrepresented minority student awareness of and motivation for STEM education and careers through improved information, counseling, and outreach" (p. 11).

In addressing the low subscription among underrepresented minorities in STEM fields - and especially so among Latinx students - we were motivated by one fundamental principle; that all students deserve a space to learn about science and explore their individual interests in STEM fields. Thus, ours is defined as a space for learning, not one defined by the physical boundaries of our campus.

Our review of the available literature revealed several factors that contribute to the low numbers of underrepresented minorities in STEM fields, wonderfully and eloquently summarized in the aforementioned Institute of Medicine (2011) report with gender disparities further highlighted in the report by Simard (2009), and issues specifically affecting Latinx students emphasized by Flores (2011) and others. Clearly the "build it and they will come" approach is inadequate, and a different strategy should be implemented, one premised upon actively reaching out to these students and their families. The Institute of Medicine report (2011) was the platform upon which we built our STATUS program, mainly by focusing on the recommendations we could control (i.e., develop summer programs in mathematics, science, and engineering that include or target underrepresented minority high school students, p. 178) and not on factors beyond the scope of this project (i.e., recruitment, preparation, and professional development of well-qualified elementary and secondary education teachers, p. 176). Yet, we encountered a paucity of data on how best to address the factors that contribute to the development of a supportive environment for pre-college students from underrepresented minorities. For example, recent evidence regarding positive outcomes associated with incorporation of science activities with parents (i.e., DeLeon & Westerlund, 2021) was not available when the project was initiated. While not the only factor driving student success, lack of familial support among underserved students has been identified as contributing to decreases in individual motivation and academic performance and poorer retention rates (e.g., Dennis et al., 2005), with many researchers recommending that efforts to better engage these students must first attempt to meet them where they are at, by actively cultivating buy-in from family members, themselves best situated to provide daily support and encouragement (see also Garriott et al., 2014). Since we could not find a specific set of ideas or practices shown to contribute to this goal, we developed a series of topics to be discussed with the parents, and this is our *College Knowledge* program, which we developed to help disarm anxieties among parents of first generation students.

How was STATUS Structured?

We adopted an evidence-based approach to shaping every aspect of our program. Our response to the national call to engage underserved students expressing interest in STEM fields was the creation of a sustainable and easy to implement model program to attract *pre-college,* underrepresented students to STEM fields by creating a more personalized path from high school to college. As Graham et al. (2013) pointed out, the need to cultivate the students' sense of confidence and motivation early in their academic career is paramount if they are to succeed in their efforts at STEM education. Thus, our first objective was that students must feel that they belong in a college setting and that attending college is something they can and should achieve. The second objective was to expose them to student-centered investigative laboratory experiences in STEM fields and impress upon them their capacity for accomplishing college-level science work of high quality.

Supporting Mechanisms

It was clear from the beginning that a successful effort would require resources, though not necessarily extensive ones. On the institutional side, we recruited Latinx undergraduate students who were available to participate in this program to accomplish three main goals: first, they served as mentors and role models to the high school students; they had common experiences and they could communicate in meaningful and authentic ways. Second, they served as tutors during the laboratory activities; that way they served as guides to discovery, not only by their presence, but also through their skills and knowledge. Finally, they served as translators, facilitating in-depth discussions during our semi-structured informational sessions with the parents while the students conducted their experiments.

Recruitment of Pre-College Students

One of the most important elements of STATUS was that students and their families felt welcome to our campus. Every aspect of the process had to be authentic and sincere; after all, providing authentic college-level laboratory experiences in science was the chosen way to enhance the students' confidence and sense of belonging. Our nascent effort required beyond-campus thinking on the part of the authors, especially given the dearth of institutional outreach efforts to underserved high school students interested in the sciences. Following a series of planning meetings with officials from the local school district, we received permission to contact the high schools in our area to recruit qualified and interested underrepresented students for this work.

As far as we were concerned, this was the most important aspect of the entire project. It became very evident that our success was predicated on creating connections with existing mechanisms that support these students to enter college in the first place, and we had to incorporate mechanisms that allowed us to come alongside these students and their families. The school district has created special positions for Community Science Outreach Coordinators (CSOCs), who serve as liaisons between teachers, students and their families, and outreach opportunities for students (i.e., internships). The CSOCs also hail from underserved backgrounds and are committed to helping *all* students succeed in school. Their multiple connections to the local community provide them with instant credibility with students and their families. The critical role school counselors play in underrepresented students entering and succeeding in college has been documented elsewhere (i.e., Cholewa et al., 2018). During our meetings with the CSOCs from each of the local high schools, we received enthusiastic support and helpful suggestions that shaped our program. More importantly, we received their endorsement for this work, and they took it upon themselves to identify students who should participate in STATUS; these students had expressed interest in science and most were interested in attending college, although none had any information about options for post-secondary education. We selected second- and third-year high school students (rising juniors and seniors), with an eye towards their remaining high school education serving as a stepping stone for college admission. We generated informational material in two languages (English and Spanish), and the CSOCs distributed them to the students. Within a short time (less than two weeks) we had reached the maximum number of students (twenty) our program could accommodate, since laboratory space is limited. Two more students were added as younger siblings of students initially selected (one rising junior and one rising sophomore) for a total of N=14 female students and N=8 male student participants. In addition, the CSOCs volunteered to serve as interpreters for our introductory gathering with students and their families. Following suggested best practices, we planned this meeting as an informal greeting session accompanied by food for all students and their families, with a menu recommended by the CSOCs. At this informal gathering, we were careful to introduce ourselves on a first name basis, always with a native speaker at our side, as we explained the objectives and design of STATUS. We answered questions and worked with the families on scheduling of events, parking passes for those who drove, vouchers for those who relied upon public transportation, and directions to the various buildings on campus where the activities would be held each week. We were careful to schedule all meetings during the late afternoon hours when the parents would be done with work and had adequate time to visit the campus. We encouraged both parents to attend and bring along any siblings. Each week we provided ample snacks for all (fresh fruits, juice, and cookies) and access to nearby computers (under supervision) to help younger children remain happy and engaged, freeing their guardians to participate in the parent informational sessions.

STEM Curriculum

We developed partnerships with faculty from diverse STEM fields (Psychology, Genetics, Biophysics, Exercise and Health Science, Neuroscience) who created a series of interdisciplinary, STEM-related modules designed to make science approachable, enjoyable, and interesting to these students. Since STATUS was intended as an incubator for students to pursue STEM disciplines in college, the emphasis on teamwork, the appreciation of the importance of the practical skills gained, and the realization of their potential for a successful college career are among the crucial outcomes for this group of pre-college students. We note that, in our approach, these disciplinary activities were considered little more than a tool for reaching these young people, aiming to offer a variety of experiences and opportunities for hands-on learning.

In our STATUS model, underrepresented students attended a series of investigative laboratory workshops once per week for at least six weeks throughout the early summer (immediately after the end of the school year), designed to expose them to theoretical and methodological questions in each STEM area. Each STEM module also included training in the use of data acquisition systems, and education on topics such as experimental design, data collection and analysis, and presentation of results. Each module was taught in English by a faculty member actively engaged in research on the topic, and students were provided with guided activities to answer their "research" question. Every week students were introduced to a lesson plan that included a brief theoretical justification, description of procedures, and a brief assessment designed to help students reflect on what and how they learned. See Table 1 for details on this and other interdisciplinary, STEM-related modules.

The grip strength experiment was the first in the sequence, and students were asked to consider a relatively accessible question: whether their dominant hand was stronger than their non-dominant hand. They were encouraged to offer an initial response, and the dominant hand was invariably considered to be stronger. When asked to explain why they think this is the case, students usually cited evidence that they use the dominant hand to write, hold a utensil while eating, or in handling their cell phone. The instructor then challenged the students with an analogy to help them consider these responses: would mere walking make one a better runner? The obvious negative answer to that question helped students consider whether the stimuli they described were sufficient to cause the dominant hand to become stronger or just more agile. This served as a reminder that in science, obvious answers are not always accepted as correct until they are supported by data/evidence. Students were then asked to think of ways to actually test whether one hand is stronger than the other, and they offered ideas such as bench pressing, or lifting weights with one hand or the other, or whether batting a ball with one hand or the other is evidence of greater strength, ideas that were praised by the instructor as excellent starting points for inquiry. Soon however, the students identified that such approaches did not actually answer the research question: which *hand* was stronger? They were encouraged to use lab computers and identify examples of hand strength measurement and quickly settled on a grip strength test as the preferred experimental technique. The instructor then guided student thinking towards articulation of a formal research question (*Which hand is stronger?*) and a testable research hypothesis (*The dominant hand is stronger than the non-dominant hand*) on the whiteboard agreed upon by the students prior to data collection.

The instructor guided the students through a grip strength data collection and analysis session using the Biopac™ data collection systems, simultaneously emphasizing that these are the same systems used by college students enrolled in Human Physiology courses. The instructor placed particular emphasis on proper experimental protocols and avoiding data collection errors (e.g., students laughing or looking at the screen during the experiment, since such actions could alter the results). Students then calculated grip strength and wrote the results for the dominant and non-dominant hand side by side on the whiteboard. A simple review (no statistical analyses used in this module) revealed that not all participants exhibited greater strength using their non-dominant hand, thus the research hypothesis had to be rejected. Having gained a basic understanding of the data collection and analysis process, students were encouraged to work in groups and design experiments of their own using the Biopac™ devices; some examples include testing strength using the thumb opposed by each finger (one at a time), muscle fatigue by exerting maximal strength until force declined by approximately 50%, and whether keeping an arm extended or bent at the elbow makes a difference in maximal force exerted. The next step in this activity was that each group gave brief informal presentations/demonstrations to the others, and answered questions about their research question and the methodology or their findings. Finally, they invited their parents to become participants in their experiment and share the experience.

Table 1

Science Modules Developed by College Faculty.

Lab Title	Description
Grip Strength	Students learned about the use of data collection instruments to answer research questions (i.e. differences in maximum grip strength between the dominant and non-dominant hand); they are also exposed to the fundamentals of scientific hypothesis testing and the role of statistics.
Earthworm nerve conduction	This lab focused on the study of action potentials as drivers of all thought and movement. This activity placed emphasis on experimental setup and potential for errors in measurement.
Balance	A comparison between different instruments that measure the same variable (balance) provided an opportunity for students to understand the concepts of reliability, validity, and accuracy in measurement. Students also considered the application of such tests for people with mobility difficulties or the aging population.
The teenage brain	In this module, instructors introduced the idea of the teenage brain, focusing on risky behavior and driving. Students had a hands-on opportunity to engage with a research study on peer influences on teenage risk taking and discuss the findings and implications of research in this area.
Blood pressure and ECG	In addition to performing these measurements in the lab, students used the blood pressure cuffs at home to practice on relatives and friends at different times of the day. The importance of these simple measurements for health and disease was also discussed from an epidemiological perspective.
Sheep brain dissection	Students used a sheep brain dissection as an entry point for discussing neural changes during development, with an emphasis on asynchronous brain development during the teenage years, which can help explain risky behavior during adolescence. Students had a hands-on opportunity to dissect a sheep brain to introduce basic brain anatomy. Students then learned about non-invasive neuroimaging methods and discussed the findings from neuroimaging research on the teen brain.
Lie detector testing	A more playful activity where students designed a set of questions for a lie detector test using research-grade data collection systems. The emphasis was on identifying events through multiple physiological variables to identify truthfulness of responses. The potential for error and applicability (i.e., in a court of law) were discussed.
Microscope construction	Students examined the structure/function relationship of items they collected around campus using an inexpensive portable microscope (https://www.foldscope.com/) and taking pictures using their cell phones. The emphasis is on the physics of optics and the engineering aspects of the microscope along with generating excitement for students to collect and analyze their own samples.
Vision	This lab helps students understand the structure and function of the eye and the neural processes involved in vision. Cow eye dissections and a series of visual tests helped students understand this sensory mechanism and identify how problems with vision can be corrected.

Note: Each student participated in at least six activities, each designed with a set of specific science objectives in mind. All lesson plans were designed for novice student participants.

All STATUS modules followed a similar pattern of first establishing a basic theoretical framework and relevance for the work, followed by hands-on activities, and critical evaluation of evidence, all the while providing students with the freedom to experiment on their own and gain the confidence needed to consider a STEM education in college.

College Knowledge: Parent Information Sessions

Our review of the literature helped us realize very quickly that in this population of underserved students, critical decisions such as attending college are made by the entire family in ways that consider the best interests of the entire family. Accordingly, if we were to succeed in this effort of encouraging students to a) enter college, and b) enter STEM fields while in college, it was imperative that we also involve the students' families. That way they too could join any session if they wanted, contribute to the work of these students, and encourage them in their efforts. In the absence of a set of best practices to follow, we were guided by our desire to provide support for parents so they could navigate the college landscape: how could they help select the right school for their student, apply for admission, enroll in classes, examine financial aid models, negotiate housing options, and navigate academic advising and resources, campus life, extracurricular activities, and so on. According to a report by the Get Schooled Foundation (2013), these topics represent uncharted territory for many parents of first generation students, especially those from underserved populations. Several resources (e.g., Ajinkya et al., 2016.; Berumen et al., 2015) helped shape the information and material we provided to the parents.

In planning this comprehensive set of informal information sessions with parents (with the help of current students who were native speakers that relayed their own experiences) we aimed to help the parents become more knowledgeable, and thus more effective, in their support of their student. As Dennis et al. (2005) demonstrated, this support is of paramount significance, as lack of family support negatively affected college outcomes such as GPA, adjustment and commitment, even if family expectations were not valued as significant in a population of Latinx students. The study provided evidence of the important role families play in helping prospective students develop intrinsic motivation for attending and succeeding in college. While studies have highlighted the important role integration and a sense of belonging play in the success of underrepresented students in college (i.e., Wadenya & Lopez, 2008), little evidence exists regarding the steps a family can take to prepare their college-bound student. We prepared for the *College Knowledge* work by relying on material and ideas from the earlier contribution by Tierney and Auerbach (2004), and the suggestions by Moore (2006), as positive steps towards a successful strategy to recruit students from underserved populations.

Project Assessment

Best practices in science pedagogy require comprehensive, IRB-approved assessment plans; for this project we used a mixed-methods design. We developed a series of surveys for students: 1) focusing on metacognition, after each of the modules we asked them to reflect on the main ideas and methods used, and to draw reasonable conclusions from the data they collected. These reflections helped students internalize the specific learning objectives and guided faculty to refine their lesson plans for future iterations of the program. 2) Before and after the sequence of lessons, we administered a self-efficacy survey to gauge gain in students' confidence in engaging with science work. This survey employed a 5-point Likert scale (1: Not at all confident, 5: Totally confident) and was adapted from the biology self-efficacy scale developed by Baldwin et al. (1999). 3) At the end of the period we asked students to submit (anonymously if they chose to do so) a one-page reflection on their experience participating in the STATUS program. We used these comments in a qualitative analysis of student attitudes about STATUS. We emphasize here that while these data are not offered as evidence of comprehensive evaluation of the goals we established for our program, they proved beneficial to helping us frame suggestions for future adaptations of STATUS for use by others.

Outcomes

In terms of participation and interest, the STATUS program was a success. For our pilot effort we recruited 20 students and added two more at the request of family members. These students attended all weekly sessions, although regretfully only 15 students were able to participate in the last meeting, where the students and their families attended a BBQ where we celebrated their accomplishments with a certificate and the awarding of an iPad tablet to one student via random drawing.

At the end of the program we evaluated the success of the first goal of STATUS (students must feel that they belong in a college setting and that attending college is something they can and should achieve) by asking students to comment on their views regarding the program in a personal reflection, a format they were familiar with through their weekly work. Student responses to this reflection were very complimentary and can be grouped in four general categories:

A. Students gained enjoyment from their participation in this program
   - "I learned so much and I'm glad I was part of this amazing learning opportunity."
   - "Being able to participate in STATUS was an amazing experience."
   - "At the end of the day I am glad I was able to be part of this program and I really enjoyed every piece of it."
   - "I was surprised that I really got in to this. I am thankful to be in that class of science."
   - "This experience made me a better person and have a better thought about science and I really hope I get to experience this again sometime."
   - "My overall experience with STATUS has been great. I was able to learn new things and also things that would be of benefit for me later on in my future."

B. The program offered opportunities for training and careers in STEM
   - "Every class created an even bigger desire for me to work in the medical/health field."
   - "This program helped me confirm that I do want to be in the health field."
   - "I learned a lot and made me more interested in science. I would like to have science as an elective in high school now because of this… This science program helped my interest in science a lot."
   - "Being in the STATUS program made me realize that there are some careers that could be really fun, for example when we had the blood pressure activity… the students were able to experience what a nurse or any medical field requires."
   - "My overall experience during the program excited me to continue following my dream in getting in the medical field."
   - "it was very interesting being able to contribute in experiments that were able to show us what the type of things you do when [sic] your in a science/health career."
   - "Participating in the STATUS session helped me realize how much I am interested in entering into a career that involves science."

C. Students enjoyed specific lessons
   - "I mostly enjoyed the class session on blood pressure, considering the fact that I want to study to be a cardiac sonographer…"
   - "My favorite lab was brain dissection…"

- "In my opinion I find the function of the eye really interesting and would like to learn about it more."
- "Being able to learn how to take blood [sic] preasure was really interesting…"
- 'My favorite activity during the program was dissecting the sheep brain. It was cool how we were able to see how a brain functions and name the different parts of the brain."

D. Students experience science teaching in a college environment
  - "Having those lessons was very helpful because it gave me an idea of how lectures are in college and it prepared us for the future."
  - "My participation in the STATUS program has been very beneficial to my long-term plans in terms of attending a college or university."
  - "I find it extremely grateful that professors from Willamette took time to teach us different areas in science. Thank you all so much for your time!"
  - "This benefits me/will benefit me in the future because I wanted to learn more about [sic] spychology, and with the last lab I have learned that [sic] spychology isn't really my thing, although everything was interesting and fun."

Such comments reveal the students' appreciation for having this opportunity and that they are making meaningful connections between the STATUS activities and future aspirations.

For the second goal of STATUS (impress on students that they are capable of accomplishing college-level science work of high quality) we assessed the success of our pilot project using a pre/post self-efficacy survey which the students completed anonymously using a unique alphanumeric code for matching. The results of the analysis are presented in Table 2.

These data are presented not as unequivocal proof of the success of STATUS, but as cautious evidence that students' STEM self-efficacy increased over the course of this summer science program. Taken together, the student responses indicate appreciation for the opportunity to participate in a college-level STEM experience, and confidence in their ability to succeed in a STEM field in the future. The parents of the students were very complimentary of the informational sessions we provided, especially the discussions regarding the admission and financial aid procedures, and campus life opportunities. Their responses to a separate qualitative survey indicate their appreciation for their children having the opportunity to visit the university and engage in college-level laboratory activities. Above all, they expressed their strong commitment to supporting their children entering college and following STEM careers; of particular interest was their conviction that their children would enter STEM fields with their compass pointing towards ways to benefit others. We are pleased to report that all the students in our project have entered college and are pursuing STEM fields of study.

Conclusion

Our response to the national call for increased participation of underrepresented minorities in STEM fields was the creation of STATUS, a summer program with hands-on, authentic laboratory experiences in a variety of scientific fields. We present our STATUS model in hopes that others will identify the same need and potential for creating opportunities for underrepresented students to engage in STEM fields. Our nascent, bottom-up approach was founded on a spirit of inclusivity and every aspect of this work benefited from the available literature. The lab curriculum reflected college-level activities and learning objectives; as Jimenez et al. (2016) recommended, setting high expectations and helping students meet that standard is essential for their success in post-secondary education. The success of this undertaking mirrors outcomes reported by the University of Massachusetts Donahue Institute (2011) report and others (see examples at https://www.edexcelencia.org/programs-latino-student-success), and strategies employed by other successful programs (see Foltz et al., 2014). It was imperative that students experienced science in a college setting; only then would they have an increased sense of belonging in a college science field. In providing active learning opportunities we followed current standards in science education (e.g., Wieman, 2007); our approach was recently found to be especially beneficial at closing the STEM achievement gap for students from underrepresented minorities (Theobalt et al., 2020).

The success of STATUS cannot be attributed to any single factor of the program; by employing the framework model described by Dennis et al. (2005), we offered a comprehensive approach to introduce students from underrepresented populations to a college-level STEM environment. Our findings support the recommendations put forth by Kezar and Holcombe (2017b) and reflect the holistic model described by Moore (2006) regarding male African American students' persistence in engineering, namely the important role played by parents, teachers, and school counselors (Lichtenberger & George-Jackson, 2013).

This project was transformative for the instructors who had to adjust lesson plans and tailor them for the high school students. College faculty had to use appropriate language, customize the work to match the students' skill level, and learning objectives had to be reasonable and reachable. We benefited from our interactions with the students and their families who appreciated our genuine interest and care, which was also highlighted through our interactions with the CSOCs prior to the start of the program. Our willingness to listen and accept the CSOCs' suggestions, down to the menu for the initial informational meeting was a catalyst for open discussions with parents during the *College Knowledge* sessions. It is thanks to their advice that we planned to provide snacks for the whole family and child care during the sessions, so the entire family could attend. For anyone who plans such science outreach activities with Hispanic/Latinx students in the future, we strongly recommend developing a welcoming environment for the entire family; the setup allowed parents to observe their children engaging in scientific investigations and allowed the students to share their excitement with their parents. As discussed earlier, this is a central element of the social support necessary for the success of these students in college. Finally, the high school students really appreciated the presence of college students who served as mentors and role models; they answered questions, offered advice and encouragement, and served as ambassadors for the institution to this group of participants and their families. The modest stipend we could offer did not adequately reflect their enthusiasm, positive attitude, and many contributions to the success of STATUS.

We note that this effort was successful, despite such outreach efforts not being part of our institution's mission statement or our strategic vision, thus limiting institutional support. We are exploring ways to expand STATUS within our institution and our community first in line with the recommendations put forth by Holcombe and Kezar (2019), recommendations for institutional changes and further research by Crisp and Nora (2012), among others, and resources such as those available by the Center for Urban Education (2016; see https://cue.usc.edu/tools/stem/). Finally, we stand prepared to provide support (material, laboratory activities, and assessments) to anyone who plans to initiate a pre-college STEM outreach program.

Table 2

Student Responses to the Self-Efficacy Questionnaire

Question STEM: How confident are you that…	PRE M±SD	POST M±SD	t-value * (p<0.05) ** (p<0.01)
after reading an article about a science experiment, you could write a summary of its main points?	3.07±0.88	3.93±0.70	**
you could evaluate a science class lab report written by another student?	2.93±1.28	4.00±0.65	**
you could write an introduction to a science class lab report?	2.80±0.67	4.07±0.70	**
after reading an article about a science experiment, you could explain its main ideas to another person?	3.13±1.06	4.13±0.74	**
you could read the procedures for an experiment and feel sure about conducting the experiment on your own?	3.53±0.74	4.07±0.59	**
you could write the method section of a science class lab report (i.e., describe the experimental procedures)?	3.20±0.94	3.93±0.59	**
after watching a television documentary dealing with some aspect of science, you could write a summary of its main points?	3.60±0.73	4.00±0.75	0.069
you can be successful in a science course?	3.87±0.91	4.47±0.74	*
you could write up the results to a science class lab report?	3.33±0.97	4.13±0.74	**
after watching a television documentary dealing with some aspect of science, you could explain its main ideas to another person?	3.33±1.11	4.27±0.79	**
you will be successful in a science course?	3.60±0.91	4.40±0.82	*
you could write the conclusion to a science class lab report?	3.20±0.67	4.27±0.59	**
after listening to a public lecture regarding some science topic, you could write a summary of its main points?	2.93±0.70	4.00±0.65	**
you would be successful in a college biology course?	3.13±0.83	4.40±0.63	**
you could analyze a set of data (i.e., look at the relationships between variables)?	3.33±0.61	4.07±0.59	**
after listening to a public lecture regarding some science topic, you could explain its main ideas to another person?	2.87±0.91	4.40±0.73	**
you would be successful in a college chemistry course?	2.87±0.83	4.13±0.35	**
you could tutor another student on how to write a lab report?	2.33±0.97	3.73±0.59	**
you could critique an experiment described in a science textbook (i.e., list the strengths and weaknesses)?	2.93±0.88	3.87±0.99	*
you could tutor another student in a science course?	2.40±0.98	3.87±0.91	**
you could ask a meaningful question that could be answered experimentally?	2.87±0.83	4.27±0.70	**
you could explain something that you learned in this program to another person?	3.80±0.94	4.73±0.59	**
you could use a scientific approach to solve a problem at home?	3.00±0.75	4.53±0.74	**

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