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IN SCIENCE & MATHEMATICS EDUCATION
VOL. 26, NO. 4, i-vi

Lessons Learned: Reflecting on Our First Three Years as Editors of *EJRSME*

Mark A. Bloom
Dallas Baptist University

Sarah Quebec Fuentes
Texas Christian University

Three years have passed since we assumed the role of Editors for the *Electronic Journal for Research in Science & Mathematics Education* (*EJRSME*). Seeing as we are now publishing our twelfth issue, we want to take a moment to look back on where we came from, what we have accomplished in the last three years, and what lessons we have learned about the world of publishing an academic journal.

A Brief History of *EJSE* and *EJRSME*

The first issue of the *Electronic Journal of Science Education* (*EJSE*) was published in 1996 and, in so doing, claimed the title of the first ever journal of science education research published entirely electronically. In addition, *EJSE* was also open access and free for authors and readers. Because of the online nature of the journal, it welcomed hyperlinks to databases, photographs, videos, and other media as well. *EJSE* was the brainchild of Dr. John Cannon who published *EJSE* with the help of Dr. David Crowther (both from the University of Nevada at Reno) from 1996 to 2007.

In 2007, Dr. Michael Kamen of Southwestern University assumed editorship. During this time, with the help of Associate Editor Dr. Molly Weinburgh of Texas Christian University, Dr Kamen made a concerted effort to increase contributions from international science education colleagues. Indeed, the last analysis of *EJSE* downloads (conducted in 2013) revealed that over a 32-month period, the journal received on average 2,185 site visits per month, from 179 countries. Over half of the site visits were from outside the U.S.

In 2011, Dr. Weinburgh took over the editorship of *EJSE*. During this time, *EJSE* was indexed in the Directory of Open Access Journals (DOAJ) as well as EBSCO and later, in 2017, *EJSE* was added to the ERIC database. In 2019, Dr. Weinburgh and Dr. Kamen proposed the idea of *EJSE* becoming the flagship journal of the International Consortium for Research in Science & Mathematics Education (ICRSME) and that we assume the editorship. After serious consideration, we agreed and, the rest, as they say, is history.

Changes to *EJSE* Since Assuming Editorship

The first change that occurred upon transitioning into the editorship was a change in journal scope and title. *EJSE* is now the *Electronic Journal for Research in Science & Mathematics Education* (EJRSME) to match the mission and goals of ICRSME. The scope of the journal expanded to include mathematics and mathematics education articles alongside the corresponding science-focused articles. As we were in the midst of rebranding ICRSME, the journal appearance was impacted. Figure 1 shows the change in cover from *EJSE* to *EJRSME*. The new cover was designed by Dr. Dusty Crocker at Texas Christian University.

In addition to the new look of the journal, we also decided to publish four issues of *EJRSME* each year (spring, summer, fall, and winter) for consistency. Two of the issues have been special issues. The first special issue was published in Fall 2020 and focused on how science and mathematics educators shifted their teaching to adjust to restrictions in place due to the COVID-19 pandemic. While many journals have published articles describing such pedagogical shifts, *EJRSME* acted quite nimbly and had the special issue out by the first week in October, just several months after schools went fully remote in the U.S. Interestingly, this special issue includes some of the most accessed and cited articles in our three-year term. Our second special issue focused on the Sinai and Synapses Fellowship, in which Mark participated. This issue described numerous ways that science educators (formal and informal) addressed the intersection of science and religion and how they endeavored to elevate the discourse between scientifically and religiously minded individuals. We will soon be publishing our third special issue on Critical Rhetorics in Science and Mathematics Education.

Figure 1

EJSE Cover (2019) and EJRSME Cover (2020)

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Through these experiences over the past three years, we have learned a great deal about the world of academic publishing. Once we saw all of the steps of the publication process from the vantage point of Editors, we fully understood why it can seem to take so much time. More importantly, we realized just how many people were involved - people who generously give of their time and expertise in the mission of advancing scholarship in science and mathematics education research and in helping each and every one of us in our own mission of academic advancement, tenure, or promotion. In other words, the *we* in the opening paragraph represents a community of volunteers contributing to the various phases in the publication of an issue.

Publication Process

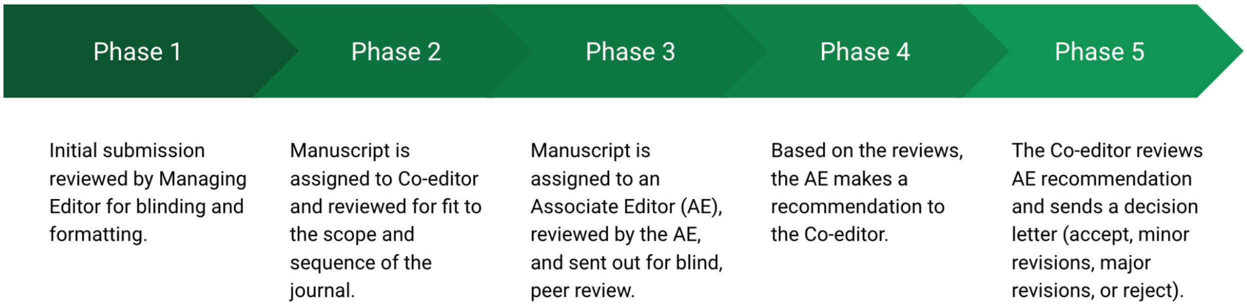
The publication process from initial submission through final decision and publication if a manuscript is accepted involves multiple phases (Figure 2). In the first phase, the Managing Editor of the journal reviews the newly submitted manuscript for blinding and formatting. If the manuscript needs to be blinded further or formatted to meet the journal guidelines, it is returned to the author(s) for these initial revisions. When the manuscript is fully blinded and appropriately formatted, the Managing Editor assigns the manuscript to one of the Co-editors. In Phase 2, the Co-editor reviews the manuscript for fit to the scope and sequence of the journal:

> *EJRSME* publishes manuscripts relating to issues in science/mathematics education and science/mathematics teacher education from early childhood through the university level including informal science and environmental education. *EJRSME* reviews original science and mathematics education manuscripts that report meaningful research, present research methodology, develop theory, and explore new perspectives and teaching strategies.

If the manuscript falls within the scope of the journal with respect to both substance and structure, the Co-editor assigns the manuscript to an Associate Editor (AE).

Figure 2

First Five Phases of the Publication Process



Initial submission reviewed by Managing Editor for blinding and formatting.

Manuscript is assigned to Co-editor and reviewed for fit to the scope and sequence of the journal.

Manuscript is assigned to an Associate Editor (AE), reviewed by the AE, and sent out for blind, peer review.

Based on the reviews, the AE makes a recommendation to the Co-editor.

The Co-editor reviews AE recommendation and sends a decision letter (accept, minor revisions, major revisions, or reject).

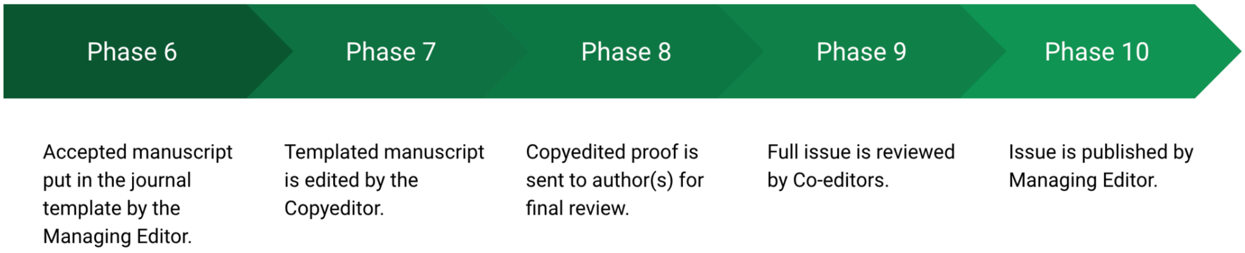
The peer-review process is initiated in Phase 3. The AE reviews the manuscript and then sends it out for blind, peer review to two reviewers. The AE may need to send out multiple invitations to secure two reviewers for a manuscript. Phase 4 commences when all of the reviews are submitted. The AE examines the reviewers' feedback and makes a recommendation to the Co-editor, synthesizing the assessment of the manuscript. In Phase 5, the Co-editor sends a decision letter based on the AE recommendation and reviews. The four possible decisions are:

- The manuscript is rejected.
- The manuscript requires major revisions. When the manuscript is resubmitted, it returns to Phase 3. If possible, the manuscript is sent out to the reviewers assigned to the original manuscript.
- The manuscript requires minor revisions. When the manuscript is resubmitted, it returns to Phase 4 and is reviewed by the AE.
- The manuscript is accepted.

When a manuscript is accepted, it proceeds to the copyediting stage (Figure 3).

Figure 3

Five Phases of Copyediting Stage



The Managing Editor moves each accepted manuscript through the copyediting stage. First, the Managing Editor formats the article in the journal template (Phase 6) and sends the templated manuscript to the Copyeditor. In Phase 7, the Copyeditor completes a thorough edit of the manuscript with respect to grammar, general formatting, and alignment with APA 7. The copyedited proof is then sent to the author(s) for review (Phase 8); the full issue is also reviewed by the Co-editors (Phase 9). Finally, in Phase 10, the Managing Editor uploads the issue for publication.

Valuing Volunteers

Volunteers are involved at every phase of the publication process, including the Co-editors, AEs, reviewers, and Copyeditor. In other words, the journal would not function without the dedicated service of its volunteers. Further, since COVID-19, journals are experiencing challenges in securing peer reviewers for articles, which has resulted in delays in the publication process (Flaherty, 2022). We would, therefore, like to express our gratitude to all of the volunteers, who have helped *EJRSME* thrive over the past three years. Thank you all for your service.

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Reference

Flaherty, C. (2022, June 13). The peer-review crisis. *Inside Higher Ed.* https://www.insidehighered.com/news/2022/06/13/peer-review-crisis-creates-problems-journals-and-scholars

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Nature of Science Understandings and Instructional Perceptions: Moroccan Preservice Primary Science Teacher Educators' Responding Variables to a Professional Development Series

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ABSTRACT

The study explored science and science education professors' nature of science (NOS) understandings and perceptions on NOS instruction before (T1), during (T2), and after (T3) a professional development (PD) series. Using repeated measures design, findings showed an increasing trend across NOS aspects. Summary scores were used to classify participants' NOS views as *alternative*, *transitional*, or *informed*. From T1 to T3, participants (n=19) shifted from *alternative* (16%) and *transitional* (84%), to *transitional* (100%) at T2, and ended as *transitional* (53%)/*informed* (47%). There were particularly significant changes in participants' understanding of observations and inferences and the sociocultural influence on the enterprise of science. The findings did not reveal significant changes in participants' perceptions on NOS instruction. On reflective responses, however, a majority expressed a desire to learn about more NOS activities that can be used in their instruction. The study provides evidence that relatively short PDs, when implemented with explicit NOS activities, have potential to positively impact NOS understanding. While less impactful on participants' NOS instructional perceptions, it is encouraging that the majority of the participants indicated a desire to learn strategies to teach NOS. More research can help improve the efficacy of PD methods and help identify key constructs that are most relevant for perceptions of NOS instruction.

Keywords: nature of science, professional development, teacher education, preservice teachers

Introduction

Understanding the nature of science (NOS)—what science is and how scientists work—is considered an important part of science literacy in the United States (Lederman et al., 2014; McComas & Clough, 2020) and has been a fundamental, enduring goal for important reform efforts in science education worldwide (Abd-El-Khalick, 2013; Kampourakis, 2016; Lederman & Lederman, 2019). Yet, research shows that most teachers around the world have limited understanding of NOS (Capps & Crawford, 2013). Research also shows that even when teachers understand NOS, they often struggle to teach it (McComas et al., 2020; Lederman & Lederman, 2014; Wahbeh & Abd-El-Khalick, 2014).

While many NOS studies examined teachers' NOS conceptions (e.g. Abd-El-Khalick & Lederman, 2000; Brickhouse, 1990; Cofré et al., 2019; Lederman, 1992, 1999; Kite et al., 2021), only a few (e.g. Librea-Carden et al., 2021; Leden et al., 2015) examined teachers' perceptions on the relevance of teaching NOS. Teachers who understand NOS do not necessarily value the importance of teaching it (McComas et al., 2020; Lederman & Lederman, 2014; Wahbeh & Abd-El-Khalick, 2014). Studies show that teachers' intention to teach NOS influences their instructional decisions (Librea-Carden et al., 2021; Bell et al., 2016; Lederman, 1992, 1999; Mulvey & Bell, 2017). Thus, teachers' instructional practices may be influenced by their perceptions of the importance of NOS instruction.

While there is increasing international attention to NOS research (e.g., Cofré et al., 2019; Ma, 2015; Thye & Kwen, 2004; Wong et al., 2014), NOS research in Middle East and North Africa (MENA) countries is largely neglected (Alhamlan et al., 2018). Our research is situated in Morocco, where extensive reform efforts are addressing challenges, such as suboptimal teacher education, lack of facilities and hands-on supplies, and a traditional science education curriculum (Dagher & BouJaoude, 2011; Llorent-Bedmar, 2014).

Recently, the Ministry of Education in Morocco has made changes in primary school curricula including allocating additional time for science instruction (Hatim, 2020). Morocco's primary science program aims to help students realize the importance and benefits of science and to provide opportunities to work like scientists (Moufti et al., 2020). Traditional foci remain, such as on acquiring large amounts of science content knowledge (Dagher & BouJaoude, 2011) with a strong emphasis on the role of controlled experiments (Lahlou, 2019). The curriculum also requires "procedural understanding of the scientific procedure (approach)" (Lahlou, 2019, p. 82). In the Update on the Curriculum for Primary Education (2020), this is referred to as "the" scientific method, which reflects a traditional view of NOS.

One way to improve science instruction is through professional development (PD), which provides important opportunities for teachers to enhance science content and pedagogical knowledge (National Research Council [NRC], 1996). Research has shown the impact of PD on improving teachers' NOS understanding and their instructional practices (Akerson et al., 2009; Akerson & Hanuscin, 2007; Lederman & Lederman, 2019), particularly PD that incorporated explicit-reflective NOS instructions/activities (Mulvey et al., 2017).

Nature of Science

"Nature of science" is a multifaceted construct that has some generally agreed upon characteristics. These have been synthesized into goals for elementary and secondary students (Lederman, 2007). The present study focused on these characteristics: (a) *Science is made up of observations and inferences.* Scientific knowledge includes both information gathered by all the human senses and by logical reasoning. (b) *Science is empirical.* Scientific knowledge is based on direct or indirect observations. (c) *Science is creative.* It is a blend of logic and imagination. (d) *Science is subjective.* Scientific knowledge is theory-laden, influenced by individuals' own beliefs, prior knowledge, experience, and values. (e) *Science is socio-cultural.* Science is a human activity that involves individuals of different social, cultural, religious, political, and socio-economic status. (f) *Science has multiple methods.* Science does not follow a linear procedure or single scientific method. One can use or apply several varied ways to do science. It is not only through experiments that one does scientific research. (g) *Theories and laws are two different types of scientific knowledge.* Although both provide information about a phenomenon, theories explain why and how it happens, while laws describe the phenomenon. There is no hierarchical status between the two:

theories do not become laws. (h) *Science is tentative.* Scientific knowledge is not absolute fact. Thus, laws and theories may change or be further supported when new evidence emerges.

The present study focused on the aforementioned aspects in exploring the impact of a synchronous online PD on Moroccan preservice elementary science (content and/or methods) professors' NOS understanding and their perceptions of NOS instruction to their students before, during, and after PD. We addressed the following research questions (RQ):

(1) How do participants' NOS understandings change across the three PD sessions?
(2) How do participants' perceptions of NOS instruction vary across the three PD sessions?

Our hypothesis is that providing NOS PD will potentially improve participants' NOS understanding and will lead to positive perceptions on the importance of teaching NOS.

Methods

This study used qualitative and quantitative data in a *repeated measures design* across a series of three NOS PD interventions occurring over a three-month period. The following instruments addressed the research questions: the Arabic version of *Student Understanding of Science and Scientific Inquiry* (SUSSI) (Al-Saghir, 2019) and *Perceptions of the Relevance of Instructions and Pedagogical Practices of NOS* (PRIPNOS) surveys. We used repeated-measures MANOVA to compare before PD (T1), after the second PD (T2), and after the third PD (T3) for SUSSI and PRIPNOS responses. We also calculated the Partial Eta Squared effect size for the significant differences (5% significance level) in variables. Qualitative data included open-ended questions and prompts on the surveys, as well as on exit tickets. These responses were coded and analyzed using Miles et al. (2014) guidelines.

Participants

Nineteen pre-service elementary science education and science content professors volunteered to participate in the study. There were 14 males, and five females. Content specializations included Biology (n=5), Chemistry (n=5), Physics (n=3), and Earth and Life Sciences (n=6), and science education (n=7).

NOS interventions

Participants completed three PD sessions conducted online via Zoom, which were approximately 120 minutes each. We used presentation slides in Arabic and French, and the presenters spoke in English with French translation by one of the authors. Table 1 shows the NOS aspects addressed by each activity and the duration of each activity per PD. The intervention and activities are described below.

During the first PD, we shared with the participants the importance of teaching and learning NOS as stipulated in positional statements (i.e., National Science Teachers Association) and recommended by science educators around the world (e.g., Jenkins, 2013; McComas & Kampourakis, 2015). It served as an introductory session that included an interactive presentation about NOS; participants were asked to participate in a survey poll in Zoom to determine whether statements are a myth or truth. Common NOS misconceptions were used, such as "Experiment is the route to all scientific knowledge" (McComas, 1998, p. 64). At the end of the PD, we asked the participants to respond to exit ticket questions: "What did you learn from the PD?" and "What else do you want to learn (in the next PD)"?

Table 1

Summary of NOS Interventions

NOS-related activities and PD sessions	Target NOS aspects and Timing
"Truth or Myth" Polly Survey (PD 1)	Misconceptions of NOS
"Inquiry cubes" (PD 2)	Scientific methods, empirical evidence, observations, and inference (60 minutes)
"Card Exchange" (PD 2)	Subjectivity, sociocultural (60 Minutes)
"Ambiguous Images" (PD 3)	Subjective, Sociocultural (30 minutes)
"Mice, Men and Scientists" (PD 3)	Subjective, Sociocultural (30 minutes)
"That's Part of Life" (PD 3)	Sociocultural (50 minutes)

The second PD was designed as a workshop that engaged participants with NOS activities that (a) they could use in their instruction, and (b) reinforced NOS aspects presented during the first PD session. Based on the initial analysis of pre-SUSSI survey responses, participants showed low mean scores on the influence of socio-cultural aspects and individual perceptions, development of scientific knowledge, and doing science in many ways. We used tested NOS activities that target understanding of the said NOS aspects including "Inquiry cubes," (National Academy of Sciences, 1998) and "Card Exchange" (Cobern & Loving, 2020). Both activities were modified for online implementation. During this session, we asked the participants to observe the cubes as being shown to them (i.e., showing each side). Then, we explicitly asked them "How is this like what a scientist would do?" to draw their attention to the process of making observations and inferences and drawing conclusions (i.e., "what's at the bottom of the cube?") without following "the" scientific method. At the end of the activity, we discussed how they can make their scientific argument without going through the step-by-step scientific method and experimentation. We provided participants opportunities to share their different observations and conclusions about the cube and critique each other's arguments. We explained how the activity is like what scientists do; scientists make different observations of the same data (as influenced by their individual perceptions to construct an explanation to a certain phenomenon. During the "Card Exchange" activity, participants worked in group engaged in a collaborative examination of NOS statements and misconceptions about science. Participants chose two statements that they most agree with at each phase (there were four phases). In the last phase, they were asked to choose the top two statements that they most agree with and explain their reasons for choosing those statements. Similar to the "inquiry cube activity," we also asked them "How is this like what a scientist would do?" We drew their attention to the idea that scientists reach a consensus based on data and empirical evidence. Finally, participants responded to the same exit ticket questions as in the first PD at the end of the session.

The third PD was a continuation of the second PD; we continued to provide NOS activities used by Bell (2009) including "Ambiguous Image," (Dallenbach, 1951) "Mice, Men and Scientists" (Bugelski & Alampay, 1961), and texts with ambiguous meaning (Bransford & Johnson, 1972) to emphasize the theory-laden nature of scientific knowledge and sociocultural embeddedness of science. During this session, we explicitly directed the participants' attention to their varying responses to the ambiguous images despite looking at the same sets of pictures. The last activity was reading ambiguous texts which described a procedure on how to wash clothes. During the group discussion, we asked them to respond to the question "What does this tell you about the nature of science?" We described how scientists differ in their interpretations of the same data as influenced by their different educational backgrounds, perceptual frameworks, and beliefs. Finally, participants responded to the same exit ticket questions as in the first PD at the end of the session.

Data Collection and Analysis

RQ1: Because the participants speak Arabic, we used the validated Arabic version of the SUSSI survey (Al-Saghir, 2019) to examine NOS understanding. SUSSI has good reliability in small scale studies (e.g., Herman & Clough, 2013) and has been used with students and teachers (e.g., Kruse et al., 2021). The survey consists of six NOS constructs (considered as variables for this study): (i) Observations and Inferences, (ii) Change of Scientific Theories, (iii) Scientific Laws vs. Theories, (iv) Social and Cultural Influence on Science, (v) Imagination and Creativity in Scientific Investigations, and (vi) Methodology of Scientific Investigation. Each construct has four Likert items (except variables iii and v) with five options: strongly disagree, disagree, uncertain, agree, and strongly agree. Using Liang's (2006) SUSSI protocol, we assigned numerical values to which they agree or disagree; one is for strongly disagree and five is for strongly agree, and these were reversed for negative statements. We determined mean scores across participants for the six variables. Then, we referred to Al-Saghir's (2019) scale: > 3.5 = *informed*, 2.5-3.5 = *transitional*; < 2.5 = *alternative*, to determine the participant's levels of NOS conceptions.

To reduce response-shift bias—where participants overestimate knowledge, abilities, or behavior prior to an intervention—retrospective survey items were included (Klatt & Taylor-Powell, 2005). These paired items generally start with, "Before the workshop…" and "After the workshop…". For example, Pair 1 explored participants' perceived understanding of contemporary views of NOS and Pair 2 explored their perceived knowledge of NOS misconceptions. Statistical significance of the pairs was determined with a paired *t*-test. We also included open-ended questions in the retrospective survey items to support their responses to paired items such as "If you were to teach the nature of science to preservice teachers or elementary school students, what aspect of the NOS (e.g., creative, subjective) do you think would be most important to teach them? Why?"

RQ2: Our PRIPNOS survey has six items selected from *Views on Science, Scientific Inquiry, and Science Teaching [VASSIST]* (Herman, 2010) as a measure of participants' perceptions of their NOS instruction. These items were translated to French, which is one of the participants' spoken languages and the language of instruction at Moroccan universities. The reliability of the survey, calculated Cronbach's Alpha, was within an acceptable range (α=.70). Open-ended items were included as a complement to the Likert items and to deepen our understanding of participants' perceptions. One retrospective survey item was included in the posttest for RQ2. The pair focused on knowledge of strong NOS activities for their preservice teachers. We also added open-ended questions such as, "What activities do you think are useful for your students to better learn about the NOS? Why?" to elaborate their understanding of NOS activities. We employed the same protocol used for SUSSI analysis.

Participants' responses to open-ended questionnaires (i.e., PD exit tickets and retrospective questions) were used to cross-check SUSSI and PRIPNOS survey responses (Swart, 2019). We used Microsoft Excel translate tools to translate French responses to English and these were verified by the native-French speaking author. Responses to open-ended questions were analyzed using Miles et al. (2014) guidelines on coding as a form of analysis.

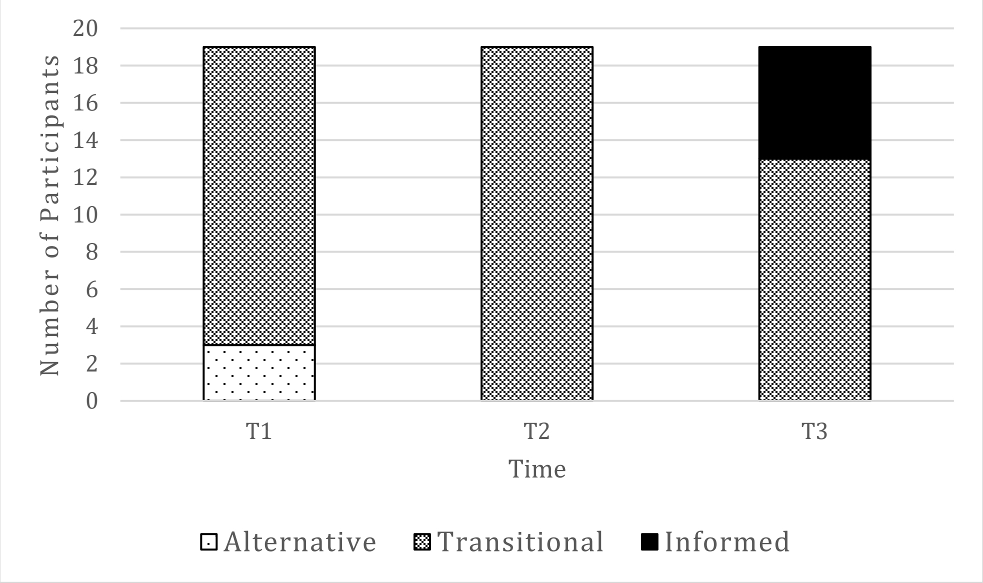
Findings

RQ1: How Do Participants' NOS Understandings Change Across the Three PD sessions?

Before the PD (T1), 19 participants were characterized as *transitional* and three as *alternative* based on summative SUSSI scores (see Figure 1). After the second PD (T2), all participants who were initially *alternative,* shifted to *transitional* NOS. Figure 1 shows results after the third PD (T3) where 31% of the participants have *informed* NOS views. Six out of 19 participants who were initially *transitional,* shifted to *informed* NOS. Analyzing the six participants who moved into *informed* NOS post-PD (T3), four have *informed* NOS in five out of six SUSSI variables and two have *informed* NOS in four variables post-PD (T3).

Figure 1

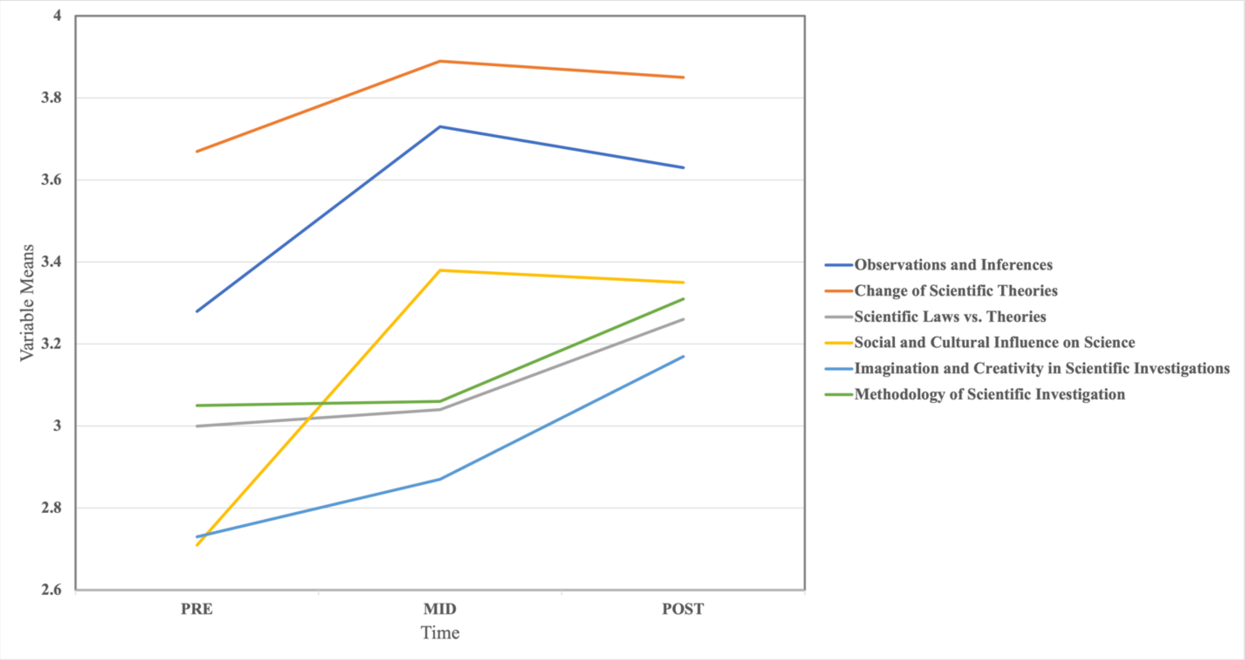
Changes in Participants' NOS Conceptions Across Three PDs



The SUSSI variable means (see Figure 2) all increased from T1 to T2, three variables decreased from T2 to T3, and three variables increased from T2 to T3. There is a general increasing trend from T1 to T3 across all variables. From the repeated-measures MANOVA test, participants' NOS understanding changed significantly (.004) with a large effect size (.93). To find out exactly where the changes were significant, we conducted a post hoc analysis using the Bonferroni correction to decrease the chance of type I error (see Table 2).

Figure 2

SUSSI Variable Mean Scores Trend for T1, T2, and T3



The changes from T1 to T2 were statistically significant for the SUSSI variables "Observations and Inference" and "Social and Cultural Influence on Science." Changes from T1 to T3 were statistically significant for the variables "Scientific Laws vs. Theories," "Social and Cultural Influence on Science," and "Imagination and Creativity in Scientific Investigations." No significant changes were found for the variables "Change of Scientific Theories" and "Methodology of Scientific Investigation." There were no significant changes in any of the variables from T2 to T3. Finally, we calculated effect size for the significant changes. The variable "Observations and Inferences" between T1 and T2 had the biggest effect size (.93), while the "Social and Cultural Influence on Science" variable showed considerable effect sizes between T1 to T2 (.78) and pre to post (.61). The "Imagination and Creativity in Scientific Investigations" variable had a smaller effect size (.58) from T1 to T3. Lastly, the variable "Scientific Laws vs. Theories" had the smallest effect size (.07) from T1 to T3.

There were significant differences in the results of the paired *t*-test of the retrospective NOS understanding items. Pair 1, A) "Before the workshops, I had a good understanding of contemporary views on the NOS" ($M = 3.79$, $SD = 0.54$) and B) "After the final workshop, I have a good understanding of contemporary views on the NOS" ($M = 4.42$, $SD = 0.61$) were significantly different $t(18) = 4.0$, $p < .001$, with an effect size of 1.09. Pair 2, A) "Before the workshops, I knew the common misconceptions about the NOS" ($M = 3.26$, $SD = 0.93$) and B) "After the final workshop, I know some common misconceptions about the NOS" ($M = 4.11$, $SD = 1.24$) were significantly different $t(18) = 5.3$, $p < .001$, with an effect size of 0.77.

Table 2

Comparisons of Participants' SUSSI Scores Across Three PDs

SUSSI Variables	PDs	Mean Difference	Sig.
Observations and Inferences	T2 – T1	.447	.001*
	T3 – T2	-.105	1
	T3 – T1	.342	.136
Change of Scientific Theories	T2 – T1	.224	.536
	T3 – T2	-.039	1
	T3 – T1	.184	.447
Scientific Laws vs. Theories	T2 – T1	.042	1
	T3 – T2	.224	.102
	T3 – T1	.266	.043*
Social and Cultural Influence on Science	T2 – T1	.671	.005*
	T3 – T2	-.026	1
	T3 – T1	.645	.015*
Imagination and Creativity in Scientific Investigations	T2 – T1	.137	1
	T3 – T2	.326	.075
	T3 – T1	.463	.031*
Methodology of Scientific Investigation	T2 – T1	.013	1
	T3 – T2	.250	.113
	T3 – T1	.263	.074

Note. * Indicates a statistically significant difference

RQ2: How Do Participants' Perceptions of NOS Instruction Vary Across the Three PD Sessions?

The repeated measures findings for PRIPNOS revealed no significant changes from T1 to T3. However, the paired *t*- test of the retrospective teaching item showed significant differences. For Pair 3, A) "Before the workshops, I knew of some good activities to help my students discover the NOS" (M = 3.3, SD = 1.1) and B) "After the final workshop, I know of some good activities to help my students discover the NOS" (M = 4.3, SD = 0.65), $t(18) = 3.3$, p =.004.

Reflections on PD

PD Exit Tickets

After the first PD, a majority (11) of participants wrote "nature of science" as a response to the "What did you learn from the PD?", which were coded NOS-related ideas; many (8) expressed methods to facilitate teaching NOS as desired learnings from the PDs. After the third PD, their responses to questions that asked about their learning from the PD indicated more nuanced ideas about NOS. For example, some participants described science as: "influenced by our society, religion, education, environment," "influenced by the theories to which we adhere," and "not absolute, but it is always an innovation given the technological development that the current world is experiencing." Some of the responses to "what else do you want to learn from the PD?" included "other example activities to teach NOS," "approaches to teach NOS," and "appropriate approaches to teach NOS to preservice teachers."

Responses to Open-ended Questions in the Retrospective Questionnaire

Many participants (7/19) identified creativity as one of the most important NOS aspects to teach preservice primary teachers "to better develop the scientific spirit in their students." However, eight participants also pointed out that experimentation is the most important. For example, one of the participants, with an informed NOS level post PD, said that experimentation "brings the preservice teachers closer to the manipulations, on the practical side." Many (8/19) seemed to adhere to a traditional didactic approach stressing the role of experimentation. There were some (6/19) who identified activities used in the workshop as useful to teach NOS to their preservice teachers. However, participants expressed constraints that can potentially hinder them from teaching NOS, such as lack of time and pedagogical knowledge, too much science content to address, and misconceptions of NOS.

Discussion and Implications

This study, situated in Morocco, adds to the existing NOS research base and addresses the limited research on NOS in MENA countries by investigating preservice primary teachers' professors' NOS understanding and their view on its instruction.

NOS Interventions and Change in NOS Understanding

In three NOS PD sessions, participants showed statistically significant gains in NOS variables occurring between T1 and T2, defying reports that short-term PDs are not likely to improve NOS views (Lederman & Lederman, 2014). The growth from T1 to T2 may be attributed to the "truth or myth" activity in PD1, which provided participants opportunities to reflect, share, and confront possible alternative NOS conceptions. Between T1 and T2, participants also engaged in explicit NOS activities during PD2, which may have also influenced their understandings. In this study there were improvements in NOS understandings that were not found in other studies, including understanding creativity (Bang, 2017). On the other hand, our findings on participants' improvement in their understanding of the socio-cultural embeddedness support previous studies (e.g., Akerson et al. 2000; Bell et al., 2016; Edgerly et al., 2021; Herman & Clough, 2016; Librea-Carden et al., 2021). This could also be attributed to the NOS intervention that emphasized the sociocultural aspect of science through activities that focused on the influence of culture, personal experiences, and beliefs on science.

Consistent with other studies is the significant change in participants' view of creativity/use of imagination (e.g., Akerson et al., 2000; Bell et al., 2011; Bell et al., 2016; Donnelly & Argyle, 2011; Herman & Clough, 2016; Librea-Carden et al., 2021). This change occurred despite the participants' strong adherence to experimentation and the emphasis on "the scientific approach" in Morocco science education (Moufti et al., 2020). The improvement in participants' understanding of methodologies and use of imagination in scientific investigation is a promising outcome. Such outcomes may be attributed to the PD NOS activities that explicitly debunked the myth of "the" scientific method (e.g. "Man, Mice and Scientists" and "Inquiry cube") and engagement in the discussion after the activities that emphasized making sense of the data to construct new ideas.

The insignificant change in understanding other NOS aspects is not surprising as past studies also showed that even with explicit NOS interventions, participants struggle in making a conceptual change (Abd-Khalick & Akerson, 2004; Lederman, 2007). This may be accounted for by participants' tendency to ignore the new information when it contradicts their prior ideas, therefore, they may have modified the new information to fit their prior knowledge, rather than vice versa (Clough, 2006). Conceptual change occurs within longer time periods (Hatano & Inagaki, 1997; Vosniadou, 2007) and may be influenced by contextual, social factors (Abd-El-Khalick & Akerson, 2004). Still, the positive outcomes in participants' NOS understanding are promising considering the relatively short NOS interventions. The retrospective items help alleviate high pretest self-evaluations that occur when participants "don't know what they don't know." The high reflective improvement in these items, the generally positive trend of SUSSI items from T1 to T3, and movement of individual professors to higher summative SUSSI levels, suggest growth in NOS understanding.

Perceptions on NOS instruction

The PRIPNOS survey, while having good reliability, did not show a significant change in participants' means across PDs. This could mean that the instrument was not sensitive to changes in instructional perceptions. Future studies could seek to develop or refine items to measure professors' NOS instructional perceptions. The lack of change in the variables could also mean there were no significant changes in these perceptions. While the retrospective item suggests a strong improvement in knowing explicit-reflective NOS activities, instructional perceptions changes may take longer to develop and be highly dependent upon first changing NOS understanding. Findings on the limited change in instructional perceptions are consistent with previous studies where even participants with *informed* NOS understanding may not necessarily have positive perceptions towards NOS instruction (e.g., Akerson et al., 2017; Summers et al., 2020).

Research suggests that science experiences are an important influence on preservice science teacher's beliefs (Azam & Menon, 2021). However, research also shows that learning NOS is not part of many science or science education courses (Lederman & Lederman, 2019). Therefore, helping preservice teacher educators value NOS instruction and be comfortable with NOS activities to implement can be important preliminary steps for preparing future teachers of science. We also argue that the present study may provide an impetus for participants to consider inclusion of NOS instruction in their science education and content courses.

Limitations of the Study

The within-subjects research design used the instruments before the PD (T1), after the second PD (T2), and after the third PD (T3). To be sure, this design reduces variance and bias by controlling factors that cause variability between subjects, resulting in greater statistical power with a smaller number of subjects. Results however, should be interpreted with caution because of threats of history and testing. For history, other events may have occurred simultaneously to influence the scores. For testing, exposure to the surveys may have led to changes in perspective.

The open-ended responses for PD reflections and PRIPNOS were limited to short phrases due to time constraints during the survey administration. As such, detailed responses are lacking in the qualitative data. Time was taken from English to French and French to English translations throughout the PD sessions that may have reduced time to respond to surveys.

Conclusion

Overall, our results showed that Moroccan science and science-education professors working to prepare preservice elementary teachers, engaging in three PD sessions, improved their understanding of NOS. Similar studies with longer periods of PD NOS interventions (e.g., Abd-El-Khalick, 2005; Kruse et al., 2021; Kartal et al., 2018; Maeng et al, 2020) showed similar gains. However, this study provides evidence that short PDs when implemented with explicit NOS activities have the potential to positively impact NOS understanding. While the PD was less impactful on their NOS instructional perceptions, it is encouraging that most of the participants indicated a desire to learn strategies to teach NOS. Reports show that teachers' intention to teach NOS is important (Lederman, 1999; Mulvey et al., 2016).

With the scarcity of NOS research in MENA countries and relatively limited science education research in Morocco (Dagher & BouJaoude, 2011), this study: a) can provide an evidentiary basis to advance NOS research in these countries, b) suggest a need for an extensive and comprehensive research agenda focused on science and science education professors of preservice elementary teachers, and c) offer strategies for online, synchronous NOS PD for preservice and inservice teachers. The logic is simple: if we want to improve children's' NOS conception, we need to ensure that teachers must have accurate and substantial understanding and pedagogical knowledge of what science is and how scientific knowledge is constructed. This ideally would be cultivated throughout their education but should explicitly be addressed in their preservice teacher education. Thus, their science and science methods professors must be continually provided with appropriate and effectively designed professional development to help them accomplish their role as key players in science education reforms.

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Emergent Multilingual Learners Use of Multimodal Discursive Resources in Science Journals to Communicate "Doing" and "Learning"

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ABSTRACT

Sociocultural language learning theory and situated learning theory stress the importance of social interactions and context in both science and language learning. In addition, researchers have highlighted the important role that multimodal language plays in meaning-making and communication in science. The purpose of this study was to examine the multimodal discursive resources emergent multilingual learners (EMLs) used in their journals on the topic of erosion. Thus, we ask "in what ways do multimodal discursive resources differ as EMLs describe doing an investigation (practices) and learning (content) in response to a writing prompt (What I did-What I learned)?" This research, grounded in an interpretive/constructivist paradigm, examined the journals of 18 EMLs who participated in a summer program where they engaged in the social context of scientific practice. Students used the What I Did/What I Learned (WID/WIL) writing prompt to describe the practices used in the classroom investigations and the knowledge resulting from these investigations. The WID/WIL journal entries were examined using template analysis coding. The template consisted of four major categories: writing, mathematical expressions, manual-technical operations, and setting. Findings indicated that EMLs utilized writing and mathematical expressions to communicate their manual technical operations (practice) and knowledge (content) of erosion. EMLs did not use visual representations as part of their multimodal resources. Implications for science teaching and the use of the WID/WIL as a writing prompt are included.

Keywords: multimodal discursive resources, science writing, emergent multilingual learners

Introduction

English learners, also referred to as emergent multilingual learners (EMLs), are the fastest growing student subgroup in US classrooms (National Center for Education Statistics [NCES], 2020). These students, who may already speak several languages, are expected to learn and use English as the medium for content development. Meaning-making and communication in science classrooms are dependent on a students' ability to use academic discourse, including highly technical language in the social context of schooling and science (Brisk & Zhang-Wu, 2017; O'Hara et al., 2012). Academic language can be difficult for students having English as their first language because the linguistic devices and strategies of scientific language are unique (Seah & Chan, 2021). For EMLs this language is particularly difficult. Therefore, it is essential for EMLs to participate in science lessons that scaffold both academic language and conceptual understanding of practice and science content (Lee, 2005; Tang & Rappa, 2021).

Educating EMLs from diverse linguistic, social, and economic backgrounds is increasingly recognized as a key challenge for science education in the US (National Research Council, 2012; NGSS Lead States, 2013). This challenge is evidenced by the pervasive opportunity gap affecting EMLs in science, technology, engineering, and mathematics (STEM; National Academies of Sciences, Engineering, and Medicine, 2018). There is an urgent need for EMLs to be well prepared in STEM to enter our increasingly technology-dependent workforce.

Consequently, more research is needed "on understanding the role of languages and learning environments learners use and engage with in building understanding of science concepts" (Hand et al., 2019, p.110). In pursuit of this understanding, the purpose of this study was to examine the discursive resources EMLs used in their journals to communicate the topic of erosion as they described their scientific practice (did) and their meaning-making (learned). Specifically, we ask in what ways do multimodal discursive resources differ as EMLs describe doing an investigation (practices) and learning (content) in response to a writing prompt (What I did-What I learned)?

Theoretical Framework

Guiding our research is a theoretical framework that combines sociocultural language learning (Eun & Lim, 2009; Mustafa et al., 2017) and situated learning (Gee, 2004; Lave & Wenger, 1991). The overlap of these types of learning provides a space to envision the science language used by EMLs in a socially constructed context of a science class. Within this space, EMLs engage in the practices of science as outlined in the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) over multiple investigations. EMLs also have the opportunity to display conceptual understanding of practice and product of science through multimodal discourse. Thus, the gap being filled by this research is an understanding of how EMLs use multimodal discursive resources, including the use of writing, mathematical expressions, visual, and manual-technical operations, needed to communicate doing and learning science.

Sociocultural Language Learning

Influential studies on learning by Bandura (1986, 1997) pushed against the emphasis on conditioning and reinforcement as seen in behavioral learning theory. Instead, Bandura proposed a social cognitive theory that emphasized the role of social interactions in cognition and asserted that people can reproduce acts they observe being conducted by others. Similarly, Vygotsky's (1978) theory of sociocultural learning stressed "the interaction of interpersonal (social), cultural-historical, and individual factors as the key to human development" (Schunk, 2020, p. 331) and learning. Both theories underscored learning as highly dependent on context and interaction with others.

Mustafa et al. (2017) pointed out that sociocultural theories of language differ from other theories of language because they emphasize that the "social environment is not the context for, but rather the source of, mental development" (p. 1170) and take into "account the complex interaction between the individual acting with mediational means and the sociocultural context" (p. 1170). Thus, a sociocultural theoretical lens would predict that language learning does not occur in isolation, but in connection to particular experiences, social interactions, and cultural norms (Martinez & Mejia, 2020). Researchers have examined the social aspect of learning as it applies to language acquisition (Knain, 2015; Lantolf et al., 2015). Lantolf et al. (2015) stated that "language in all its forms is the most pervasive and powerful cultural artifact that humans possess to mediate their connections to the world, to each other, and to themselves" (p. 211). Ma (2020) stated that "cognitive and linguistic development, as an integrated entity, is possible only when the meaning contained in the sign system is interpreted by the individual" (p. 171). In sociocultural theory, the social activity of mediation "transforms unmediated behavior into higher mental processes through tools" (p. 171) which can be symbolic, material, and cognitive.

Sociocultural theory helps explain early language development which is centered within the home where children develop their primary discourse. This language develops without significant instruction and is the result of physical maturation, social interactions, and cultural norms. As with all social activities, community norms are passed from the more advanced or knowledgeable member to the novice. Secondary discourses develop as children are socialized into schools and other institutions beyond the home community and are more focused and highly specialized. In addition to receiving explicit instruction about discourse practices, students observe and imitate the discursive practices of others. This learning involves change that is "demonstrated based on what people say, write, and do" (Schunk, 2020 p. 4). Thus, a proxy (text, drawings, symbols, speech, etc.) is used to denote that learning has occurred.

Situated Learning

Situated learning theory also emphasizes the active role of contexts in knowing and learning (Lave & Wenger, 1991). From this perspective, all members, and the resources (e.g., ideas, norms, tools) of the group, are part of the context. As individuals are enculturated into the situated practice of a social group or community, change takes place. The construction of knowledge and skills occurs in the space defined by authentic activities that allows for the influence and refinement of the domain-specific tools. Therefore, learning cannot be divorced from the situation in which the learning develops.

Building on earlier research by psychologists and educators, Klassen (2006) criticized the decontextualized and tedious way science is often taught. He proposed five contexts (i.e., practical, theoretical, social, historical, affective) for teaching. Overall, the five contexts advocate for moving away from science teaching in which students learn facts but very little about how ideas were developed (historical and social), their position within the bigger picture (theoretical), and their appeal to students (affective). Klassen (2006) suggested a science teaching where students, in contextualized experiences, become emotionally involved and stay motivated by conducting authentic (practical) science investigations in groups (social).

From the position of the overlap of these two theories, we would expect students to use the academic discourse that is both explicitly introduced and intentionally modeled during the investigations. In addition, the theories suggest that students will use language that is specific to the situation and represents the investigation being conducted.

Literature Review

EMLs and Multimodal Science Discourse

Lemke's work (1990, 2002, 2004) posited the discourse of science as a hybrid of four interconnected communication modes: natural language, mathematical expressions, visual representations, and manual-technical operations. In his work, Lemke highlighted the importance and limitations of natural language. With this line of conceptualization, the diverse forms of representation can be considered 'modes', which are "… organized, regular, socially specific means of representation" (Jewitt et al., 2001, p. 5).

Multimodal communication has been studied from different foci (Jewitt, 2017; Jornet & Roth, 2015; Kress et al., 2001). Studies can be found that examine natural language (Brown & Ryoo, 2008; Cervetti et al., 2012; Fang et al., 2010; Lee, 2005), mathematical expression (Friel et al., 2001; Olivares, 1996; Osterholm, 2005), visual representations (Kress & van Leeuwen, 2006; Roth, 2002; Tytler & Hubber, 2016; van Leeuwen, 2014) and manual-technical operations (Roth & Lawless, 2002; Siry et al., 2012) in science education. Muna et al. (2020) stated that "developing proficiency in the visual and symbolic/mathematical modes is a protracted process" (p. 2744), just as proficiency is in written and oral language. Weinburgh et al. (2018) also pointed out that the manual-technical mode develops over time with multiple engagements. More recently, researchers have expanded Lemke's four-mode interpretation by positing other forms of communication (e.g., gestures) (Bezemer & Kress, 2016; Kang & Tversky, 2016).

The notion of multimodality positioned language is a tool for participating in communities of practice (Wenger, 1999). However, this tool is not equally accessible to all students. Additional scaffolds are needed for EMLs to fully participate in these communities. Woolfolk (2014) described scaffolds as tools that allow "teachers and students (to) make meaningful connections between what the teacher knows and what the students know and need in order to help the student learn more" (p. 393). For example, when a new concept is introduced, the teacher might provide students with some information so that the students can focus on a specific part. That support would gradually be reduced as students become more proficient.

The linguistic demands of science present challenges to EMLs in understanding text, communicating ideas, and presenting written responses (Bunch, 2013; Echevarria et al., 2011; Lee, 2005). These challenges vary given the linguistic and cultural diversity among EMLs (Allexsaht-Snider et al., 2017; Freeman & Freeman, 2009). Thus, scaffolding language and science content can help with student success. For EMLs, capitalizing on the multimodal communication patterns in the science classroom increases their opportunity to access information and construct meaning (Hand et al., 2016; Weinburgh et al., 2019).

A growing body of research indicated that when EMLs engage in context-rich, student-active science, both conceptual understanding and language competencies result (Lee, 2005; Lee et al., 2005; Wilmes & Siry, 2018). The use of observable events and/or manipulatives helps to reduce the cognitive load associated with science. In addition, allowing students to use language that is familiar can facilitate entry into the science experience (Brown, 2011; Brown et al., 2017).

Journaling

The process of writing allows for an engagement in "intensive meaning-making related to the larger process of making meaning as we experience ourselves in the world" (Yagelski, 2009, p. 13). It has been argued that writing science is not only an essential product of science literacy, but it is also an opportunity to attain science literacy (Hand et al., 2001). Journaling in science is considered an important component of learning to use language, as writing promotes the development of scientific vocabulary, grammar, spelling, punctuation, argument construction, and technical writing (Hand et al., 2001). For EMLs, writing can be especially constructive for vocabulary development since writing takes more time than talking and students can experiment with new words turning *passive* vocabulary into *active* vocabulary (Dikilitas, & Bush, 2014). Several studies documented the power of science notebooks for verifying students' thoughts, ideas, and investigations (Huerta et al., 2016; Varelas et al., 2012). Wu et al. (2019) explicitly investigated Lemke's notion of hybrid language to demonstrate knowledge of science found in journals. Recently, journals have been deemed semiotic and social spaces, and not as mere products, where students construct ideas based on diverse resources (Wilmes & Siry, 2020).

In addition, journals provide a space for communication through mathematical computation and expressions. Lemke (2003) pointed out that "the history of mathematical speaking and writing is a history of the gradual extension of the semantic reach of natural language into new domains of meaning" (p. 217). Discrete (typological) meanings are found in the natural language domain while continuous (topological) meanings are found in the mathematical domain. Mathematical expressions have the power to establish meaning (Moschkovich, 2010) and inclusion of these expressions in journals can extend the student's concept of communication. Using mathematical symbols and mathematical syntax during writing appears to increase overall mathematical literacy (Hillman, 2014). Lemke (1990) underscored that "learning science entailed learning how to communicate in the language of science and act as a member of the scientific community" (p. 1).

Methodology

Our research is grounded in an interpretive/constructivist paradigm (Guba & Lincoln, 1994). Within this paradigm, we investigated the social phenomenon of language used by EMLs to communicate practice and product of science. We, like Shah and Al-Bargi (2013), entered the research with the assumption that meaning-making is an act of interpretation, language derives its meaning from context and from the relationship of words to one another, and realities exist in the system of numerous and intangible mental constructions. Thus, our epistemological stance recognizes the multiple assemblies of knowledge. Our ontological stance considers the scientific canon while holding to the subjectivity of reality. Our axiological stance questions the ethical issue of research by recognizing that we bring biases into the research. For this study, we define multimodal discursive resources as the semiotic practices that are expressed through writing, mathematical expression, visual representations, or manual-technical operations.

Context

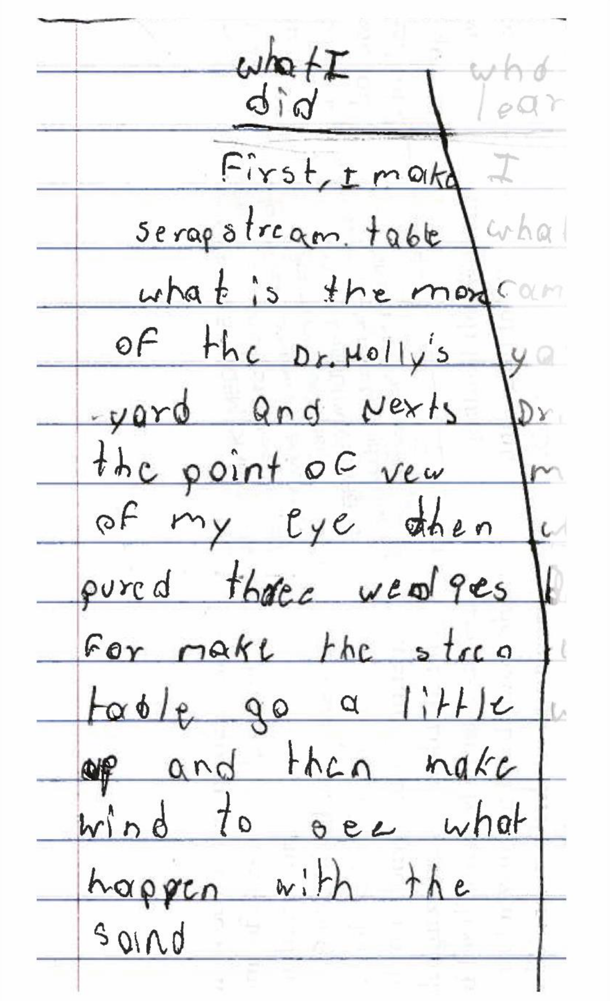
A southwestern university and a local school district collaborated for 12 years to provide a summer experience to newcomers for whom English was an emerging language. The experience was conducted at the university for 16 days in June and was taught by three college professors and two district teachers (see Silva et al., 2008 for details). The philosophical stance for the program centered on the integration of mathematics, science, and language (MSL). The underlying decision for the science topic had more to do with providing a transdisciplinary understanding of investigations (NGSS practices) and the engagement in multimodal communication than with the specific content.

Fostering Multimodal

To avoid lexical and grammatical features from becoming barriers that "mask the depth of students' science understandings" (Wilmes & Siry, 2020, p. 1000), the instructors participating in the summer experience invited students to focus on meaning-making and communication (see Figure 1 for examples).

Figure 1

Examples of Student's Original Entries and Re-written Entry Showing Conventional Writing



what I
did
First, I make
serap stream table
what is the mor
of the Dr. Molly's
yard and nexts
the point of vew
of my eye then
pured three wedges
for make the strea
table go a little
up and then make
wind to see what
happen with the
saind

What I
did

First, I make
serap [set up] stream table
what is the **more** [model]
of the Dr. Molly's
yard and nexts
the point of **vew** [view]
of my eye then
pured [poured] three wedges
for make the **strea** [stream]
table go a little
up and then make
wind to see what
happen with the
saind [sand]

Note. Misspelled words are in bold. The text in brackets indicates the correct spelling of the words.

"Rather than privileging the language of schooling over other forms of language, the MSL team emphasized language as a tool for communicating within and across contexts and with and between various audiences" (Griffith et al., 2014, p. 342). Viewing language as an epistemic tool (Hand, 2017), they believed that increased linguistic sophistication is the result of scaffolded opportunities for EMLs to engage in conceptual activity that requires specific uses of language (Heritage et al., 2015).

Mathematics as a communication tool (NGSS Lead States, 2013) provides students with the ability to be more descriptive and precise. This aligns with Klassen's (2006) suggestion of a context in which students are emotionally involved and are motivated by seeking solutions or answers to real problems. Visuals, produced for and by the students, were used to provide alternative ways of meaning-making and of communicating understanding. In addition, the philosophy emphasized the importance of engaging with natural material as events by which the mode of manual-technical operations could be the focus. To this end, students were provided with reoccurring opportunities to manipulate scientific materials. Throughout the program, the students engaged in language-intensive instruction targeted at science communication as part of inquiry-based instruction (Lemmi et al., 2019; NGSS Lead States, 2013).

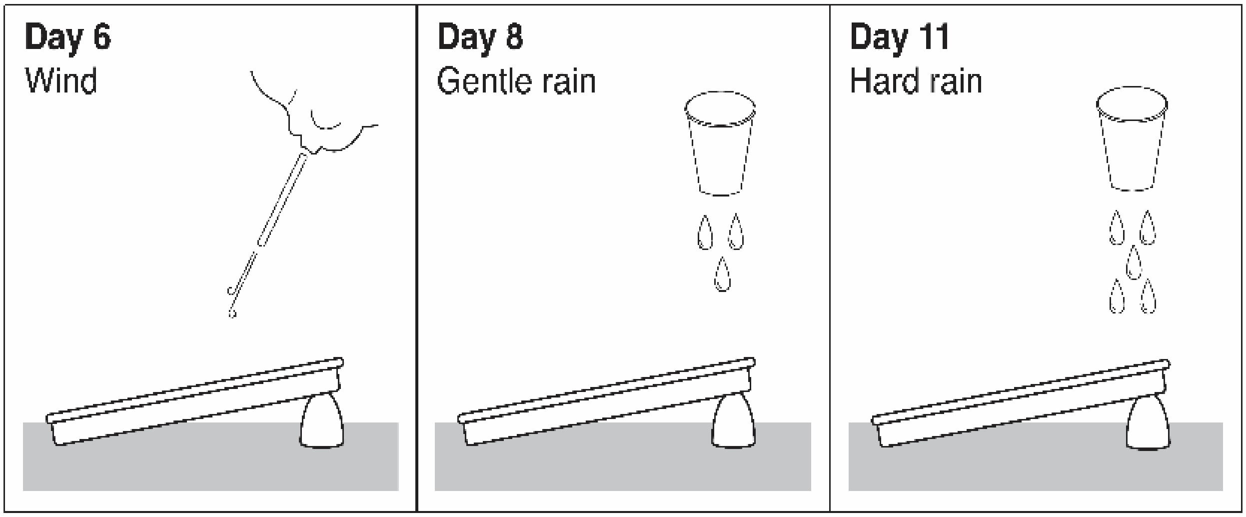
Erosion Unit

The students in this study participated in a unit on erosion. The science and mathematics content were grade level appropriate as they were aligned with the state's science and mathematics standards. Students used dynamic models to investigate the results of changing only one variable at a time (i.e., wind, gentle rain, hard rain) as they developed a concept of erosion as an earth process. Students kept a journal and were encouraged to record their investigations in words, symbols, and visuals. The journal served as a space for the students to document each event of the investigation through drawings, tables, and other notations that they felt were important.

On Day 3, students were given a description of Dr. M's yard—a hill that sloped to the road, grass removed during landscaping, very sandy soil—and were asked to decide how the class could study the yard. In teams of four, students developed a plan for a model of the yard and shared it with the class. Consensus resulted in using a prefabricated stream-table and a prescribed amount of sand to scale the model to the dimensions of the hill. On Day 6, students were presented with a question: *What will happen to Dr. M's yard if it is a very windy day, as forecasted in the local weather report*? The variable of 'wind' was manipulated, data collected, and information recorded in the journals. Later in the program (Day 8 and Day 11), students were asked: *What will happen to Dr. M's yard if there is gentle rain and hard rain* (see Figure 2)? With each investigation, one variable was manipulated, and the results recorded.

Figure 2

Diagram of the Model of Dr. M's Yard and Variables Manipulated by Day



The program alternated between days of science and days of mathematics with language always at the forefront. During the mathematics sessions, students spent a significant amount of time discussing the importance of mathematics communication, and its use in the mathematics classroom, other content areas (especially science), and real-world settings. Thus, mathematical content was systematically selected to support the science investigations and to communicate the findings (NGSS Lead States, 2013).

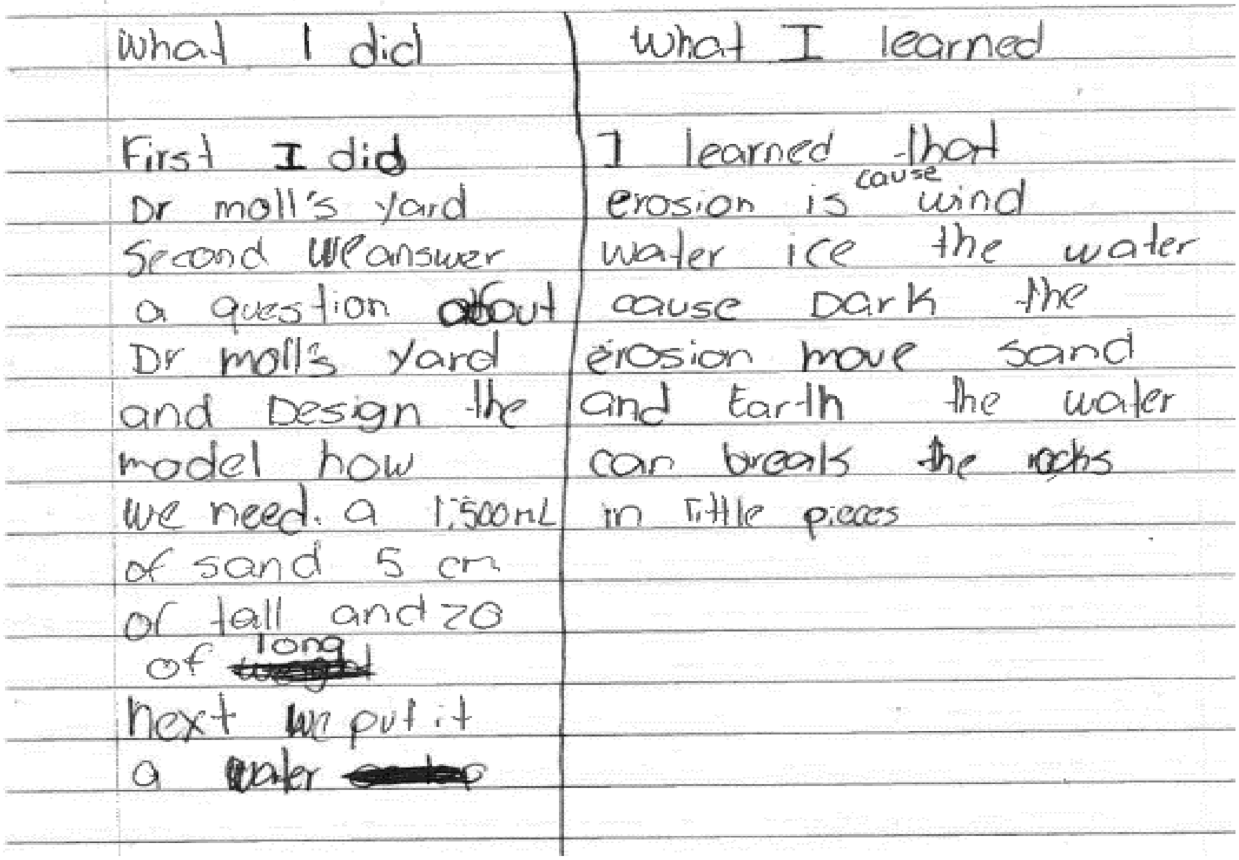
Similarly, students engaged in discussions and activities comparing features and usage of informal and academic language in the science classroom. Instruction included scaffolds to support the development of science-based discourse. For example, EMLs were introduced to, and supported in using, relevant general and specialized vocabulary within the context of the investigations. As they engaged in related reading and writing activities, they examined features associated with science text (e.g., signal words, text features, common genres). The science topic varied each summer (i.e., erosion, wind turbines, crime scene investigation) but the general format was constant.

What I Did/What I Learned Writing Prompt

A ubiquitous artifact used to document the process and product of science investigation is the lab report. The typical format requires students to state the problem/question, outline the procedures (maybe list equipment), explain the results, and justify a conclusion. Rather than use some more elaborate reporting template (e.g., Science Writing Heuristic; Keys et al., 1999), we used the *What I Did/What I Learned* (WID/WIL) writing prompt. This organizer uses the familiar T-chart form to invite students to write a summary of the classroom activities (i.e., what I did) on the left and their new knowledge (i.e., what I learned) on the right (see Figure 3).

Figure 3

Page from Student Journal Showing What I Did and What I Learned Displayed in the T-chart.



What I did	What I learned
First I did	I learned that
Dr moll's yard	erosion is cause wind
Second We answer	water ice the water
a question about	cause Dark the
Dr moll's yard	erosion move sand
and Design the	and Earth the water
model how	can breaks the rocks
we need. a 1:500mL	in little pieces
of sand 5 cm	
of tall and 20	
of long ~~[illegible]~~	
next we put it	
a water ~~[illegible]~~	

For EMLs, this writing prompt provided a scaffold not only for expressing science understanding but also for thinking about the type of language (genre) needed for communicating certain tasks. Researchers (Hand et al., 2001; Klein, 2004; Townsend, 2015) have provided evidence that organized writing may assist students in thinking critically and constructing new knowledge by exploring the connection between ideas. Also, writing may help transform undeveloped ideas into more coherent and structured forms.

The *What I Did* section of the T-chart represents a summative writing task. In general, summative writing is considered a basic task since it is grounded on memory and recall (Lamb et al., 2019). However, and especially for EMLs, summative writing that details scientific activities presents many challenges (Beck et al., 2013). Writing summaries involve complex cognitive processes like choosing salient concepts, removing details, and connecting ideas (Gelati et al., 2014).

The *What I Learned* section of the T-chart is regarded as a reflective writing task since reflection deals with the reorganization of the knowledge one already has in order to achieve an outcome (Moon, 2006; Rodgers, 2002). An advantage of introducing the reflection task with the "what I learned" prompt, is that instructors avoid confusing students about what is expected.

Participants and Data Collection

Eighteen seventh grade students' journals were used for this study. School A participants (*N* = 8; six males and two females) were enrolled in the district's newcomer program and received English as Second Language (ESL) instruction, as well as content and elective classes in English. School B participants (*N* =10; three males and seven females) were enrolled in a bilingual school (Spanish and English), where they also studied additional languages. All students spoke a language other than English at home and were identified as *English learners* using the state-approved English language testing criteria (Texas Education Agency, n.d.). The program's objective was to provide continued development in English as well as academic content. Data consisted of 46 written WID/WIL entries from Day 6, 8, and 11. We selected the WID/WIL entries as they captured the students' ability to recount practice as well as describe learning and have been used for assessing students' knowledge after a single lesson (Hartweg et al., 2017; Pearce et al., 2020). Overall, this writing prompt provided a space for students to display their 'take-away' message from the activities conducted in the classroom.

Data Interpretation

Template Development

We examined the journals through template analysis (King & Brooks, 2017) for evidence of multimodal discourse resources. The template was developed in steps. First, we listed the *categories* based on Lemke's (2004) four modes of hybrid language of science (natural language, mathematical expression, visual representations, manual-technical operations) and added the category of 'setting'. Because our theoretical framework included situated learning, the addition of where the students located their understanding of the scientific concepts seemed necessary.

Second, we subdivided each category into *codes* (King & Brooks, 2017). See Table 2 for information on the categories and codes. The codes were grounding in the literature we found within language (Schleppegrell, 2004), the mathematics standards (National Council of Teachers of Mathematics, 2014), and manual-technical operations (Weinburgh et al., 2019). After applying the template to the journals, we eliminated visual representation because no graphics were found in the WID/WIL part of the student journals.

Table 2

Categories and Codes

Natural Language		Manual-Technical Operations		Mathematical Expressions		Setting	
academic word	[L:aca]	measuring	[MT:mea]	measurement	[M:mea]	general	[S:gen]
signal word	[L:sig]	tool	[MT:too]	numbers	[M:num]	specific	[S:spe]
learned about	[L:abo]	set up	[MT:set]	topology	[M:top]		
cause & effect	[L:cau]	transfer	[MT:fer]	typology	[M:typ]		
comparison	[L:com]	transport	[MT:port]				
example	[L:exa]						
explanation	[L:exp]						
observation	[L:obs]						
procedure	[L:pro]						
synthesis	[L:syn]						
learned that	[L:tha]						

Coding

The codes were first applied to journals not included in the data set. The research team discussed discrepancies and rules were developed for each of the codes. When coding collaboratively, researchers have suggested interpretive convergence or inter-coder alignment (Guest & MacQueen, 2008). However, Saldaña (2009) states that there is no standard agreement of the percentage of overlap (but suggest 85%) and that consensus in qualitative research is often the goal. We selected to use consensus after intensive discussions.

Data Analysis

Other researchers have noted that most of the multimodal communication of the science classroom is embedded within oral or written text (Gunel et al., 2016; Lemke, 1998). Thus, examining the written WID/WIL entries in the student journal still allowed for a multimodal analysis. Using the template, the team coded all 46 entries. This provided a way to look for patterns and relationships within and across 'doing' and 'learning'. These were then used to develop explanations of how EMLs used multimodal discursive resource.

Trustworthiness

Although only one data source (i.e., students' journal entries of WID/WIL) was used, trustworthiness was increased by the application of the pyramid approach. Each researcher coded individually and then came together as an insider/outsider team. The insider involved one of the professors and the outsider was a graduate student who had not participated in the summer program. Simple mismatches in coding were corrected (e.g., missing the coding of a word or utterance). More substantial discrepancies (e.g., using a different code) were reconciled. If a team continued to disagree, the whole research team was consulted.

Findings

In answering the research question (in what ways do multimodal discursive resources differ as EMLs describe doing an investigation (practice) and learning (content) in response to a writing prompt?), we organize the findings by multimodal discursive resources (natural language [writing], mathematical expression, manual-technical operations) and setting; first discussing practice (as found in the WID) and then content (as found in WIL). Students' entries selected as examples are in italics and followed by the students' initials, the prompt, and day. The codes assigned are in brackets (see Table 2 for a list of categories and codes). Strikethroughs show texts that students wrote and then crossed out.

Writing

Two codes were prevalent in the analysis of the WIDs. Students' entries were organized around a series of step-by-step actions (*procedures*) taken to accomplish the task at hand. In their writing, the students used *signal words* (e.g., first, second, next) when introducing the steps. For example, one student wrote:

> *Next*[L:sig] *we used a cup with a hole in the bottom and we fill it with water* [L:pro].
> *Then*[L:sig] *we went for our water and put it on our cloud but first we set_up the ruler and the cloud* [L:pro].
> *Finally*[L:sig] *we put more water for trial_2 and it made a big river, holes, alluvial_fan, gullys and etc.* [L:pro]. GAI (WID - Day 11)

Another student wrote:

> *First*[L:sig] *I did a talk about erosion* [L:pro].
> *Den*[L:sig] *I ~~done~~ do tolk what happen with the yard, if get a gentle rain* BAR9 (WID - Day 9)

While a third stated:

> *First*[L:sig] *I sat up a modl* [L:pro]. RD(WID-Day 9)

Yet another EML wrote:

> *First[L:sig], I make serap stream-table[L:aca] what is the more[L:aca] of the dr Molly's yard and nexts[L:sig] the point of vew of my eye then[L:sig] pured three-wedges for make the strea-table[L:aca] go a little up and than[L:sig] make wind to see what happen with the saind [L:pro].* BAR(WID-Day 6)

In the WIL entries, *cause/effect* and *learned that* were coded most frequently. Unlike the procedural *signal words* used in WID, cause/effect *signal words* (e.g., if, can cause) were more prevalent in the WIL. Students often framed their initial response to this prompt with the expression 'I learned that…'. Further in-depth analysis revealed that when students used 'that,' the text presented more complex writings that linked at least two other argumentation features (i.e., *cause/effect*, *comparison*, *explanation*, *observation*, and *synthesis*) in their response. For example, in the following entry the student linked an explanation and a synthesis:

> *I learned that* [L:tha] *theres 3 things that can cause erosion and they are water, icea and wind all of them am cause erosion the wather by geting inside rocks then when it turns into ice it expans and cracks the rock the*

> *water hits the rocks then the rocks dissolve little_by_little wind can cause* [L:cau] *sand_duns by blowing it a sand_dum is a big hill made of sand* [L:exp] [L:syn]. MUJ (WIL - Day 8)

In contrast, when students used "about" most entries only incorporated one text feature, mainly *synthesis*.

> *after we learned mor about* [L:abo] *the eresia how many types of erosion have What is the cause* [L:syn]. FHB (WIL - Day 8)

However, occasionally they used *cause/effect* as a condition to reiterate an *observation*:

> *I learned about* [L:abo] *erosion because when* [L:cau] *at first trial the gentle rain made a small hole* [L:obs]. LJ (WIL - Day 8)

In both, WID and WIL entries, students extensively incorporated academic terms that had been introduced by the instructors as part of the inquiry process. Some of these were specialized academic words (e.g., alluvial fan). The students also incorporated common, non-technical terms contextualized for scientific investigations (e.g., trial) and polysemous words (e.g., record, table) as seen in the journal of these two students:

> *After that we filled up a container with 500_ml of water ~~to represeant the cloud filled with water~~ than we set the container with a hole to represent the gentle_rain*[L:aca]. *And poured the water to the container to see what happened. finally we record*[L:aca] *the reselts in a table*[L:aca]. SAD (WID - Day 8).

> *I learned that in first_trial*[L:aca] *sum rain got in street and I also learned in trial_2*[L:aca] *alout of water got in street, I observed the water made a big gully and a big alluvial_Streame*[L:aca]. VIR (WIL - Day 11)

Mathematical Expressions

In the WID section, while describing the procedures for setting-up of the model and the parameters used to test the variables, students' entries paralleled the instructions for the science experiments. *Topology* was frequently found in the WID with the corresponding code of *measurement.*

> *Thin measured the straw to fou*r[M:num] 4[M:num] *cetimeter*[M:mea][M:top]. DC (WID – Day 6)

> *Because We lower the higth*[M:typ] *to 10_cm*[M:num][M:top][M:mea] *instead of 20_cm*[M:num][M:top][M:mea]. DC (WID – Day 6)

Even though *topology* was frequently noted, *typology* was the most common mathematical code used in WID. This included writing that implied mathematical descriptions.

> *second, we started measuring the width*[M:typ] *of the stream to find the middle*[M:typ]. GA (WID-Day 6)

> *Next ~~we~~ I had to measure everything*[M:typ] *so we knowed how and from were to start.* VR (WID – Day 11)

The *numerical* code was used on numbers and words that expressed value. Therefore, these examples could be linked directly with *measurement.* Interestingly, *numerical* was also assigned when students were communicating quantities or sequences. Below is an example that shows how *numerical* was not linked with *measurement.*

> *Finally*, *when we blow the first_time*[M:num] *the sand want to the end of the stream_table and is made a hole the 2*[M:num] *try was a smaler*[M:typ] *hole at the third*[M:num] *try my other partner made the first*[M:num] *hole deeper*[M:typ]. GA (WID – Day 6)

For WIL, the most common code was *typology.* The code for *numerical* was found frequently, but it was a small fraction of those noted in the WID section. The numbers used in this case were not to show measurement, but rather as a signifier for number of trials or variables.

> *I learned about erosion because when at first_trial*[M:num] *the gentle_rain* [M:typ][M:mea] *made a small*[M:typ] *hole.* LJ (WIL – Day 8)

> *I learned that theres 3*[M:num] *things that can cause erosion and they are water, icea and wind all*[M:typ] *of them am cause erosion...* MJ (WIL – Day 8)

> *We learned about the hard_rain*[M:typ][M:mea] *is, the Dr M's yard the rain are more_mstrong*[M:typ][M:mea] *because the note are more_big*[M:typ][M:mea] ~~*strong be*~~ *and learnes about the variables.* FHB (WIL – Day 11)

Manual Technical Operations

In the WID section, students often began by describing the *set-up* of the investigation. Many continued with more detail about the process.

> *First, we started building*[MT:set] *Ms. Dolly's yard.* DC (WID – Day 6)

The second most used code was *transporting* (e.g., using equipment such as beakers or straw to move a liquid, solid, or gas) as students moved sand, air, or water as part of the investigation. This was followed closely by *measurement* (e.g., ruler) and *transfe*r (e.g., energy related), both of which were only used in WID. There were only two incidents of the code *tool* (e.g., safety items).

When describing the rain investigation, EMLs used more of the transporting code as they measured the correct amount of water and then moved it from the original beaker to the 'cloud' (i.e., a plastic cup with one or more holds for various degrees of rainfall).

> *Thin measured*[MT:mea] *the straw to 4 centimeter.* DC (WID – Day 6)

> *After that we start blowing*[MT:port] *for 5 seconds with a straw.* SAD (WID – Day 6)

> *I blowed*[MT:port] *on it, and also I holde*[MT:set] *the straw and the ruler.* ROA (WID – Day 6)

Manual-technical codes were found less often in the WIL as students did not appear to realize that they had developed a new skill such as measuring mass with a triple-beam balance or measuring volume with a graduated cylinder. Rather, they indicated that they learned some new content about erosion because they transported and used wind or water in the model. This was often signaled by stating that 'when' an action was taken, something happened.

> *I learned that you can have a different effect whenever you blow*[MT:port] *it from different angles.* EJ (WIL – Day 6)

> *For example, when we blow*[MT:port] *the sand with the straw it make a hole in the sand that changed the size of the hill and form.* MUJ (WIL – Day 6)

Setting

In the WID section, setting often referred directly to the situation being examined in the classroom. The code *specific* from the setting category was often found when describing 'doing' within the context of Dr. M's yard. As students described the procedures, they focused directly on the investigation as it was conducted in class.

> *Finally we draw a illustration and write what was happening with the sand* [S:spe]. GAE (WID – Day 11)

When the student broadly discussed the setting by going beyond the actual in-class investigation, the code *general* was used. This code was exclusively assigned in the WIL. In the following example, the student concluded the WIL entry by making a generalization as to the use of models in the process of conducting investigations. This is the only instance of a student stating the usefulness and the dynamic nature of the model:

> *The final_thing I learnd is that we can conduct other investigations with the same model* [S:gen]. SAD (WIL – Day 6)

> *and can take the sand or what you have in your yard to the street* [S:gen]. GAE (WIL – Day 6)

Discussion

Situated Meaning

The students wrote a WID/WIL entry after they tested the effect of a natural event (i.e., wind, gentle rain, hard rain) on a dynamic model of Dr. M's yard. Thus, learning was situated not only within the 16-day summer school program, but also within the need to learn about the effects of each variable on the erosion using the model of the yard. With each trial, EMLs needed to communicate what they did (re-establish the model and test for each variable) and what they learned (content and skills) as they engaged in authentic practical situations (Klassen, 2006). These social interactions within the authentic investigation provided students with a context in which to learn language, mathematics, and science. Thus, in the context of situated learning and sociocultural language learning, students used language for making meaning rather than demonstrating grammatical proficiency.

For the EMLs participating in this unit on erosion, the multimodal language is a way to communicate a particular socially situated scientific investigation. The situated meanings constructed (and later communicated) by the students are rooted in the embodied experiences of creating the model and manipulating one variable with each investigation (manual-technical operations). Thus, the language and science knowledge, as predicted by the intersection of situated and sociocultural theories, developed in response to particular practice and topic.

Multimodal Communication for Doing and Learning

The WID/WIL entries showed that EMLs used the appropriate multimodal communication resources needed to express the physical act of 'doing' and the cognitive act of 'learning'. In responding to the WID/WIL tasks, written entries presented general features of summative and reflective text respectively. Accordingly, students integrated mathematical expressions as both typology and topology. They described their use of manual-technical operations through their writings by recounting their actions.

The WID triggers a summative writing task. In general, summative writing is considered a basic task since it is grounded on memory and recall (Lamb et al., 2019). Writing summaries involves complex cognitive processes like choosing salient concepts, removing details, and connecting ideas (Gelati et al., 2014). However, and especially for EMLs, summative writing that details scientific activities presents many challenges (Tang & Rappa, 2021). Therefore, the students in this study used the prompt to focus their attention on practice. Not only did they have to recount procedures but also use academic discourse that was appropriate.

As suggested by Scheppegrell (2004), the summative WID entries reflected features of *procedure* and *procedural recount* genres typically used to summarize the series of steps they took in setting up their investigations. Prevalent in the WID entries was the use of signal words (e.g., first, next, finally) to organize a sequence of instructions to be followed when assembling tools and materials needed for a procedure. In contract, the WIL is regarded as a reflective writing task since reflection entails reorganization of the knowledge one already has in order to achieve an outcome (Moon, 2006; Rodgers, 2002). An advantage of introducing the reflection task with the "what I learned" prompt, is that instructors avoid confusing students about what is expected from them. The students sometimes identified the content (*learned about*) with little elaboration as to specific conceptual understandings or making connections between events. However, more students were able to use this prompt to write complex responses that included causal relationships, comparisons, explanations, and synthesis.

As emerging users of English, EMLs were not only learning new words, but also learning the function of these words. Each word was, therefore, important in expressing new technical terms. The students' writing also reflected their developing understanding of the expository language used in the science classroom to construct meaning. This helped address Tang and Rappa's (2021) concern that teachers often do not help students understand "the hidden conventions in science that govern the language used to produce and communicate scientific knowledge (p. 1312).

Noticeable across the writings are the typical grammatical and vocabulary errors (e.g., subject/verb agreement, spelling, lack of article) made in the process of learning English. These mistakes, accepted by the instructors/researchers, allowed for *linguistic flexibility*. When the reader of the journal moves past these mistakes the students' intended meaning emerges. The entries indicate that students were appropriating the discourse practices needed to authentically communicate in the science classroom. Moreover, this linguistic flexibility aligns with the teaching goal of helping students become comfortable in talking and writing about their experiences within the learning environment (Brown et al., 2017; Krashen, 1988).

Although we anticipated the incorporation of visuals representations, no student used drawings to complete the WID/WIL tasks. This may be explained by the nature of the WID-WIL task and the records of the investigations found prior to the WID-WIL entry within the journal. The students had detailed drawings of the model for each variable manipulated. These drawings represented different perspectives (e.g., bird's eye view and worm's eye view) of the event before and after variable manipulation and included measurements. Other journal entries also contained a number of tables used to record results after each trial. The extended use of visual representations might be one reason why students chose not to integrate this modality in their responses. Another possible explanation is the format of the WID/WIL, a T-chart dividing the journal page into two slim columns, discouraged them from including visual representations.

Lemke (2002) argued that the modality of natural language is not precise enough to represent the nuances of measurement and other mathematical phenomena. Thus, humans find it necessary to extend natural language from typological (qualitative meaning) to include topological (quantitative meaning). In their WID, the EMLs used numbers to express meanings more precisely regarding how to set-up the investigation. They recognized the need to use the modality of mathematical representation to communicate the number of trials, the length and height of the yard, placement of the straw for wind, and amount of water for gentle and hard rain.

Not surprising was the more general mathematical language used for WIL entries. Students shifted from using *topology*, a feature that can be considered as part of "cookbook" laboratories, to using *typology* almost exclusively. Students were asked to observe and give descriptive accounts rather than to measure the exact changes in the model after each trial. Therefore, students included general descriptors (e.g., "made a small hole") instead of providing precise information to communicate what they learned. Consequently, students did not view mathematics as a central part of supporting scientific findings (NGSS Lead States, 2013). Rather, the students used numerical values to communicate the procedural aspects of the investigation.

While the modality of manual-technical operations could only be measured through the students' reflections on their awareness of this modality, they integrated this understanding in the WID, but failed to reflect on the process of learning these manual-technical operations in WIL. While new equipment (e.g., triple-beam balance and digital scales) and new skills such as setting up a model or manipulating the independent variable were introduced to the students during the investigation, they did not write in the WIL about their engagement with these new tools. The discourse of science learning occurs in both factual knowledge and skill-related practices. Skill learning is certainly a part of the science curriculum but, in this case, the students did not acknowledge the learning of science practices. A possible explanation may be that these students are used to "normal science education" (Klassen, 2006, p. 2) in the form of cookbook laboratories and acquiring 'factual' knowledge.

Setting/Context

In order to test a variable, the students had to re-construct the model of the yard with each investigation. Rather than giving details of this procedure, they simply stated that they 'set up' for the investigation. As with providing visuals, describing the model set-up may have seemed redundant and not relevant as seen in the general statements, "*I measured everything so we know how and were to start*" and "*I make serap stream-table what is the more of the dr. Molly's yard.*" In addition, students were more apt to write typological explanations to describe their procedural recounts. Students extended their description by including more precise mathematical expressions. Therefore, a relationship can be observed between manual-technical and mathematics. The students provided a specific measurement (e.g., 4 cm) when explaining the manual-technical operations of the experiment.

The context helped dictate the student responses with regard to the setting. The initial task of designing the model of Dr. M's yard to be tested set the practical, social, and affective context (Klassen, 2006). Each investigation continued stressing these contexts as they were framed using Dr. M's yard as the research site. However, in the WIL, the prevalence of references specific to the model of Dr. M's yard and the rare use of readings and personal knowledge to generalize what they had learned from the class results, indicates that EMLs struggled connecting the classroom investigation to a general idea.

Conclusions and Implications

Sociocultural theory provided researchers with the expectation that students would construct knowledge using social cues and science norms within the class. During the summer program, many nuanced norms of scientific inquiry were utilized with each investigation. The reiteration of these norms was an important pedagogical practice in helping students become comfortable conducting investigations. Situated learning theory, emphasizing the role of context, helped explain the students' focus on Dr. M's yard as they were given a real-world problem and were asked to create a dynamic model to test the effect of three different variables allowing them to experience "an infusion of scientific culture" (Meyer & Crawford, 2015, p. 631). Scaffolding helped the EMLs not only develop multimodal language, but also develop a way to communicate their growing understanding of scientific investigations and erosion. The linguistic flexibility found in the journals and supported by the researchers allowed the students to express their science knowledge.

The following implications for instructional practice and teacher education are based on what was found and was absent in the student texts. First, the students did not transfer their understanding of erosion as seen in the model to a more general context. This lack of generalization calls for teachers to help students move beyond the immediate context of the classroom activity. Considering the importance of deliberate and intentional planning around the NGSS practices, teachers need to scaffold students into the application of the concepts learned into new contexts.

Second, when teaching science, teachers may assume that practices and skills are learned, but sometimes neglect to identify the skill as a learning outcome. The lack of students communicating that they learned a skill or how to use equipment highlights that these students either did not see skills and practices as 'learning' or did not feel the need to discuss them. Areas that educators should explicitly emphasize are: (a) scientific models and modeling; (b) scientific practices and skills as learning objectives; (c) relationships between mathematics and science; and (d) mathematical thinking used to support the communication of scientific findings.

Third, the findings indicate that to scaffold the use of discursive resources needed for summative and reflective journal entries, the WID/WIL writing prompt is an effective tool. The T-chart explicitly separates the actions of scientific practice from the learning, thus addressing the limitations of the classical lab report. However, to make the WID task more demanding, educators should scaffold instruction so that students provide enough information that varied audiences can understand and follow their experiences (Lamb et al., 2019). As presented in previous research (Wilmes & Siry, 2020), context-rich activities that truly engage students help them improve their language and science concepts. Students should also be encouraged to start their WIL prompt responses by writing the phrase "I learned that". This phrase—different from using "I learned about"—serves to focus students on generating more complex responses.

Fourth, the lack of visual representation found in the data is worth noting and indicates that more explicit instruction should be included. Teachers should remind students that it is acceptable to include visual representations if these might serve to better communicate meaning within the WID/WIL. While these suggestions do not guarantee rich responses, we believe they can lead students to engage in substantive writing without including extensive instructions. We also stress that when using the WID/WIL writing prompt teachers attend to the students' intended meaning, rather than focusing on grammatical mistakes.

Limitations

The most important limitation of this study lies in the fact that three authors were teachers in the summer program. However, we mitigated potential bias and increased credibility by using an insider/outsider team approach for the analysis. In addition, the students were only engaged in the instructions for 16 days. Although this amounts to 80 hours, it does not allow for the extended time needed to become fully proficient in the multimodal discursive resources.

As a closing remark, we considered pertinent to mention that in the fall of 2017, after Hurricane Harvey hit the coast of Texas and a year after the summer program ended, Dr. M received a phone call from one of the teachers on behalf of her students. They were worried about her yard in the wake of Harvey. This anecdote substantiates Klassen's (2006) idea of affective context. It illustrates how students' strong emotional involvement in the summer program propelled them to raise their concerns about the vulnerability of Dr. M's yard long after they had participated in the summer experience.

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Oh, the Places We Learn! Exploring Interest in Science at Science Fiction Conventions

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ABSTRACT

Science fiction conventions are places where individuals with an interest in diverse genres and mediums can engage with a community that bridges the world of science fiction and fact. Many of these conventions provide a science "track" where science experts share their expertise and research on scientific findings and applications of science with science fiction enthusiasts. This study explored science fiction conference attendees' ($n = 241$) interest in science, as well as how attendees ($n = 172$) plan to utilize science shared at science track sessions. Survey responses were analyzed within "STEM career" groups by comparing science track and non-science track attendees, and documenting what science track attendees plan to do with the information gained at a science track session. There were no differences in how science track attendees and non-science track attendees with STEM careers reported their interest in science. For the attendees that did not report having a career related to STEM, science track participants reported higher interest scores than non-science track attendees. Over half of the science track attendees (66%) shared they will apply what they learned from a science track session to their own personal context. Furthermore, the demographics of the survey respondents may suggest that science fiction conventions are an untapped science learning environment connecting to a younger, more diverse community. Overall, recognizing the benefit of science fiction conventions is crucial to provide spaces for accessible venues of science communication to foster an interest in science for a diverse, public audience.

Keywords: science fiction, informal science education, science interest, adult learning

Introduction

Science fiction conventions are spaces where individuals can engage with a community that bridges the world of science fiction and fact (Obst et al., 2002). These conventions allow individuals who enjoy interacting with science fiction through diverse mediums (literature, TV, movies, etc.) to collaborate within the science fiction community with experts and fellow enthusiasts. Historically, the first science fiction community gatherings were documented in the 1930s, and attendees of these informal assemblies were often white male science fiction writers (Roberts, 2006). In 1939, the first World Science Fiction Convention was held in New York (Gooch, 2008; Roberts, 2006). According to Bacon-Smith (2000), since the inaugural science fiction gatherings in the 1930s, attendance at science fiction conventions has grown over the decades, connecting a community of science fiction enthusiasts together. Conventions today range in size from small, local gatherings to large international events, such as San Diego Comic Con with 130,000 or more fans in attendance (Biagi, 2021). Overall, the purpose of these conventions is to offer an opportunity for individuals to gather in a social setting and explore multiple dimensions of science fiction or fantasy genres.

Traditionally, many of these science fiction conventions have multiple "tracks" of programming centered on different aspects of science fiction fandom, including costuming, art, video programming, readings, autograph sessions, children's activities, and special guests, often with continuous, 24-hour programming (Bacon-Smith, 2000). Most established science fiction conventions are focused primarily on fictional literature, but have grown to include television, film, comics, video or computer games, board or card games, and animation. These conventions are largely fan developed, often not-for profit, and consist of various programming options, all connected to the world of science fiction and fantasy. In essence, one becomes completely immersed in the fan experience, often spending days at the larger conventions where participants cosplay (dress in costumes). While the focus of all these conventions is on science fiction with a core of similar programming, most conventions have a unique theme with differences in duration, session options, and activities (Dragon Con, 2021; Biagi, 2021).

Many of these conventions provide "science track" sessions in which science professionals share their expertise and research on scientific findings and applications of science related to science fiction and fantasy with fans. The nature of these science-based sessions is wide and varied. Some sessions directly connect to specific genres (literature or media) and are structured with individual speakers and panels, while other sessions are more interactive. Common science track experiences may include film viewing, stargazing (virtual or in-person), hands-on activities, and interactive robotics experiences (Dragon Con, 2021). Topics can be expanded to include trends in education, socio-scientific issues, and recent advances in all fields of science (Slater & Slater, 2019). For the context of this paper, a science fiction convention is defined as a gathering of individuals who participate in the culture and fandom related to an array of science fiction and fantasy genres.

Because of the growing popularity of these events and the varied backgrounds and interest of attendees at science fiction conventions, a more comprehensive picture is needed to document attendees' interest in science and what, if any, is the impact on behavior or actions after attending science track sessions. The science track sessions offered at many science fiction conventions are spaces dedicated to the learning and exploring of science. These sessions may assist in addressing issues related to interest in science, scientific literacy, and science communication in public venues, as there is a need for "creative and innovative strategies" in providing science learning opportunities to the public (Monzack & Zenner Petersen, 2011).

As suggested by the National Science Teaching Association (2012) and the National Research Council (NRC, 2009), informal learning environments, such as science sessions at science fiction conventions, are critical for individuals to develop interest in science, beyond the traditional, formal learning environment. This study sought to compare interest in science between those individuals who attend science track sessions and those who do not attend science track sessions at a science fiction convention. The comparison of science interest among attendees were further examined within STEM career groups as prior research may suggest that individuals with a STEM career may have a higher interest in engaging in science-related informal learning experiences (Jones et al., 2019). Secondly, this study documented what actions or activities science track attendees plan to take, using the information learned or shared at a science track session based on the Contextual Model of Learning (CML) framework. How individuals process and act on science learned in informal settings can provide insights into how comfortable they are crossing borders into the culture of science (NRC, 2009). This information may allow planners, researchers, and educators insight into the public mindset regarding science, help them utilize these accessible venues of science communication, and consider other out of the box ways to foster an interest in science. The research questions guiding this study are described below.

> RQ1: Are there differences between science track and non-science track attendees' (within STEM career groups) interest in science?
>
> RQ2: How do science track attendees utilize the information provided at a science track session?

Review of Literature

Entrenched within current events and policy related to science, technology, engineering, and mathematics (STEM), experts are calling for the need to have a scientifically literate populace and the development and perseverance of STEM career professionals (Priest, 2014; Rosenzweig & Wigfield, 2016). However, fostering both student and public interest and knowledge in STEM-related learning experiences and careers has been problematic, as indicated by national test scores and shortage of diverse professionals in the STEM workforce (Ball et al., 2017; Cannady et. al, 2014). Aikenhead (2001) suggests that "Science can be thought of as a culture with its own language and conventional ways of communicating" (p. 24). Feeling comfortable in the culture of science for all individuals participating in STEM informal learning events may be dependent on understanding that language, as well as the customs, norms, and values of science. Because of the unique language, customs, and skills involved in understanding science, participating in the culture of science can be difficult for the public.

Furthermore, there are barriers that result in non-participation in science learning events, spurring concerns that some of these events may not be equitable. Some of these concerns include accessibility of the event (e.g., infrastructure and associated costs), communication and relationship building between the science event organizers and the community, and acceptance and celebration of groups who may have been excluded from similar events in the community's past (Dawson, 2014; Hite et al., 2019). As equity and access are complex issues, engaging with the public via science learning experiences related to specific contexts (i.e., science fiction conventions and fandoms), may create learning spaces that value diversity and inclusion and connections to the public's personal interest, such as science fiction, to science.

To address these issues, researchers have suggested that in order to support learner interest in science, motivation must be fostered to help the public feel more comfortable in the culture of science (Aikenhead, 2001). Science and STEM learning opportunities should be available through informal learning contexts that support science communication, learning, and literacy (Aikenhead, 2001; Schwan et al., 2014; Stocklmayer & Rennie, 2017). When science communicators participate in public activities, people feel more at ease in the culture of science (Aikenhead, 2001). Informal learning environments may support social interactions between learners and science experts and promote interest and motivation in science or STEM careers; this includes museum and science centers (Martin et al., 2016), summer science camps (Kong et al., 2014), science festivals (Jensen & Buckley, 2014), science cafés (Childers et al., 2022), STEM-related hobbies (Jones et al., 2017), and citizen science projects (Jones et al., 2018). Science fiction conventions, situated as unique informal learning environments, may also contribute to addressing the need to promote science and border crossing into the culture of science.

Science Fiction and Education

Science fiction is a bridge between human imagination and scientific discoveries. The term science fiction has a myriad of definitions because of the complex nature and breadth of the genre (Roberts, 2000). Generally, science fiction has been described as imaginative fiction, scientific fictionalizing, a thought experiment, and metaphorical but metonymic (Broderick, 1995; Jones, 1999; Roberts, 2000; Suvin, 1979). Science fiction, as a genre, can influence public thought and opinion as well as question the affordances of scientific endeavors (Menadue & Cheer, 2017). Furthermore, science fiction can capture an audience's imagination and spark creativity and ingenuity, enabling science experts to create unique opportunities to connect science fiction and science fact with the public (Menadue & Cheer, 2017). Science education and communication, framed by science fiction, may be a conduit to increase interest and understanding of science as the public is lured into the culture of science.

The field of science fiction has gained traction in education instructional practices and curriculum to teach science concepts through the lens of fan fiction such as movies and comics. The use of science fiction in classrooms enables learners to build critical thinking skills and support interest and positivity towards reading (Vrasidas et al., 2015). Saunders et al. (2004) suggested that curriculum designed to capture learners' imagination may recruit a diverse group of learners and promote novel approaches to teaching. Additionally, Cavanaugh (2002) shared that the value of science fiction entertainment media supports student interest and learning in science. There are multiple examples of lesson plans and ideas shared by educators exploring the concept of utilizing science fiction in the classroom to teach science in content areas using science fiction films and shows (Barnett & Kafka, 2007; Cavanaugh, 2002; Dubeck et al., 1993; Laprise & Winrich, 2010; Stutler, 2011), comics (Matuk et al., 2019), literature (Berne & Schummer, 2005; Czerneda, 2006; Liberko, 2004; Oravetz, 2005; Singh, 2014; Vrasidas et al., 2015), and through a variety of science fiction media (Allday, 2003; Bixler, 2007). Science learning through the integration of science fiction in formal classrooms has been used as a tool to support student interest in science; however, it has been suggested that there may be cultural and gender biases that may limit female interest in science if fiction is utilized as a learning tool in formal learning spaces (Hasse, 2015).

Science Fiction Conventions as Informal Science Learning Experiences

Outside the context of formal education learning spaces, there are informal spaces to learn science at science fiction conventions. Similar to science cafés (Childers et al., 2022; Dijkstra, 2017; Norton & Nohara, 2009) and science festivals (Jensen & Buckley, 2014; Rose et al., 2017), engaging science-themed spaces and activities, such as science fiction conventions, have increased in popularity and access for the public. These conventions provide educational opportunities to learn from science experts about current and future trends in scientific research, and the science fact in science fiction, in addition to a variety of sessions dedicated to the fictional aspects of the genre (Slater & Slater, 2019). The science tracks at these science fiction conventions are a type of informal learning experience, specifically designed to engage the public in science. According to the National Research Council (2009), "informal environments are generally defined as those including learner choice, low consequence assessment, and structures that build on the learners' motivations, culture, and competence" (p. 47). These science tracks meet all the criteria for an informal learning environment as characterized in the 2010 report by the National Academies of Sciences (NRC, 2010). See Table 1 for information on the alignment of the characteristics for an informal learning environment as described by the National Academies of Sciences (NRC, 2010) and the science tracks found at science fiction conventions.

Table 1

National Academies Characteristics and Alignment of Science Track Descriptions at Science Fiction Conventions (NRC, 2010)

National Academies Characteristics	Science Tracks at Science Fiction Conventions
"(1) designing diverse opportunities for the learner both emotionally and intellectually	There are multiple offerings within the science tracks that resonant with participants both emotionally and intellectually
(2) supporting an environment for learner-selected interactions	Participants self-select which talks they wish to go and there is no requirement of attendance
(3) facilitating events that build on prior knowledge and interests	Participants often choose talks based on cross-over interest in fandom or in science and evaluations seek to learn about future learning interest
(4) providing choice in the level and extent in which the learner participates	Participants may engage to the level they feel comfortable, they may sit and listen, or actively participate
(5) highlighting "multifaceted and dynamic portrayals of science" (NRC, 2010, p. 5)	The speakers and topics are vetted by a track committee who works to ensure participants will have a variety of topics and speakers to choose from

Just as professionals attend conferences to enhance their learning, science fiction enthusiasts attend conventions where they can interact with others in the science fiction community and share in deeper experiences of their science-related interests. Included at many of these conventions are specific learning tracks where participants can attend lectures delivered by "experts" in their field (Bondi, 2011; Slater & Slater, 2019). Tracks in this context refers to programming strands that are related by a common theme. The organization of sessions by theme allows for attendees to understand the nature of sessions that can be expected in specific context. Conventions with large numbers of offerings can be organized and identified based on the specific interests of each attendee. The experts that participate as speakers or panelists are professionals who share a common cultural interest with the participants, such as science experts who are currently in a STEM career.

One of the major differences between attending a lecture at a professional conference versus a science fiction convention is how science is communicated to the public; as the space at a convention is much more relaxed, easy to understand, and focused on a lay person understanding of the topic. A recent study by the American Academy of Arts and Sciences (2019) found that while people encounter science at entertainment venues such as science fiction conventions, there is still research to be done on the impacts of this type of science communication on motivation and interest in science. In addition, they recommend that these types of venues can play a vital role in developing "lives empowered by STEM literacy, knowledge, and identity" (p. 29). Science tracks at science fiction conventions have the potential to create spaces for community dialogue and collaboration among attendees. In addition, conventions providing opportunities for attendees to explore the connection between science and science fiction may have a positive influence on motivation and interest in science.

The interplay between science fiction, informal learning spaces, and interest in science is an untapped resource, as science fiction conventions offer an exceptionally unique opportunity to promote and engage the public in the culture of science. However, there is a dearth of literature focused on the benefits of the public attending science fiction conventions. Science fiction conventions create spaces for community dialogue and collaboration among science experts and attendees, in addition to constructing opportunities for attendees to explore the connection between science and science fiction (Slater & Slater, 2019). By making science (i.e., language, customs, and skills) accessible to the public, these informal learning environments have the potential to facilitate motivation and interest in science while making border crossings into the world of science more comfortable. Furthermore, as science fiction conventions cater to a diverse population of science fiction enthusiasts, documenting attendees' interest in science is important for the continuous improvement of science programing in an informal science learning space.

Theoretical Framework

For this study, two lenses are used to explore interest in science and future motives of science fiction convention attendees. First, general science interest will provide a framework in documenting science fiction convention attendees' interest in science. Secondly, for attendees who participate in science track sessions at science fiction conventions, the CML will provide a foundation in which to investigate how these specific attendees will utilize the science information shared at an event. These two lenses (interest and CLM) will provide insight into the public mindset regarding science at a science fiction convention.

Science Interest

As a variable, interest can document an individuals' degree of curiosity, activity level, relevance and meaningfulness, and significance related to an activity. Deci (1992) describes interest as "…the interaction between a person and an activity, operating within a social context" and suggests that interest is connected to motivation by three domains: the person, (including experiential components and dispositional components), the activity, and the social context (p. 49). The person component of interest states that interest occurs when an individual "…encounters novel, challenging, or aesthetically pleasing activities…" that allows for satisfaction (Deci, 1992, p. 49). These components describing interest are governed by the specific activity (attending science track sessions) and the associated social contexts (communication between science experts and the science fiction community) to foster motivation (Deci, 1992). Several research articles have focused science interest as a construct of study within informal science and STEM education. Overall, these studies have found 1) parental and/or guardian levels of education was a positive factor for children developing interest in science (Dabney et al., 2015), 2) a positive association between social competencies, belonging, and science and math interest (Hoffman et al., 2020), and 3) science interest is a significant mediator regarding science performance (Tang & Zhang, 2020). As science interest is a foundational construct, exploring this variable within novel informal science learning spaces, such as science track sessions at science fiction conventions, is important in examining attendee interaction and learning.

Science track sessions at science fiction conventions have the potential to merge these three domains as science track attendees are provided with opportunities to explore their interest in connecting science fiction with science fact. However, there is also importance in documenting the science interest of individuals who are not attending science track events but are engaging in other events at a science fiction convention. As a form of entertainment, science fiction conventions are a rich environment for the public to engage in science or science-related topics in the context of science fiction. However, what is unclear is the degree of interest in science, with a specific focus on the person interest construct of individuals attending science fiction conventions and how the interest in science may differ between science track attendees and non-science track attendees.

Contextual Model of Learning (Future Motives)

To explore the actions and behaviors of science track attendees after attending a session, this research has been pursued through the lens of the CML. This theory can provide information on the motives and future applications of learning for science track attendees. CML is an appropriate framework that illustrates learning in informal contexts, which was originally applied to museum experiences (Falk & Dierking, 2000). CML is comprised of three constructs that align with the three domains proposed by Deci (1992): personal context (personal interest and intrinsic motivation), social context (connections and interactions with others), and the physical context (design of the environment) (Falk & Dierking, 2000).

Although the CML constructs are closely related to the self-determination constructs of motivation and interest, CML may provide context to the future application of learning from an informal learning context. In recent studies, the contextual model of learning has provided a foundational lens for informal science education learning spaces. Dunlop et al. (2018) found creating a *third-space* (*i.e.*, a learning space that co-existed in collaboration between the formal and informal education space) enabled student autonomy in learning and connected learning to personal interest and prior knowledge. Regarding adult learners, Childers et al. (2022) documented factors, such as social interactions and fulfilling personal needs, that motivated adults to attend science café events in their community by creating a conceptual framework based on self-determination theory and the contextual model of learning. Overall, there is a need to examine how the personal, social, and physical contexts are perceived by individuals within novel informal science education spaces.

For this study, the frameworks provide insights into how attendees participate in the culture of science when attending science track sessions at a science fiction convention in the qualitative analysis. Science tracks at science fiction conventions are situated in an environment that promotes science through the interplay of interest and motivation, via science track attendees perceived personal, social, and physical contexts. The researchers used the frameworks to provide the foundation to analyze what attendees do with the information gained after attending a science track offering.

Methods

This exploratory study documented science fiction convention attendees' interest in science and how science track attendees engage with the information they gained after attending science track sessions at a science fiction convention through an online survey instrument. The survey protocol was designed to elicit information from attendees by asking questions including demographics, interest in science, sharing the degree to which science is meaningful or relevant to the attendees' daily lives, and perceived benefits of learning science at a science track session. University institutional review board (IRB) approval was granted to obtain research data.

A survey booth was available in one of the main convention sites, accessible to all science fiction convention attendees, and was staffed by the researchers during the operational hours of the overall science fiction convention track sessions. Although the survey booth was available to all attendees, only adults (individuals 18 years of age or older) were invited to complete the survey. Both electronic tablets, connected to an Internet source, and business cards with a QR code/URL for survey access on personal devices, were provided for participants to access the survey. Survey data were housed in an online repository (Qualtrics) and downloaded onto a password protected computer and converted into SPSS and Microsoft Excel data files for analysis.

Study Context

The study site for this exploratory research was an annual science fiction and fantasy convention (Dragon Con) located in the Southeastern United States that features comics, films, television, costuming, art, music, and gaming programming related to science fiction genres. Attendance for the most recent convention in 2019 was approximately 85,000 individuals (Mandel, 2019). Attendees at this convention can choose to engage in 37 different tracks, including the Science, Skeptics and Space tracks which engage participants in informal science learning, with an emphasis on the connections between science fact and science fiction (Dragon Con, 2021). On average, there are 80-100 hours of programming available for informal science learning that encompasses these specific tracks over a five-day period, including more than 75 guest speakers and panelists, as well as sessions in other tracks that bring together the world of science and fiction (Dragon Con, 2021). The cost of attending all sessions is included in the annual conference rate (as of 2021, the annual conference rate is $115 for the 5-day convention), with no additional charges for attending specific science track sessions. At Dragon Con, there is no advance selection requirements for attendance; participants show up at the scheduled time for each session. It should be noted that these sessions, which have a capacity of 100-200 attendees, are quickly filled to capacity, and interested attendees are turned away.

The world of science fiction and fantasy allow for every possible science concept to be explored and one could expect to find a range of topics covered, including astronomy (space), biology (genetics), and physics (superheroes). Some of these activities may including multiple hour-long sessions consisting of either individuals or panels of speakers who are science experts that can connect their area of expertise within the context of specific science fiction themes. Sessions may include the accuracy of science presented in specific visual (i.e., television or movies) or print (novels, comic books, etc.) media; or alternatively connect real-world science issues to a broader science fiction genre (i.e., artificial intelligence in science fiction). For example, a session focused on genetic inheritance and inbreeding in the fictional world of Game of Thrones discussed how science may explain many of the characters' struggles (Mock, 2019).

In addition to the science track, this convention also hosts a space track, where astronomers, astrophysicists and rocket scientists provide updates on current missions and discuss other space science related themes (i.e., medical issues with space travel). Examples of sessions provided in the space track might include representatives from the private space sector who share information about private sector initiatives, as well as amateur astronomers who provide opportunities for participating in solar and nighttime telescope (on-site and remote) observations. While these sessions represent the opportunities at this convention, it should be noted that not all science fiction conventions will have the same types of informal science learning prospects.

Participants

Individuals attending the science fiction convention answered a series of questions about demographics, track attendance behavior, and science interests with additional open-ended response items. Study participants (*n* = 241) were adults (18 years of age or older) who attended the science fiction convention hosted in the Southeastern United States. The survey respondents included 172 science track attendees and 69 non-science track attendees (science track attendees: 74 males, 92 females, and 6 preferred to not self-identify; non-science track attendees: 32 males, 36 females, and 1 preferred to not self-identify). The majority of science track and non-science track attendees identified as white (73% and 67%, respectively) and held college degrees (science track attendees: 72% have a bachelor's degree or higher; non-science track attendees: 67% have a bachelor's degree or higher). Most of the science track attendees (68%) and of non-science track attendees (81%) were under 45 years of age. Approximately a quarter of science track attendees (27%) and a fifth of the non-science track attendees (18%) reported their career was related to education. Chi-square tests were calculated to determine if the two groups' demographics (nominal/categorical data) were similar for comparative tests. As noted in Table 2, there was a difference in the representation of individuals with STEM careers between science track and non-science track attendee groups.

Table 2

Science Track and Non-Science Track Attendees' Demographics

Factor	Description	Science Track Attendee** (*n* = 172)	Non-Science Track Attendee (*n* = 69)	Chi-Square X^2 (*p*-value)
Gender	Male	45% (74)	47% (32)	0.119 (.729)
	Female	55% (92)	53% (36)	
Race	Caucasian	73% (126)	67% (46)	2.110 (.145)
Education	4-Year Degree or Higher	72% (123)	67% (46)	1.332 (.248)
Age	Younger than 45	68% (117)	81% (56)	2.861 (.091)
STEM Career	Yes	63% (108)	44% (30)	6.953 (.008*)
	No	37% (64)	56% (38)	

Note. * *p*-value is less than 0.05. **Some science track attendees chose not provide gender, race, education, or age demographic data.

The description of "STEM career" for this research was based on the U.S. Bureau of Labor Statistics' (2021) definition as occupations requiring "scientific or technical knowledge at the postsecondary level" including jobs related to "computer and mathematical, architecture and engineering, and life and physical science occupations" (para. 7). Furthermore, a vast majority (82%) of non-science track attendees stated that they would be interested in attending science track events at science fiction conventions if the science track events were cross listed with other events hosted at the convention. Additionally, 86% of science track attendees and 76% of non-science track attendees shared that science fiction conventions would be an appropriate place to learn science.

Survey Protocol

The survey solicited information about science track and non-science track attendees' demographics, track attendance behaviors, and interest in science using Likert-scaled items and open-ended questions designed to document what attendees will do with the information gained at a science track session. Likert-scaled survey items were adapted based on a review of literature (identifying common themes) and from two published instruments: the Relevance of Science Education (ROSE) survey (Sjøberg & Schreiner, 2010) and the Student Attitudes Toward STEM (S-STEM) survey (Friday Institute for Educational Innovation, 2012), which was originally designed to capture student and teacher interest in science, STEM, and careers related to STEM. These survey items were modified to capture a broad, public audience's interest in science and aligned to the interest construct of person. Participant responses to the 10 Likert items were on a scale of one to five (strongly disagree to strongly agree). Cronbach's Alpha was calculated with an acceptable reliability value of 0.91 (Cronbach, 1951). An open-response question specifically posed to document what science track attendees plan to do with the information gained at a science track event was present at the end of the survey if respondents indicated they attended science track sessions.

Analyses

Quantitative Analysis: In consideration for comparing groups, survey responses were analyzed and reviewed within "STEM career" groups to examine differences between science track and non-science track attendees as there was a higher representation of individuals with STEM careers in the science track attendee group than in the non-science track group. A Mann-Whitney U test was conducted to analyze comparisons between groups. This test is a nonparametric statistical test that compares two unrelated samples with a Bonferroni correction to protect against Type 1 error (α = 0.005; two-tailed). This test is appropriate for comparison of data that is measured at the ordinal variable level that does not pass the assumptions for a parametric test. Furthermore, mean, median, standard deviation, mean rank, Mann-Whitney U test statistic, *p* value, and effect size (Field, 2013) for each Likert scaled-item were calculated and compared for science track and non-science track attendees.

Qualitative Analysis: The open-ended question designed to document what science track attendees plan to do with the information gained was analyzed by employing qualitative textual analysis (Creswell & Poth, 2018; Hsieh & Shannon, 2005). Approximately ninety-one percent (125 of 138) of the participants responded to the open-ended question, with answers ranging from one to 95 words. Six of the responses (e.g., "undetermined" and "probably not") could not be coded as they were too brief to provide adequate context. The average length of participant responses was 26 words and were analyzed using the components of the CML. After a review of the literature, a CML-based codebook was created. Codes corresponded to the primary constructs of CML (personal context, social context and physical context), along with their established sub-components. Statements with an emphasis on a personal interest in science, whether that interest was connected to a career or not, were coded as Personal context. Depending on the reference frame provided by the respondent, these were most often connected to the subcategories of "prior knowledge, interest and beliefs," "choice and control," or "motivations and expectations." Sociocultural codes were applied to statements in which the respondent discussed sharing information "within their social group" or "with others," including family, friends, or colleagues.

Physical context, according to Falk & Dierking (2000) includes the use of advance organizers for orientation, design of the setting, and extends to reinforcing events that go beyond the initial experience that reinforces learning. While this code was not as frequently used as the personal and social ones for exploring participant responses, it was most often applied to participant responses connected to how they would use the information they learned in specific settings as reinforcing events. For example, a specific application (rather than general) in the respondent's career such as "I repair welders and use the information to access the cutting-edge welding techniques and helps keep me employed." Other factors within the Physical context (i.e., advance organizers or design) as identified within CML were not relevant to this setting. It should be noted that some statements were coded in more than one category, depending on the complexity of their responses. For example, one participant responded to the question by stating, "I love science and like learning about different fields. And I tell stories to kids; this gives me ideas." This statement was coded as applying to both Personal (prior interests) and Sociocultural (sharing with others) factors. A total of 48% of participant responses were coded in more than one category. Three science education researchers were trained on the use of the codebook and jointly coded the data. Differences in coding were identified and resolved via discussion, and the codebook was refined and amended as the coding process unfolded. The remaining responses were divided equally among the three coders and were closed-coded for CML constructs using the refined codebook. After one round of coding (78% inter-rater agreement), the coders collaborated to resolve any conflicts in categorization resulting in a final inter-rater agreement of 97%. For each construct, frequency counts and percentages were calculated based on the science track attendee responses.

Results

Research Question 1- Are there differences between science track and non-science track attendees' (within STEM career groups) interest in science?:

In comparing science track attendees (*n* = 108) and non-science track attendees (*n* = 30) in which both groups stated they work in a STEM career, there were no differences in reported interest in science between science track and non-science track attendees. See Table 3 for this information.

Table 3

Individuals With STEM Careers – Comparison of Science Interest Between Science Track and Non-Science Track Attendees

Item (*alignment to interest construct*)	Group	Mean, Median (SD)	Mean Rank	*U*	*p* (effect size)
I find science interesting.	Science Track Attendees	4.89, 5.00 (.318)	70.36	1393.00	0.085 (0.14)
	Non-Science Track Attendees	4.70, 5.00 (.651)	61.93		
I enjoy learning about science.	Science Track Attendees	4.85, 5.00 (.357)	70.85	1474.00	0.243 (0.09)
	Non-Science Track Attendees	4.79, 5.00 (.651)	64.63		
Science has practical value for me.	Science Track Attendees	4.81, 5.00 (.582)	72.00	1350.50	0.032 (0.18)
	Non-Science Track Attendees	4.63, 5.00 (.669)	60.52		
Science is relevant to my life.	Science Track Attendees	4.82, 5.00 (.494)	69.86	1446.00	0.237 (0.10)
	Non-Science Track Attendees	4.70, 5.00 (.651)	63.70		
Science relates to my personal goals.	Science Track Attendees	4.72, 5.00 (.579)	69.84	1515.50	0.523 (0.05)
	Non-Science Track Attendees	4.63, 5.00 (.669)	66.02		
Science challenges me.	Science Track Attendees	4.79, 5.00 (.496)	71.72	1314.00	0.035 (0.17)
	Non-Science Track Attendees	4.60, 5.00 (.563)	59.30		
Understanding science gives me a sense of accomplishment.	Science Track Attendees	4.78, 5.00 (.460)	71.55	1291.00	0.051 (0.16)
	Non-Science Track Attendees	4.59, 5.00 (.568)	59.52		
I think about how I will use the science I learn.	Science Track Attendees	4.64, 5.00 (.676)	73.17	1224.00	0.012 (0.21)
	Non-Science Track Attendees	4.30, 4.50 (.794)	56.30		
I think about how the science I learn will be helpful to me.	Science Track Attendees	4.71, 5.00 (.581)	72.11	1338.00	0.058 (0.16)
	Non-Science Track Attendees	4.50, 5.00 (.682)	60.10		
I trust science.	Science Track Attendees	4.69, 5.00 (.587)	70.14	1550.50	0.634 (0.04)
	Non-Science Track Attendees	4.53, 5.00 (.937)	67.18		

In comparing science track attendees (*n* = 64) and non-science track attendees (*n* = 39) who stated they did not have a career related to STEM, science track attendees reported significantly higher scores relating to science interest (Question 1), personal relevance of science (Question 4), and sense of accomplishment (Question 7) with small effect sizes (Rosenthal, 1996). See Table 4 for this information.

Table 4

Individuals with Non-STEM Careers – Comparison of Science Interest Between Science Track and Non-Science Track Attendees

Item	Group	Mean, Median (SD)	Mean Rank	*U*	*p** (effect size)
I find science interesting.	Science Track Attendees	4.84, 5.00 (.407)	56.92	933.00	0.004* (0.29)
	Non-Science Track Attendees	4.51, 5.00 (.683)	43.92		
I enjoy learning about science.	Science Track Attendees	4.81, 5.00 (.432)	56.87	936.50	0.006 (0.27)
	Non-Science Track Attendees	4.49, 5.00 (.683)	44.01		
Science has practical value for me.	Science Track Attendees	4.64, 5.00 (.627)	55.88	1000.00	0.046 (0.19)
	Non-Science Track Attendees	4.38, 5.00 (.747)	45.64		
Science is relevant to my life.	Science Track Attendees	4.66, 5.00 (.511)	58.23	849.00	0.002* (0.30)
	Non-Science Track Attendees	4.21, 4.00 (.767)	41.77		
Science relates to my personal goals.	Science Track Attendees	4.20, 4.00 (.800)	56.44	964.00	0.041 (0.20)
	Non-Science Track Attendees	3.79, 4.00 (.978)	44.72		
Science challenges me.	Science Track Attendees	4.60, 5.00 (.661)	55.92	950.00	0.027 (0.21)
	Non-Science Track Attendees	4.31, 4.00 (.766)	44.36		
Understanding science gives me a sense of accomplishment.	Science Track Attendees	4.72, 5.00 (.487)	57.83	875.00	0.003* (0.29)
	Non-Science Track Attendees	4.31, 4.00 (.766)	42.44		
I think about how I will use the science I learn.	Science Track Attendees	4.36, 4.00 (.651)	57.36	905.00	0.012 (0.25)
	Non-Science Track Attendees	3.85, 4.00 (1.01)	43.21		
I think about how the science I learn will be helpful to me.	Science Track Attendees	4.47, 5.00 (.616)	56.69	948.00	0.024 (0.22)
	Non-Science Track Attendees	4.15, 4.00 (.709)	44.31		
I trust science.	Science Track Attendees	4.61, 5.00 (.581)	54.10	1049.50	0.180 (0.13)
	Non-Science Track Attendees	4.39, 5.00 (.755)	47.12		

Note. * denotes a *p*-value less than 0.005.

Research Question 2- How do science track attendees utilize the information provided at a science track session?

Science track attendees were asked to respond to an open-ended question to document what they do with the information learned or gained at a science track session. See Table 5 for information on primary codes, sub codes, and descriptions of the codes as well as example participant responses for each code.

Table 5

What Do Attendees Plan to Do with the Information After a Science Track Session?

Primary Code	Sub Code	Description of Code	Example Participant Responses	Science Track Attendees (%, *n*)
Personal	Factors that learners bring with them to the learning environment			66% *n* = 83
	Prior Interests and Beliefs	Desire to learn more comes from curiosity and to build on beliefs	"Recently I have become very interested in climate change because I think it is the most important challenge facing this world."	52%, *n* = 66
	Prior Knowledge	Knowledge that the individual brings to the learning experience	"I am a scientist. I like hearing about topics unrelated to my discipline at Con."	15%, *n* = 19
	Prior Experiences	Prior activities and background that influence the individuals desire to learn more	"I'm a physician. Sometimes I use it in my practice. Sometimes I use it in general conversation, or as an analogy in my practice or socially."	17%, *n* = 21
	Motivations and Expectations	Intrinsic motivations and desire to meet expectations contribute to learning experience	"I would like to further my career."	53%, n = 67
	Choice and Control	Learning facilitates choice and control	"Shape the world around me in a better light."	35%, *n* = 44
Social	Factors that influence learning come from the shared setting or facilitates social experiences by sharing new knowledge			42%, *n* = 53
	Within Group Interactions	Learning within a group setting provides benefits	"It helps me hold conversations with friends – passing on knowledge."	25%, *n* = 32
	With Others	Social learning that extends beyond one's social group	"I am a writer and use the information to ensure the science and facts in my stories are as correct and accurate as possible."	32%, *n* = 40
Physical	Factors that relate to what the learning experience brings to the individual in and beyond the physical learning environment			34%, *n*= 43
	Advance Information	Advance information helps provide motivation for learning	"Who knows, might come in handy specifically at some point, but even if it doesn't, I just enjoy knowing and understanding all kinds of stuff."	9%, *n* = 11
	Orientation to Space	Factors that relate to the learner's ability to navigate the learning environment	N/A	No coded response.
	Architecture Design Factors	Physical layout of information influences learning	"I love to be able to watch panels via streaming after the con, as sometimes I have to choose which of several things to attend."	1%, *n* = 1
	Design and Exposure to Programs	Factors that relate to the design of the learning experience	"Learning about science and new fields allows me to learn in a n informal and fun setting which later encourages me to do independent research and read research journals on my own."	1%, *n* = 1
	Reinforcing Events	Benefits of applying knowledge gained beyond the learning environment	"I use the information as seeds and water for ideas and playtime projects."	28%, *n* = 35

Note. Some science track attendees share more than one reason related to the codes described above.

Participants answering the open-ended prompt were allowed to provide a response that might align to more than one thematic code. Most attendees (66%) shared personal factors, such as prior experiences and beliefs, as how they plan to use the information to improve their daily lives. Statements that were coded for personal factors most often indicated some degree of personal interest which was often, but not always, connected to their career. For those whose interest was outside of their career, they often cited they would use the information they learned as, "fodder for self-improvement," for "personal enrichment," or for "developing critical thinking skills." For those whose interest was connected to their careers, they often started their response with, "I am a…." or "I work in…." then proceeded to explain their interest and how what they learned would apply to their career. For example, one respondent stated, "I'm an astronomy enthusiast, journalist, and photographer. I will use information gained from the Science track as a research resource." Other respondents showed a personal interest based on a passion for learning and felt that the information they learned would enhance their life. For example, one person who stated, "Science is the basis of EVERYTHING. Anything I can learn everyday adds purpose and understanding to our lives and improves my qualify of life in many ways. Knowledge is power. I want to learn all I can of this world while I'm still here!"

Approximately 42% of attendees indicated that they share the information obtained from a science track session with others (e.g., peers, colleagues, students, family, and friends). The responses coded within a sociocultural context related to respondents sharing information they learned in the science track within their social group or with others. For those who discussed how the information connected to their job, a sociocultural context was only also applied when their responses indicated they would engage in conversations with their peers based on what they learned. One example of this is the statement, "I work with children and teens, so sometimes I share what I've learned with them." Many of the respondents indicated the knowledge they gained in these sessions would be used informally, or in "conversation topics with friends." One respondent provided that they would share the information more creatively, "I tell stories to kids, this gives me ideas."

Over a third (34%) of attendees cited physical factors for impacting how they might apply the information in their daily lives. These responses aligned with CML as a reinforcing event, and for coding purposes, was always associated with a specific action. These respondents often indicated that the information they learned would be used in a work context to achieve a specific purpose, such as to, "create new approaches and concepts" (in computer applications) or to, "advocate for more funding for graphene research." Often, non-work-related applications were mentioned, such as one respondent who indicated they would use the information gained in their daily life by claiming "I learned some facts about water usage that will make me think about my water consumption in my daily life." It should be noted that this specific response was coded in multiple contexts (personal and physical). The application of the physical code (reinforcing event) was connected to the specific way in which the information would be applied in a specific context or setting beyond the session.

Limitations

Interpretation of the results and subsequent implications of this study are limited to the design of the survey, demographics of participants, and access to participants at a science fiction convention event. Although the survey protocol was modified from existing surveys and informed by literature concerning adults in informal learning environments, the results are not generalizable and are limited to this specific study's site, context, and population. Other science fiction conventions may have different structures when it comes to hosting science track sessions as well as target specific groups of people to attend. Another potential limitation is the number of people who answered the survey. Due to the small, focused area where the researchers were located, the traffic pattern compared to number of attendees was limited. Additionally, there may be limitations related to financial issues that may affect who can participate due to the costs associated in attending the convention, such as buying a convention membership ticket and traveling to the convention. Future research should focus on survey protocol development to document specific science education factors of adults in these informal learning contexts. Finally, research designs in investigating science fiction conventions as spaces for learning science could provide awareness of how to engage the public in science discourse to support a science literate populace.

Discussion

Science fiction conventions provide a unique opportunity for public access to science experts through science track events. It is important to recognize the potential effect of science fiction convention events on the understanding of science and the potential for impacting scientific literacy with the public. Through the opportunities these conventions offer for the public to engage in the language and conventions of science, those that attend these events may find it easier to participate in the culture of science. Science fiction conventions, as collaborative learning spaces, can connect science enthusiasts from all walks of life, including teachers, experts, students, and the public to scientific endeavors. These conventions could potentially support a rich learning experience for the public to engage in open-dialogue discussions with scientific experts, as well as an opportunity for science educators to engage with the community and expand their knowledge of scientific concepts and applications.

Diversity at Science Fiction Conventions

Science fiction convention spaces could support the learning of science with diverse communities. As noted in the demographic information, almost a third of attendees who participated in the study did not identify as white, the majority of attendees were young (under 45 years of age), and there was an almost equal representation of male and female respondents to the survey. These demographics may suggest that science fiction conventions might be an untapped science learning environment, connecting to a younger, more diverse community. Representation of diverse voices in science, STEM careers, or STEM learning environments is often limited due to perceived barriers (Hite et al., 2019; Sadler et al., 2012; Saw et al., 2018; Swafford & Anderson, 2020). As such, science fiction conventions could provide a unique opportunity for the public to interact with scientists, which may help deconstruct general misconceptions of science and scientists, and provide educational programming. Because Hasse (2015) noted that there may be cultural and gender biases and barriers that may limit participation of some individuals in these spaces, future exploration on how these groups participate in these spaces is warranted as women, diverse racial/ethnic groups, and individuals in varying socio-economic strata are attending these sessions. Highlighting the current landscape of global connection and the understanding of the impact people have on each other, the need for a scientifically literate populace, and the need for individuals to pursue STEM careers, it is imperative to support informal learning experiences that transcend the traditional formal and informal learning environments wherever they are found for diverse audiences and to allow for broader participation in the culture of science.

Science Interest and STEM Careers

There may be underlying influences or factors of career choices that may be related to attendees' science interest. There were no identified differences of interest in science between science track and non-science track attendees when the attendees reported having a STEM career. However, for those attendees who stated that they did not have a career related to STEM, there were reported differences in science interest items between the science track and non-science track attendees. Jones et al. (2019) found that adult STEM hobbyists, who had a STEM career, reported that their choice to have a career in STEM was influenced by the involvement of their informal learning experiences within the STEM hobby. In examining university students' STEM interest, Dabney et al. (2012) shared that involvement in out-of-school time science events, middle school interest in science, and gender were significant factors in STEM career interest. For science fiction convention attendees, involvement in a STEM career may be influenced by interest in science. However other factors, as noted in the aforementioned studies, may also provide information regarding the difference in science interest items among attendees who did not have a STEM career. Overall, 82% of non-science track attendees stated that they would be interested in attending science track events at science fiction conventions. Further analysis of this finding was explored to determine the interest in attending science track sessions among the non-science track attendees based on the attendee's career. Seventy-nine percent (n = 27) of non-science track attendees who had STEM careers, and 86% (n = 25) of non-science track attendees who did not have STEM careers, had interest in attending science-track sessions if cross listed in the convention programming. This may suggest that although there may be differences in science interest among non-science track attendees in relation to attendee STEM career choice, in general, non-science track attendees would participate in science track sessions if they are aware of the opportunity. Furthermore, participation in science fiction convention events may influence individuals' interest in science and career choice. This may provide the foundation to support future research into accessibility and efficacy of science programming, fostering science interest, and examining factors related to STEM career choice and the participation in science fiction convention activities for the public.

Border Crossings into the Culture of Science

While the CML is a framework designed specifically for exploring learning in informal, museum contexts, it is appropriate for this setting. Rather than consisting of exhibits, science fiction conventions provide "tracks" in which attendees choose to participate. By exploring the motives of science track attendees in the science fiction setting through the lens of the CML framework, insights are provided about how adult learners utilize what they learn in informal settings. According to Falk and Dierking (2000), CML recognizes that learning is complex and situated. Context is important for "learning that has also been emphasized by others" (Falk et al., 2007, p. 745). Track sessions within this setting provide an unusual context for informal learning in which attendees interact with experts and others.

Within this setting, Personal factors are most often cited by attendees (66%) for how they use what they learn in this setting most often connected to "motivation and expectations," and "prior interests and beliefs." While many attendees selected specific sessions because of their education, prior experiences, or jobs, many attended sessions because of the opportunity to learn for the personalized purpose of "personal enrichment." New knowledge is an end in itself, providing "new things to mull about" or "fodder for self-improvement." The desire to learn new things for the sake of learning seems to be enough of a purpose for a great many attendees. In the words of one participant,

> I like learning about the universe we live in and the possibilities for our future. As an informal learning environment, these sessions provide opportunities for individuals to engage in the culture of science for the joy of learning, without a specific or predetermined purpose.

Sociocultural factors related to the motives of attendees suggests that a large percentage (42%) of these attendees felt that the new knowledge they gained in these sessions was worthy of sharing with others, both within and outside their social group. While learning in this environment is socio-culturally situated, the intent of these attendees was to extend that context in sharing what they learn, “in conversations with friends,” “family,” and “with my students and colleagues.” It should be noted that the new knowledge these track attendees gained improves the quality of their interactions with others by allowing them to “be more informed,” and to “speak more knowledgeably.” In the words of one participant, “I don’t want to be someone who speaks out of their rear end.” Being able to engage in conversations with others about scientific “norms, practices, language and tools” (NRC, 2010, p. 20) is an important way in which individuals can participate in the culture of science.

Because our question related to how attendees planned to utilize what they learned, the Physical factors cited by participants tended to connect to reinforcing events and experiences beyond the science fiction convention. Most often these responses were connected to specific work-related purposes, such as “to improve treatment/outcomes” or to “create new approaches and concepts.” Less often, personal uses for new knowledge to reinforce events and experiences are cited such as, “to inform my politics and influence which issues I contact my elected representatives about,” or for “creating costumes.” Therefore, the knowledge gained by attendees serves specific purposes in how it is applied in a Physical context, beyond the immediate setting, building on the importance of learning that is connected to Personal and Sociocultural factors.

Conclusion

Overall, science fiction convention attendees may be interested in exploring more informal science learning opportunities in these spaces, supporting the position that science fiction conventions have a rich potential as learning environments for informal science learning. The results of this study indicate that there is a diverse population of attendees who are interested in the connection between science and science fiction, as well as share specific motives and intentions regarding their learning at science track sessions. Science interest and motives provide a unique perspective into how science fiction convention attendees learn about science, who they share their learning of science at these events with others, and how they integrate this learning into their own personal or professional spaces. Science track supervisors and convention planners could use the information garnered here and in future research to better market and advertise non-fiction offerings at conventions. By cross listing non-fiction panels with panels solely related to the fictional aspects of science fiction, these venues could potentially reach more people who are unaware of science programming offerings at conventions and who might benefit from such offerings. In addition, the diversity of attendees in this study (e.g., majority of the attendees were under 45 years of age; a third of attendees identified ethnicity/race as non-white; approximate equal representation of males and female attendees) could provide an opportunity to engage a broader cross section of the public in science. This may be achieved by engaging them in informal learning environments, where science fiction interest and science merge. In future studies regarding science fiction conventions as places to learn science, the term *diversity* should be more inclusive including women/non-binary (gender minorities), non-white (racial/ethnic) minorities, and individuals with disabilities.

Furthermore, approximately 20% of the participants in this study shared their occupation was related to education, and many participants conveyed the notion that they would integrate their learning from the science tracks into their professional lives, including creating lessons. Although these findings are encouraging and show that educators are seeking out ways to further their knowledge through informal learning and non-traditional professional development activities, more research is needed. Future research in this area may determine how educators are utilizing science fiction and science fact gained from science fiction conventions in their classrooms, whether this data is similar across the United States, and how to leverage informal learning into professional development. This information can be of particular interest to those who plan and implement professional development and researchers studying both formal and informal education contexts through the lens of science fiction. Science teachers could also benefit from this information as they consider ways to make connections with scientists in the field who have experience in communicating with the public. Future research may need to focus on attendee life-span choices, interest, cultural and social factors, and experience as to investigate how interest in science may influence the choice or engagement in science in informal learning contexts. Lastly, there is a need to examine additional factors, such as the flow of information from scientist to the community, which may enhance the understanding of how science information is viewed, perceived, and shared in science fiction convention spaces. Based on the ever-changing landscape of educational policy and practice, the interaction between the public, science experts, and formal and informal learning environments and experiences may be crucial in supporting science literacy.

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Examining Pre-Service Elementary Teacher Self-Efficacy for Engineering Education

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ABSTRACT

Engineering education is receiving increased attention, although teacher preparation for engineering in the elementary grades is not well understood. This study investigated the influences of an elementary science teaching methods course, focused specifically on elementary engineering, on teacher candidates' self-efficacy for teaching engineering in elementary classrooms. The study builds on prior research with the Teaching Engineering Self-Efficacy Scale (Yoon et al., 2014) and offers insight about the tool's use with teacher candidates. These findings are accompanied by qualitative analysis of participants' responses to course assignments and semi-structured interviews to further explore connections between efficacy and understanding. Strong gains are reported in participant self-efficacy, even as some misunderstandings remain about engineering and the relationship of engineering, science, and technology. Overall, the study reveals the power of a focused methods course that includes field experiences in an elementary school with an expert teacher. Implications for teacher educators and researchers are discussed.

Keywords: elementary engineering, self-efficacy, pre-service teachers

Introduction

Arguing for the introduction of engineering in Massachusetts' school curriculum, Ioannis Miaoulis (2010) referred to engineering as "the missing core discipline" (p. 37). That is, while elementary and secondary education in the United States has concerned itself with learning about the natural and social worlds we inhabit, it has not sufficiently prepared students to understand the engineered, designed world that influences our daily lives. However, with the publication of *A Framework for K-12 Science Education* (National Research Council [NRC], 2012) and the associated Next Generation Science Standards (NGSS, NGSS Lead States, 2013), there is increasing attention paid to engineering education in kindergarten through grade 12 (K-12) settings. The NRC (2012) explained in these reform documents that

> engineering and technology are featured alongside the natural sciences (physical sciences, life sciences, and earth and space sciences) for two critical reasons: (1) to reflect the importance of understanding the human-built world and (2) to recognize the value of better integrating the teaching and learning of science, engineering, and technology. (p. 2)

As engineering finds its home within the core curriculum, science teachers are expected to engage students in authentic engineering learning experiences that promote understanding and use of engineering practices, habits of mind, and design processes (National Academy of Engineering [NAE], 2009; Sneider, 2016). Teachers are further challenged to harness the potential of engineering design to better connect learners to concepts in science, math and other disciplines (Kim et al., 2019; Reimers et al., 2015; Wendell, 2014). The integration of engineering into the science curriculum leads us as teacher educators to ask, how are we preparing our teacher candidates to support student learning of engineering and its relationship to science and other subject areas?

Research suggests that supporting elementary teachers' preparation for engineering education is an area of need (Antink-Meyer & Meyer, 2016; Banilower et al., 2018; Capobianco & Radloff, 2021; Cunningham & Carlsen, 2014; Douglas et al., 2016; Pleasants et al., 2020; Pleasants et al., 2021; Yoon, et al., 2013). The nature of engineering has not been well defined for teachers (Pleasants & Olson, 2019), and engineering education may feel different from teaching other subject areas. For instance, without clear-cut or singular solutions, engineering design challenges can promote a level of unpredictability that requires teachers to act as a fellow participant in the learning process (Capobianco, 2011). Thus, teachers may need to shift their mindsets to embrace uncertainties in the classroom and do more to help students persist through frustrations and failures (Dickerson et al., 2016; Lottero-Perdue, 2017). In sum, teachers need to be prepared to not only understand this new content area, but also new pedagogical approaches.

Beginning teachers need opportunities to refine their understandings of both scientific inquiry and engineering design (Kaya et al., 2017; Kim et al., 2019) and gain confidence in their abilities to engage youth in authentic engineering learning (Yaşar et al., 2006; Yoon et al., 2014). Cunningham and Carlsen (2014) summarize guiding principles for professional development of both pre- and in-service teachers, including to a) engage teachers in engineering practices, b) model pedagogies that support engagement in these practices, c) provide experience as both learners and teachers, d) develop teachers' understanding of the fundamentals of and interconnections between science and engineering, and e) promote teachers' understanding of engineering as a social practice. Teacher candidates also need opportunities for authentic practice with young learners, such as through robust field experiences in schools (Park & Oliver, 2008), and reflection around these experiences.

Teacher preparation programs play an important role in promoting engineering in the elementary grades especially. While there are a multitude of complex factors that influence teachers' practice, research suggests that teachers who experience success in their preparation are more likely to make the commitment and build the understanding and confidence they need to be successful in their own future classrooms (Tschannen-Moran et al., 1998). The purpose of this research is to examine the influences of a science methods course that included a specific focus on engineering in grades 1-5 on teacher candidates' self-efficacy for teaching engineering in elementary grades.

Engineering and Science

The inclusion of engineering in *The Framework for K-12 Science Education* (NRC, 2012) marks a shift from previous science education policy documents. The *Framework* argues that "engagement in the practices of engineering design is as much a part of learning science as engagement in the practices of science" (p. 11). Here, science refers to the study of the natural and physical world, while engineering is broadly defined as "any engagement in a systematic practice of design to achieve solutions to particular human problems" and technology as "all types of human-made systems and processes" (NRC, 2012, p. 11).

Certainly, the two disciplines are related and mutually supportive. For instance, engineers often apply scientific principles in the design of solutions, tools, and products. In the K-12 context, engineering design has often been promoted as a means of enhancing and providing relevance for science education (Apedoe et al., 2008; NRC, 2012), serving as much as a pedagogical approach for science teaching as a unique discipline (Pleasants et al., 2021; Purzer & Quintana-Cifuentes, 2019). Yet, when engineering design is presented as an application of science concepts, it is important that educators be able to help students appreciate *how* the science ideas are relevant to the engineering context (Chao et al., 2017).

Engineering and science also engage in several related practices or behaviors, which are highlighted in the NGSS. Both use and develop models, plan, and carry out investigations, analyze and interpret data, use mathematical and computational thinking, rely on data and evidence to make decisions, and communicate information and ideas (NGSS, 2013). Collaboration, creativity, and innovation are also central to both science and engineering. Productive responses to failure are arguably essential to any learner of any discipline, but especially within the field of engineering given that failure is an important element of the engineering design process (Lottero-Perdue, 2017; Petroski, 2006). Additionally, both disciplines have an influence upon, and are influenced by, society. Outcomes influence the way that people interact and the environments people inhabit. Society also influences science and engineering, as they are both human and social endeavors.

Yet, there are also important distinctions between science and engineering. It must be noted that critiques of the *Framework* offer a limited perspective on these unique differences (see Cunningham & Kelly, 2017). Scientists seek to explain the natural and physical world, generating new, verifiable knowledge by asking questions that are answered through rigorous investigations. Engineers consider criteria and constraints as they design solutions to address specific problems, needs and desires that will improve lives and the environment (Major, 2018). In science the audience is typically other scientists, while in engineering, the audience is often a specific client (Pleasants & Olson, 2019). Engineering problems are often ill-structured, with constraints that limit potential solutions and even eliminate the ideal solution. Thus, engineers must consider multiple solutions and optimize based on what resources (materials, knowledge, tools) are available (Cunningham & Kelly, 2017; Pleasants & Olson, 2019). It is critical that teacher educators and teachers have a strong grasp of both science and engineering, and the relationships and distinctions between science and engineering, if they are to support youth in also developing engineering knowledge and understanding and skill.

Engineering in K-12 Education

While the United States has articulated *A Framework for K-12 Science Education* (NRC, 2012) and the related NGSS (NGSS Lead States, 2013), which point to how engineering can serve as a route to enhancing students' science learning, there still lacks agreed upon guidance for pre-college engineering education. Most frequently, engineering is incorporated into science through involving students in engineering design challenges, where they develop technological solutions to context-specific problems (NAE, 2009; Pleasants et al., 2021). One of the best-known curricula is Engineering is Elementary (EiE, see Cunningham, 2009), which was also utilized by participants in this study.

In 2014, Moore and colleagues put forth *A Framework for Quality K-12 Engineering Education* which could serve as a guide for structuring future standards and initiatives. After several iterations, these authors put forth key indicators for quality pre-college engineering curricula. This include opportunities to: Apply science, engineering and mathematical knowledge; Engage in processes of design; Develop conceptions about the nature of engineering and the job of engineers; Engage in engineering habits of mind; Gain experience with the techniques, skills, processes, and tools engineers use; Grapple with current local and global issues and the potential impacts that engineering solutions have on these, as well as the ethical considerations inherent to engineering work; and Communicate ideas in both technical and common language.

In 2019, Pleasants and Olsen put forth a framework on the nature of engineering that could support K-12 students, learning, and teacher practice. They identify and elaborate upon nine features of engineering: Design in engineering; Specifications, constraints, and goals; Sources of engineering knowledge; Knowledge production in engineering; The scope of engineering; Models of design processes; Cultural embeddedness of engineering; The internal culture of engineering; and the Relationships between engineering and science.

These frameworks will continue to inform the curriculum development within the field of engineering education as well as pre- and in-service teacher education.

Teaching Engineering Self-efficacy

The literature consistently demonstrates that teachers' classroom actions are linked to their belief systems (Luft & Roehrig, 2007). This is of interest to teacher educators since, although experienced teachers' beliefs are consistently shown to be tenacious (Luft, 2001), there are encouraging examples of beginning teachers' beliefs about teaching and learning science being positively influenced by the support they receive early on, including from a preparation, induction, or mentoring program (Osisioma & Moscovici, 2008). Thus, part of preparing teachers to meet new expectations around science and engineering education is promoting what Yoon et al. (2014) have termed *teaching engineering self-efficacy*, or "a teachers' personal belief in their ability to positively affect students' learning of engineering that reflects the multifaceted nature of self-efficacy of teaching engineering" (p. 479).

The attention to self-efficacy as it relates specifically to teaching engineering stems from the understanding that self-efficacy is situation specific. According to Bandura's (1977) social learning theory, self-efficacy beliefs are perceptions about one's capabilities to successfully perform a task or behavior within a given context. Building off this idea, Tschannen-Moran et al. (1998) put forth a model of the relationship between a teacher's judgment of their personal capabilities and competencies and their analysis of a particular future task and situation. This model also describes the cyclical nature of teacher self-efficacy. That is, a teacher's self-efficacy beliefs can influence their instructional practice in each situation, as well as students' psychological and academic outcomes. Subsequently, a teacher's perception of the degree of successful performance in that past situation can contribute to raising or lowering their self-efficacy beliefs going forward. Complementary to self-efficacy is outcome expectancy, or an individual's assessment of the outcomes resulting from their performance of a task (Bandura, 1977). While the nature of the relationship between self-efficacy and outcome expectancy is debated (Tschannen-Moran & Woolfolk-Hoy, 2001; Williams, 2010), the two constructs are typically measured together.

With a goal to understand teacher efficacy within the specific context of K-12 engineering, Yoon et al. (2014) developed and validated the *Teaching Engineering Self-efficacy Scale* (TESS), a 23-item instrument which measures teacher beliefs across four sub-scales: engineering pedagogical content knowledge self-efficacy, engineering engagement self-efficacy, engineering disciplinary self-efficacy, and outcome expectancy. See Table 1 for TESS constructs. The TESS instrument was developed through a process of exploratory and confirmatory factor analyses using structural equation modeling and exhibited high internal consistency reliability coefficients (Cronbach's α ranging from 0.89 to 0.96).

Methods

This study took place in conjunction with an elementary science methods course that was designed with a focus on engineering in grades 1-5. We sought to better understand how well the course was influencing candidates' self-efficacy for teaching engineering in elementary classrooms. Thus, we collected, analyzed, and integrated quantitative and qualitative data over two iterations of the course, following an explanatory sequential design. In this design, an initial quantitative phase is followed by a subsequent qualitative phase intended to help to explain the quantitative results

(Creswell & Clark, 2017). This mixed methods approach was selected to increase the breadth and depth of understanding and corroborate findings. It is appropriate for this study given the known complexity of measuring self-efficacy (Morrell & Carroll, 2010; Thomson et al., 2022; Wheatley, 2000).

Table 1

Constructs Around Self-Efficacy for Teaching Engineering

Construct	Definition *(adapted from Yoon et al., 2014)*	Example TESS Item	Example Statement
Engineering pedagogical content knowledge self-efficacy (KS)	Teachers' personal belief in their ability to teach engineering to facilitate student learning, based on knowledge of engineering that will be useful in a teaching context	I can discuss how given criteria affect the outcome of an engineering project.	"I now understand what engineers exactly do, the products they create, and the process that they use to arrive at these solutions." [Year 1, Essay]
Engineering engagement self-efficacy (ES)	Teachers' personal belief in their ability to engage students, while teaching engineering	I can encourage my students to think creatively during engineering activities and lessons.	"It important to "talk about students' lives and what they're interested in. I think that's a big part of it too because if you're doing a project where the students aren't interested then it's going to take longer and if they're interested then they get going and they want to get to the design phase and they want to get to the build phase and they want to get to the improve phase." [Year 1, Interview]
Engineering disciplinary self-efficacy (DS)	Teachers' personal belief in their ability to cope with a wide range of student behaviors during engineering activities	I can establish a classroom management system for engineering activities.	"It's a rowdy atmosphere. And not rowdy in a bad way but the kids are excited, and they want to socialize about the project." "They were so involved and had so many ideas and just loved to share what they were thinking." [Year 1, Interview]
Outcome expectancy (OE)	Teacher's personal belief in the effect of teaching on students' learning of engineering	I am generally responsible for my students' achievements in engineering.	"It's hard ...thinking about questions that will spark their interests and then also phrasing questions in a way that gets them thinking." [Year 1, Interview]

The study took place over two consecutive years. Given the small sample size of Year 1, additional data were collected and analyzed in Year 2 to increase the participant pool and look for trends across both years. One of the researchers was the primary instructor for the course in Years 1 and 2; the other researcher was familiar, but not affiliated, with the course and was not involved with the candidates outside of the research. Both researchers have experience with engineering education and initial teacher preparation, one specializing in science and the other in math teacher education.

Context and Participants

Participants included undergraduate teacher candidates enrolled in a semester-long elementary science methods course at a university in the central United States. The course is a requirement for candidates in the Elementary, Special Education and Bilingual/Bicultural Education programs, and all participants were pursuing one of these three programs. Eight of ten candidates enrolled during Year 1 and all 12 candidates enrolled during Year 2 of the class agreed to participate in the study.

The course was influenced by Cunningham and Carlsen's (2014) guiding principles for professional development summarized previously. See Table 2 for course component alignment with the guiding principles for teacher education.

Table 2

Alignment of Course Components and Design Criteria for Engineering Teacher Education

	Guiding Principles for Teacher Education (adapted from Cunningham & Carlson, 2014)				
	Engage candidates in engineering practices	Model pedagogies that support engineering practices	Provide opportunities to experience engineering as both learners and teachers	Develop understandings about interconnections between science and engineering	Promote understanding of engineering as a social practice
Course Component					
Course readings, discussions & written reflections				x	x
Engage in example science & engineering 5E lesson	x	x	x	x	x
Review EiE videos		x	x		x
Visit museum engineering exhibit	x		x		x
Observe & participate in elementary engineering lab	x	x	x	x	x
Conduct Engineering Talk with youth			x		
Develop lesson plans				x	

The course introduced candidates to *A Framework for K-12 Science Education* (NRC, 2012) and the NGSS (NGSS Lead States, 2013), including the presentation of engineering alongside science. Since the type of teaching and learning promoted in these reform documents was different than what most candidates had experienced in their own elementary education, it was particularly important that they had opportunities to engage in experiences that modeled strong examples of phenomena-based learning, and science and engineering integration, and to reflect upon these experiences. Candidates engaged in a sample 5E lesson as learners, in which they developed explanations for how a light bulb connected to a single battery lights up and then used that scientific understanding in the design of a hands-free, battery-powered reading lamp (see Jackson et al., 2011.) Candidates' engagement in engineering as learners continued during a visit to a local museum's engineering-focused exhibitions.

Then, as will be detailed further, candidates had the opportunity to observe and assist an expert veteran teacher to facilitate engineering learning for elementary aged youth. Weekly written assignments and class discussions allowed for candidates to reflect on these experiences from the perspectives of both learner and teacher.

A local partner school with a culturally and linguistically diverse, low-income population has a dedicated engineering lab space in which grade K-5 classes visit approximately once every seven days, following a rotating schedule. The engineering lab teacher and the methods course instructor had a strong working relationship from prior collaborations that allowed for alignment of course goals for both the university and elementary students and co-teaching. The Partner Teacher utilized the EiE curriculum (Cunningham, 2009) in conjunction with other teacher-developed engineering and science lessons. Candidates were introduced to the EiE curriculum guides and encouraged to go to the EiE website to explore videos of other classrooms and units.

Teacher candidates spent approximately one hour per week for eight weeks in the engineering lab working with the various Grade 2 through Grade 4 classes that visited the lab. Pairs of candidates typically worked with small groups of students during the class sessions and each week they were able to speak informally with the Partner Teacher, learn about her instructional decision-making, and ask questions, such as about the lessons, students, the school's approach to engineering and science education, etc. Candidates also had an opportunity to plan and conduct "engineering talks" with students to learn more about their perspectives on the lessons they were participating in and uncover their understandings about engineering.

Data Sources

Both quantitative and qualitative data were collected. The TESS served as a quantitative measure of candidates' self-efficacy beliefs toward teaching engineering (Yoon et al., 2014). The TESS was administered as a pre-test at the beginning of the course, prior to exposure to the engineering classroom or curriculum, and as a post-test upon completion of the course.

A subsequent qualitative phase allowed for additional and complementary insight into candidates' understandings of and beliefs about teaching engineering. The qualitative data were deemed important since high self-efficacy can at times negatively correspond with depth of understanding, such as when individuals are overconfident because they are unaware of what they do not know (Wheatley, 2000). Qualitative data also provided insight into participants' thoughts about specific aspects of the methods course and fieldwork, including any influence on their knowledge, understandings, and beliefs.

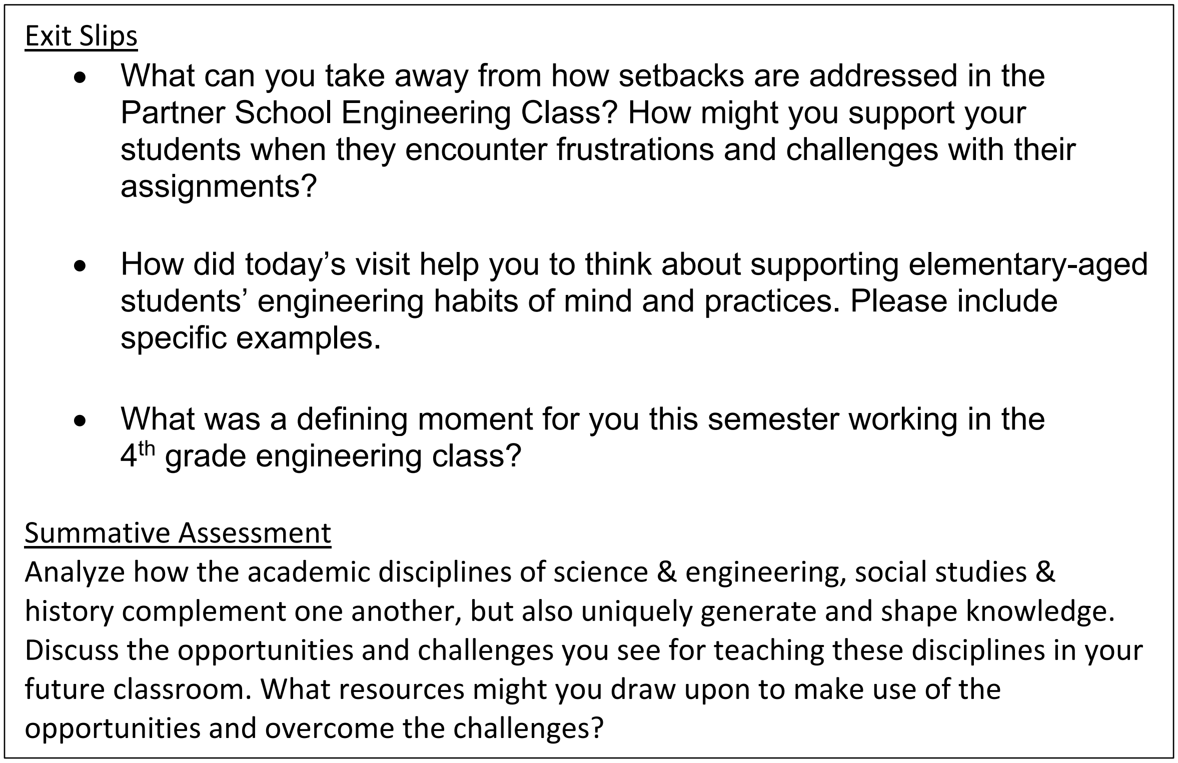
Multiple sources of data were collected for this qualitative phase: written reflections about the TESS, interviews, and various written course reflections and assignments, as will be discussed. After completing the TESS post-tests, candidates were given the results from their pre- and post-tests. They then wrote a reflection explaining why they chose the responses they did and any changes they noticed between the TESS pre- and post-tests. See Appendix A for this information.

Six candidates in Year 1 and 12 candidates in Year 2 also agreed to participate in semi-structured, in-person interviews at the end of the semester. Interviews (see Appendix B) probed candidates' thinking about their own prior experiences with engineering, how their understandings of engineering and teaching engineering had shifted throughout the semester, and implications of their semester experiences for future teaching. Each interview lasted about 25 minutes and was conducted and transcribed by a graduate assistant not affiliated with the course. Candidates who did not wish to participate in an interview were invited to complete and submit an essay addressing the same questions as the interview; three participants took this option.

Additional qualitative data came from course assignments that candidates provided access to for the study. Names and other personal identifiers were replaced with codes. These data sources included weekly open-ended reflections in the form of "exit slips" and written responses to a summative assessment. See Figure 1 for example prompts. Overall, the multiple data sources allowed for triangulation to support the validity of the qualitative conclusions (Creswell & Clark, 2017).

Figure 1

Example Written Assignment Prompt



Exit Slips

- What can you take away from how setbacks are addressed in the Partner School Engineering Class? How might you support your students when they encounter frustrations and challenges with their assignments?
- How did today's visit help you to think about supporting elementary-aged students' engineering habits of mind and practices. Please include specific examples.
- What was a defining moment for you this semester working in the 4th grade engineering class?

Summative Assessment

Analyze how the academic disciplines of science & engineering, social studies & history complement one another, but also uniquely generate and shape knowledge. Discuss the opportunities and challenges you see for teaching these disciplines in your future classroom. What resources might you draw upon to make use of the opportunities and overcome the challenges?

Data Analysis

Analysis of quantitative data began by following the guidelines outlined by Yoon et al. (2014) for calculating raw and mean scores of the four TESS constructs described above, as well as an overall raw score of teaching engineering self-efficacy. Descriptive statistics were calculated for each test administration and for each dimension of the TESS, as were changes in candidates' scores from pre- to post-test. Changes in candidates' teaching engineering self-efficacy beliefs across the course were determined through comparison of pre- and post-test scores on the TESS. The percent difference from pre- to post-test is reported (See Figure 2 and Tables 3 and 4).

Since the goal was to use the qualitative phase to bring nuance and context to results of the quantitative phase, we began with a general coding scheme related to the three themes of interest: engineering teaching self-efficacy, knowledge and understandings of engineering and engineering education, and influences on candidates' knowledge, understandings, and efficacy. For the first coding category, an a priori coding scheme corresponding to the efficacy constructs measured by the TESS instrument was outlined (see Table 3). We also applied conceptually derived ratings of high or low to indicate whether data were exemplary of high or low efficacy beliefs. The second coding category targeted candidates' knowledge and understandings of engineering and teaching engineering. These codes were derived from an interaction between the data and the literature (Bingham & Witkowsky, 2021. See Table 3 for these constructs. For instance, the code *knowledge for managing engineering learning* *environments* was not initially one we anticipated but it emerged from the data. Given that novice teachers often are concerned about but feel unprepared for the challenges of managing a classroom (Flower et al., 2017), it is not surprising that most participants brought up this topic in their interviews and assignments in both Year 1 and Year 2. Again, we applied conceptually ratings of high or low to indicate whether data were exemplary of deep or shallow levels of knowledge and understanding.

Table 3

Constructs for Knowledge about Engineering and Engineering Education

Knowledge Construct	Definition	Related literature
Engineering	Evidence of understanding about engineering as a practice and a profession	Engineering is concerned with the design of technologies (broadly defined), systems and processes (Pleasants & Olson, 2021)
Relationship between engineering and science	Evidence of understanding about how engineering and science are mutually beneficial, and how the disciplines compare	Engineering shares characteristics with the natural sciences but has unique goals and utilizes different approaches (Pleasants & Olson, 2021)
Engineering process of design	Evidence of understanding about the engineering design processes	Design processes involves iterations of defining and delimiting problems; developing potential solutions; evaluating pros and cons in light of constraints and trade-offs; testing and evaluating and optimizing solutions (Moore et al., 2014; NAE, 2009)
Engineering habits of mind	Evidence of understanding about engineering habits of mind	Engineering habits of mind include collaboration, ability to communicate with varied audiences, attention to ethical considerations, systems thinking, creativity, reflective thinking, productive responses to failure (Moore et al., 2014; NAE, 2009)
Pedagogical content knowledge related to engineering in elementary grades	Evidence of understanding about how to apply engineering design processes to classroom situations, how engineering can be integrated into science curricula, classroom management strategies for teaching engineering	Engineering design activities involve students in designing technological solutions to context-specific problems (NAE, 2009). Activities highlight how the science ideas are relevant to the engineering context (Chao et al., 2017)
Pedagogical content knowledge related to managing engineering learning environments	Evidence of knowledge about managing learning environments for elementary engineering	Elementary engineering activities often necessitate hands-on materials, cooperative group work, a variety of workspaces, and making mistakes (Petrich et al, 2013)

A third major coding category – influences on knowledge, understandings, and efficacy – served to identify those elements of the course experience that participants indicated were impactful on their knowledge and understandings and/or self-efficacy beliefs. Codes for this category emerged from the data in Year 1 and included prior personal experiences, field experience, and course readings and assignments. We utilized these same codes with the Year 2 data.

To check for inter-coder reliability, the two researchers each used Dedoose (2018) software to review the same Year 1 data source in search of meaningful segments – sentences or groups of sentences constituting a complete thought – related to the themes of interest: engineering teaching self-efficacy, knowledge and understandings of engineering, and influences on knowledge, understanding, and efficacy. The software enabled the researchers to check for areas of consistency and inconsistency. The researchers discussed any discrepancies and refined the coding scheme to increase clarity. One such point of discussion was around what terms might be included in the coding category Engineering Habits of Mind and how many different examples of habits of mind would indicate a weak versus strong understanding.

Once a consistent level of agreement (over 90%) was reached, coding of the remainder of the Year 1 data continued independently, with the researchers meeting throughout to discuss the coding, emerging patterns, and resolve any subsequent discrepancies. Verification occurred continuously throughout the entire analysis process by checking for inter-coder reliability and returning to the data corpus in search of emerging patterns as well as disconfirming evidence for each conclusion set forth. Analysis of Year 2 data followed a similar process, using the refined coding scheme from the Year 1 analysis. Overall findings were revised to account for the patterns identified across both years of data.

Results

Teaching Engineering Self-efficacy

Qualitative and quantitative data assignments revealed that at the beginning of the course candidates lacked confidence in their own understanding and in their beliefs about being able to facilitate engineering experiences for youth in the classroom. However, participants made strong gains by the end of the course. These goals align with the key objectives of the course, which included "developing specific skills, competencies, and points of view needed by teaching professionals."

Results of the quantitative analysis indicate that candidates made gains in their self-efficacy during the course, as would be expected. See Figure 2 and Tables 4 and 5 for information on TESS scores for study participants. Overall, TESS scores improved by 21% in the Year 1 cohort and by 31% in the Year 2 cohort, with scores near the maximum score possible. There was also strong growth across each of the various dimensions of engineering self-efficacy. By the end of the course, candidates demonstrated strong personal beliefs in their abilities to engage students while teaching engineering (ES) and to cope with a wide range of student behaviors during engineering activities (DS). Candidates' personal belief in their abilities to teach engineering (KS) increased by 43% (Year 1) and by 65% (Year 2) from the beginning of the course to the end of the course.

Despite the strong improvement on KS items from pre- to post-test, we note that high pre-test scores for ES and DS items in Year 2 left little room for growth. Again, this suggests that candidates may have held inflated views about their abilities initially, given their lack of experience in an elementary engineering classroom. We also caution that despite the valuable time spent in an elementary engineering lab as part of the course, candidates lacked experience leading engineering learning activities and so the applicability of the OE section of the TESS remains questionable for this group of participants.

Figure 2

Mean Pre- and Post-Test TESS Scores Across Four Dimensions for Years 1 and 2

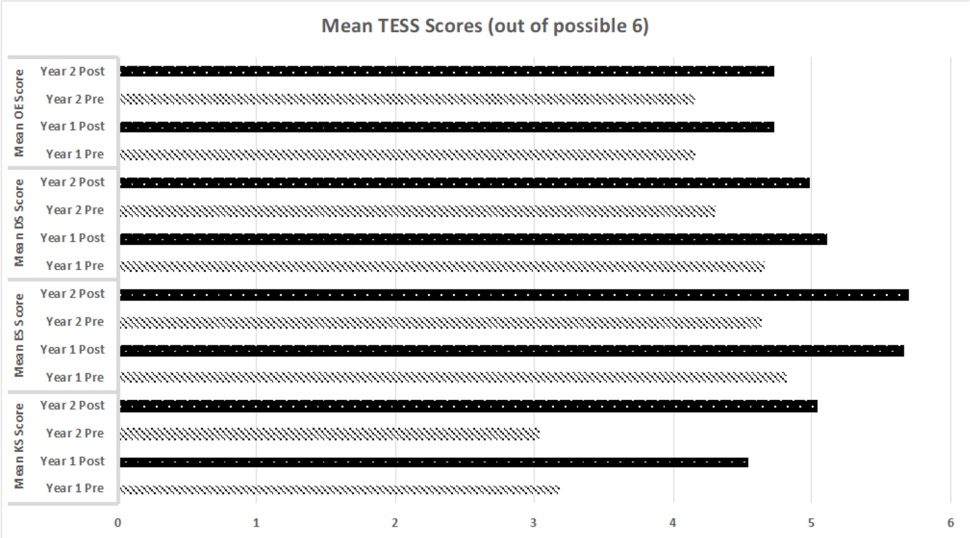


Table 4

Teaching Engineering Self-Efficacy Scale (TESS) Pre-Test and Post-Test Scores Year 1

	Mean KS Score		Mean ES Score		Mean DS Score		Mean OE Score		Overall TESS Score	
	Pre-Test	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*
Minimum	1.33	3.44	4.00	4.75	3.80	4.00	3.00	3.40	13.33	16.62
Maximum	4.11	5.22	5.50	6.00	5.20	6.00	4.80	6.00	19.36	23.22
Mean	3.17	4.53	4.81	5.66	4.65	5.10	4.15	4.73	16.78	20.01
Max possible	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*24*	*24*
Percent change	43%		18%		10%		14%		19%	

Table 5

Teaching Engineering Self-Efficacy Scale (TESS) Pre-test and Post-Test Scores Year 2

	Mean KS Score		Mean ES Score		Mean DS Score		Mean OE Score		Overall TESS Score	
	Pre-Test	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*	*Pre-Test*	*Post-Test*
Minimum	1.78	3.33	2.00	4.75	3.20	4.00	3.20	3.00	13.02	16.78
Maximum	4.89	6.00	6.00	6.00	6.00	6.00	5.80	6.00	21.49	23.58
Mean	3.04	5.03	4.63	5.69	4.30	4.98	4.31	4.98	16.27	20.68
Max possible	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*24*	*24*
Percent change	65%		23%		16%		16%		27%	

Analysis of qualitative data reinforced findings in the quantitative phase. The following statement is representative of participants' written reflections about the shifts in their scores on the TESS overall.

> When I took the TESS survey at the beginning of the year, it was obvious that I was not as confident in explaining what engineering actually is and ways that I could incorporate this into classroom teaching. I believe that I was not as sure of myself because I wasn't sure about the significance of engineering before I took this class and how it actually related to science. After going through the unit and seeing the different examples that the classroom teacher we observed presented, I can say that I walked away more confident than before and that I can teach and incorporate significant engineering topics to my students [Year 1, TESS Reflection].

Here, we see evidence that candidates like the participant quoted felt that their overall understandings about engineering and teaching engineering, as well as their efficacy for teaching engineering, improved over the semester. Other candidates also reflected on growth in their efficacy for themselves and their students engaging in engineering. "I never would have considered myself an engineer before. But I can do the stuff that [the students in the engineering lab] are doing. I [too] can be an engineer" [Year 1, Interview].

These statements are consistent with literature concluding that vicarious experiences and achieving successes in conjunction with mastery experiences promote self-efficacy (Bandura, 1995). However, as we report on in the next section, not all of those who scored high on the TESS necessarily demonstrated fully informed understandings about engineering in their written assignments and interview responses. Thus, we are also reminded that self-efficacy goals and assessments need to be complemented with content-oriented goals and assessments.

Knowledge and Understandings About Engineering

In addition to revealing shifts in candidates' self-efficacy for teaching engineering, evidence emerged of how candidate understandings developed over the semester. Overall, while there is evidence that all candidates were more knowledgeable about the field of engineering and about current visions for engineering education following the course, findings also indicated that there was still significant room for improvement in several areas.

Engineering and Engineers

At the start of the course, candidates struggled to be able to provide a concise working definition of what engineering is and were surprised to learn that they would be responsible for teaching engineering, since none had K-12 classroom experiences with engineering themselves. "I think this semester studying this engineering, I mean, it's the first time I've studied it or even really heard about it, so it's all really new to me" (Year 1, Interview), reflected one candidate. Findings suggested this statement was typical of candidates in both Years 1 and Year 2 overall. When candidates were asked to explain how their understandings had shifted over the semester, they unanimously expressed initial confusion at the start of the semester about engineering and how to teach engineering, particularly with young students.

Reflecting on the full semester, candidates were enthusiastic about their progress. Indeed, most candidates across both cohorts demonstrated basic understandings. Yet, only seven candidates across the two cohorts (two in Year 1 and five in Year 2) demonstrated what could be considered a strong understanding in their interviews or written essay responses about the field of engineering – including the work of professional engineers, the kinds of problems engineering addresses, the iterative design process that is unique to engineering, and technology as the product of engineering design. An example of what was deemed a strong understanding was the following response: "I like to think of engineering as something that like if you're looking at a problem and trying to design a solution to that problem" [Year 2, Interview]. Reflecting on her shifts in understanding, this candidate shared that she came to understand that "it [engineering] encompasses so much more than just building a bridge".

Analysis of qualitative data indicated that most candidates, however, still held an incomplete or shallow understanding of the types of problems that engineering entails at the end of the course. For instance, these candidates may have been able to list different types of engineers if pressed, but only offered up examples of civil engineering, as in those fields that related to building and constructing physical creations. And, while they were aware of the centrality of design processes to engineering, they offered a generic explanation or only described a part of the process. The following are examples of incomplete understandings:

> I feel like engineers have a lot to do with constructing, building, modeling, like 3-D models and everything like that [Year 2, Interview].
>
> Students are engaging in engineering when they are "creating a bridge in a classroom. That makes them an engineer [Year 1, Interview].

These two examples illustrate an emphasis on civil engineering, a common misconception cited in the literature (Yaşar et al., 2006). Their misconceptions may also have been influenced by the particular EiE units that candidates experienced in the class – Designing Bridges – as well as the exhibits they explored during a visit to the local children's museum, which focused on designing and constructing skyscrapers. The use of the generic term "creating" and the example of the end product (a bridge) emphasize the construction aspect of the work without referencing the problem that the design solved, specific features of the design, etc. Both statements are exemplary of the kinds of data that suggested a limited understanding of engineering and what engineers do.

Relationship Between Engineering and Science

Candidates varied in their ability to describe the relationship between engineering and science at the end of the course. The seven candidates who demonstrated strong understandings about engineering were also the ones who demonstrated strong understandings about how the two disciplines connect and interact. The following were coded as strong explanations.

> Although these disciplines are different from each other, they are all used within one another. For example, engineers design technology and use science in order to do so. These three must be intertwined when they are taught in the classroom. [Year 1, Engineering Essay].
>
> You can use what you know about science to help find solutions to problems that you're trying to solve for engineering [Year 2, Interview].

More common, however, were candidates that held an understanding of a hierarchical relationship between the two disciplines, such as "Science is the big umbrella. Engineering and technology are kind of a branch out of it. Engineers have to use technology to solve a problem or meet a need that science finds out." [Year 2, Summative Assessment]. And, the following response puts forth an oppositional view of the two disciplines, as well as misconceptions about science.

> In a general science lesson, students will gain understanding and will most likely ask questions to confirm their understanding. In a technology lesson, students can think more critically about the topic and ask questions that may relate more to their lives, since technology is a growing area [Year 1, Summative Assessment].

This response suggests that engineering problems have more relevance than those in science, and that there is little to no connection between the two disciplines.

There is more encouraging news when comparing the two cohorts. Findings indicate improvement in candidates' understanding of the relationship between science and engineering in Year 2, with approximately twice as many candidates demonstrating more robust understandings. This is likely due to additional emphasis put on this topic in the Year 2 course, following a review of Year 1 findings. Still, the results of Year 2 suggest additional emphasis is warranted in the future.

Teaching Engineering in Elementary Grades

Candidates all discussed an interest in incorporating engineering experiences in their future classrooms. "I feel like I'll definitely be incorporating it [engineering] a lot more than I thought I would" [Year 2, Interview]. They expressed this commitment even if their plans for doing so remained rather vague. For instance, when asked about her future plans a Year 1 candidate said, "I think it's important that my learners get to explore and just immerse themselves in the doing part of engineering instead of just like me giving them all the information they need." She articulates here a student-centered approach but not what "immersing themselves" entails other than citing the Engineering Design Process.

Thinking about their orientations to teaching engineering and instructional strategies that aligned with those beliefs, candidates frequently referenced engineering habits of mind that they wished to promote, including independent, reflective, and metacognitive thinking.

> The teacher would ask questions in between and for [the students] to think about, to stop building and just reflect and think about. And so there would be these questions that would go on and on and add on to the previous question and the kids were excited to make these new creations and also think about new information based on what they're building and the science behind it as well [Year 2, Interview].

Or, as another candidate shared,

> You can't give students the answers. It's their time to explore and figure it out. She never said no, that's wrong…Because if you gave them the answers, they'd just stop thinking. So it encourages them to think more [Year 2, Interview].

Multiple candidates across Years 1 and 2 also highlighted the need for building a classroom climate that supports collaboration.

> [the elementary students] are teaching each other about what they learned and their building off of each others' ideas and that's what I want to see in my classroom [Year 2, Interview].

However, most reflections, like those noted above, spoke more toward candidates' beliefs about engaging students in engineering and managing an engineering classroom space. There were less data that pointed toward candidate understanding of engineering curricula and knowledge of assessing students' progress in engineering. This may be due, in part, to the course focus on instructional strategies and orientations to teaching, whereas subsequent courses in candidates' preparation focus more specifically on designing and implementing lessons and assessments across the curriculum. Future courses would benefit from a more balanced approach to teaching about instruction and assessment.

Influences on Knowledge, Understandings, and Efficacy

Since none of the teacher candidates were exposed to specific engineering classes in their own K-5 education, they unanimously shared how it was an invaluable experience to be able to observe the Partner Teacher's instruction and then also personally engage with small groups of elementary students as they worked on hands-on projects. As one candidate said, "the idea of teaching engineering in elementary schools was very foreign to me as this is not something that I was able to experience in my own schooling" [Year 1, TESS Reflection].

> The observations in [Partner Teacher's] classroom helped me truly understand what engineering looks like in an elementary classroom. This helped me to experience what I had been reading about first-hand which helped me to understand how to properly implement engineering. Also, these experiences helped me to understand how students viewed engineering [Year 1, Essay].

These statements illustrate how candidates valued the opportunity to be immersed in an engineering classroom and experience for themselves the types of learning they were reading about in their coursework.

Discussion

This study investigated the influences of an elementary science teaching methods course on teacher candidates' self-efficacy for teaching engineering in elementary classrooms, as well as their understandings about engineering and engineering education. With the introduction of engineering into national standards for science teaching and learning, it is important for teacher educators to assess the conceptions elementary teacher candidates hold about engineering and about supporting young students' engineering learning. It is also important to critically investigate how teacher preparation programs are influencing candidates' understandings to ascertain what is working well and what could be improved. While a handful of other studies report on teaching engineering self-efficacy results with in-service teachers (Van Haneghan et al., 2015; Yoon et al., 2014), the current study offers insight into measuring and developing the engineering self-efficacy beliefs of elementary teacher candidates. In this section, we discuss results and implications for research and teaching.

Measuring Teaching Engineering Self-Efficacy

While the TESS is a relatively new instrument designed for a target audience of K-12 teachers (Yoon et al., 2014), this study provides insight about its use within teacher preparation courses and research. As teacher educators, we found the TESS to be an effective tool for measuring growth across specific dimensions of teaching engineering self-efficacy, and across cohorts. Yet, findings also suggest that the TESS could benefit from revisions and formal validation testing for the audience of teacher candidates. This population has limited experiences to inform responses to some prompts, especially at the time of the pre-test and to those items measuring outcome expectancy (OE).

To address existing gaps in the literature, such as those outlined in *A Synthesis of Research on and Measurement of STEM Teacher Preparation* (Bell et al., 2019), future research into preservice teacher self-efficacy for engineering should continue to utilize common, validated instruments such as the TESS. This will allow for examination of similar constructs across preparation programs and more coordinated programs of research (Zeichner, 2013) that contribute to "broader and shared understandings of [pre-service teacher learning] in STEM teacher preparation" (Bell et al., 2019, p.30).

The qualitative component of this study provided an additional complementary lens into teacher candidates' thinking and understanding about facets of engineering and pedagogical content knowledge specific to engineering. Other teacher educators and researchers may find benefit from coupling the TESS with a self-reflection assignment and semi-structured interviews such as those described here. This approach has potential benefits for teacher candidates; participants in this study found the TESS to be a useful tool to prompt personal reflection on their learning at the end of the semester, particularly when coupled with an assignment to review and reflect upon their pre-and post-test scores. The opportunity to spend time and participate in a partner school engineering lab during the course also meant their reflections could be linked to a specific classroom context. Research indicates this is an important component to candidates developing "a sense of belonging and competence" (Ditchburn, 2015, p. 30) within the profession.

While results indicate that the teacher candidates in this study held high efficacy beliefs and felt increased confidence in their knowledge and understandings following the course, qualitative results also demonstrated that gaps in understanding and naïve conceptions remained. These findings are a reminder that self-efficacy is associated with perceived ability which may differ from actual ability (Bandura, 1977). Thus, this study reinforces the importance of complimenting any inquiry into teacher efficacy with explorations of teacher knowledge, understanding, and practice to investigate how candidates' perceptions of their efficacy match their actual instructional practice. Future research should analyze practice data, such as teacher candidates' lesson plans and teaching observations. Longitudinal studies can also follow teacher candidates into their induction years to investigate lasting impacts on their beliefs and practice.

Course Experiences and Revisions

We are encouraged by the growth seen in teacher candidates engineering self-efficacy during this course, and in the improvements from Year 1 to 2 in some of the knowledge constructs. While the literature has reported teachers feeling hesitant and intimidated about teaching engineering (Capobianco, 2011; Douglas et al., 2016; Yaşar et al., 2006) and conflicted about the importance of doing so (Douglas et al., 2016; Lachapelle et al., 2014), findings from this study provide evidence that even a single course with an emphasis on engineering education in elementary grades can make a strong initial impact. The significance of the opportunity to be involved in an actual elementary engineering classroom with an expert mentor teacher, not solely as observers but as active participants, cannot be dismissed. Enactive, mastery experiences and the psychological arousal that accompanies these experiences are powerful influences on self-perception (Bandura, 1995; Tschannen-Moran et al., 1998). If efficacy is understood to be situated within a feedback loop (Tschannen-Moran et al., 1998), we can predict that the candidates in this study are likely to want to continue to learn more about engineering following this course and were left feeling confident and energized about teaching engineering. This prediction aligns with Bandura's (1977) argument that "efficacy expectations are a major determinant of people's choice of activities, how much effort they will expend, and of how long they will sustain effort in dealing with stressful situations" (p. 194).

Several other concerning findings warrant further attention and discussion. Misconceptions persisted about what makes science and engineering unique. These findings support other arguments that the NGSS does not adequately present engineering knowledge and practices (Cunningham & Carlsen, 2014; Cunningham & Kelly, 2017). Findings of the qualitative analysis also indicated that the excitement that some candidates felt for engineering might have come at the expense of that for teaching science. Findings revealed that some candidates expressed the idea that, in comparison to engineering, science lacks creativity and real-world relevance. Interestingly, these findings echo those reported by Sengupta-Irving and Mercado (2017), who also found that participants thought of science as procedural and prescriptive. Overall, these findings suggest that more resources are needed on both the nature of engineering and the nature of science to help teachers and teacher educators alike understand what science and engineering share as well as how they differ (NRC, 2012, see p. 46). Cunningham and Kelly's (2017) proposed set of epistemic practices of engineering makes a first step in this direction. *A Framework for Quality K-12 Engineering Education* (Moore et al., 2014) is also useful for guiding the design of course experiences and teacher candidate reflection assignments.

In our own practice, the results of this and other studies have prompted us to provide more learning experiences in our courses that aim to clarify what distinguishes science from engineering, what they share, and the relationships between engineering and other non-engineering subjects. Engineering design challenges can serve as a context for students to manipulate and transfer their understandings of varied content areas while also developing skills such as creativity, communication, critical thinking, and collaboration that are shared across academic disciplines and beyond, but explicit attention to this integration is necessary (Reimers et al., 2015).

Course adaptations include additional design challenges for candidates to participate in and reflect upon, with themselves as learners, with attention to core epistemic practices and indicators within *A Framework for Quality K-12 Engineering Education*. Other assignments include using the EiE assessments geared at uncovering student misconceptions about engineering as small group discussion prompts within class sessions. Further emphasis on the inherent interdisciplinary connections may also help to bring to light the significance of engineering to their own lives and communities, something that the participants in this study valued and wanted to further in their own practice.

Other amendments to the methods course include providing a more substantial orientation to the EiE curriculum before joining the partner classroom. In future iterations of this course, candidates chose units and accompanying professional development videos on the EIE website to review and report on. The focus here is on candidate understanding of the engineering design process, and alignment between science, engineering, literacy and equity goals. All candidates also develop (and ideally implement) lesson plans that include engineering design elements. And, while our teacher candidates are often most excited about thinking about planning and implementing curricular activities, we must continue to support their understandings of engineering and engineering education and of the theoretical perspectives that influence their instructional decision-making.

Conclusion

This study contributes to the small body of literature investigating pre-service elementary teacher self-efficacy for teaching engineering. Findings open the door for future research into supporting the development of this specific teacher population. As engineering education becomes more embedded in elementary classrooms across the United States, teacher educators are adjusting their science methods courses to include an emphasis on engineering. The idea of teaching engineering to young children can feel daunting to teacher candidates and teacher educators alike, given that this subject area was likely not a prominent part of either group's own grade school experience. There is a need for continued research describing and investigating efforts to promote candidates' knowledge, understanding, and efficacy for teaching engineering in elementary classrooms.

Getting candidates more excited about teaching engineering may be the first step, and then the second step is to ensure that they hold strong understandings themselves. Findings from this study indicate that attention is needed to achieve both goals. Findings also remind that purposeful collection and analysis of course data from year to year following the model of pedagogical action research (Norton, 2019) is central to informing iterative course improvements. Future studies should continue to utilize mixed methods and robust instruments to examine course influences on elementary teachers' preparation for teaching engineering.

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Appendix A

TESS Reflection Prompts

Now that you have completed the End of Semester TESS survey, please collect a copy of your survey responses from the beginning of the course from your Instructor.
Review your responses to the TESS survey at the beginning of the semester and at the end of the semester. Then, respond to the following questions.

1. What changes do you notice, if any?
2. How might you explain these changes, or what do you feel has contributed to the changes in your responses?
    a. You might consider new understandings or realizations you have had about engineering and engineering education, as well as new questions that arose for you over the semester.

Appendix B

Interview Protocol

- Could you start by sharing a particular experience around engineering education that stands out for you this semester?
- Thinking about the lessons you observed and helped with at [the Partner School], which were more exemplary of science and which were more exemplary of engineering? Explain.
- How would you explain what engineering is, or what engineers do?
- How would you explain what science is, or what scientists do?
- How do you see science and engineering relating to one another?
- Have your ideas and understandings about science and engineering changed since the beginning of this course? (Ex. Any new realizations? Has anything been clarified or reinforced? Anything you still feel uncertain about?)
- From your time at [the Partner School], I'm interested in what you feel you learned about teaching engineering with elementary aged students. What did you learn from the teacher? And what did you learn from the students?
- How do you see yourself approaching engineering education in the elementary classroom? How would you incorporate engineering into your science classes, even if there were not a separate engineering lab course like at [the Partner School]?
- Were there any other course experiences or assignments that you feel especially contributed to your learning about engineering and engineering education?

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An Analysis on the Effect of Design-Based STEM Activity Development Process on Prospective Maths Teachers' Problem-Solving Skills and Scientific Creativity

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ABSTRACT

The aim of this study was to investigate the effect of design-based STEM activities developed by prospective secondary school maths teachers on their problem-solving skills and scientific creativity. An explanatory sequential mixed methods design was used in the current study, involving 45 senior students (i.e., prospective secondary school maths teachers) studying at a state university in the West Black Sea Region, Turkey during the academic year 2018/19. The participants were selected according to a purposive sampling method to be involved in our study, which was conducted during a course named "Science, Technology, and Society," and the implementation stage, of which took a total of 14 weeks, as three course hours per week. The "Problem Solving Inventory" (PSI) and "Scientific Creativity Test" (SCT) were used for the purpose of obtaining the quantitative data of the research, whereas interviews were conducted with the prospective teachers for collecting the qualitative data. The quantitative data were analyzed using a dependent t-test, while qualitative data was analyzed by descriptive analysis. A slight increase was detected in participants' problem-solving skills in relation to developing STEM activities, though not statistically significant. However, as a result of the implementation process, the scientific creativity of prospective teachers turned out to increase in such a way that it indicated a statistically significant difference.

Keywords: STEM education, design-based learning, problem-solving skill, scientific creativity, prospective maths teachers

Introduction

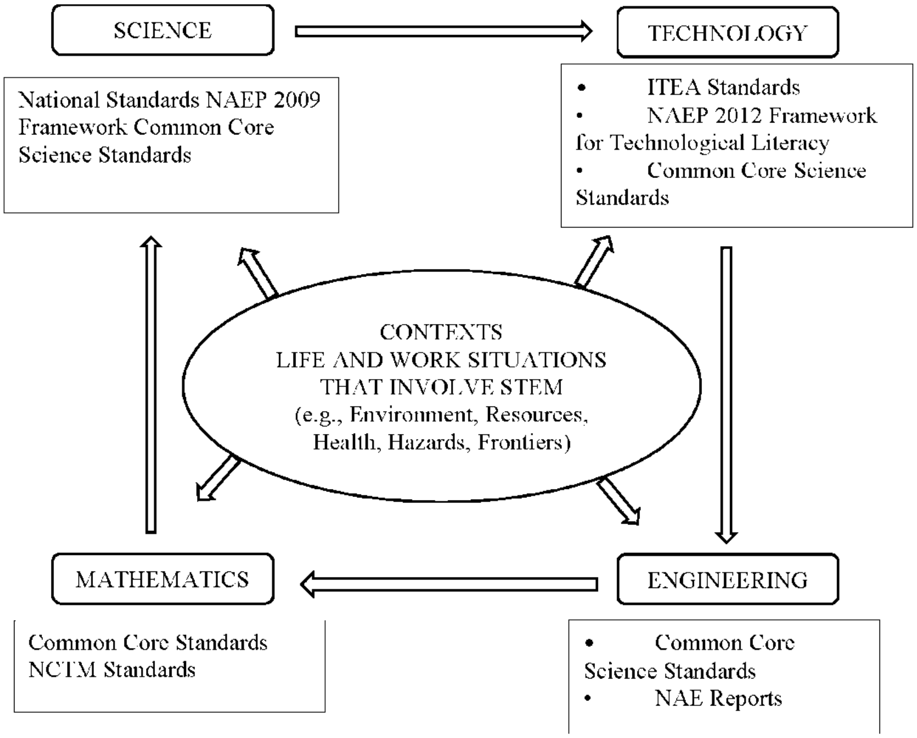
With the development of technology in recent years, the needs of countries and the workforce required to meet these needs have changed significantly. By the same token, the technological competition between countries has increased, and all developed countries have started to invest in people working in the fields of science, technology, engineering, and mathematics (STEM) (Corlu, 2014). Many researchers and industries have long emphasized that the labor supply cannot be met with the information processed and converted into products, in primary and secondary (K-12) schools. In this direction, it is recommended to re-evaluate the curricula that are currently being implemented and to focus on raising the number of people suitable for the competencies needed in today's society (Akgunduz et al., 2015; Turkish Industry and Business Association [TIBA], 2014). As a consequence, individuals are expected to think from a scientific point of view, question accordingly, think critically, develop solutions to problems, be creative and productive, and have the necessary skills to work in an interdisciplinary manner cooperatively (Akaygun & Aslan Tutak, 2016; National Research Council [NRC], 2011). In order to prepare individuals with the necessary skills, countries aim to organize their education systems in such a way that individuals can work with interdisciplinary perspectives and have 21st century skills (Demirci Guler, 2017). For this purpose, countries have initiated various reform movements in their education systems (Ministry of National Education [MoNE], 2016). STEM is one of the most popular of these reform movements (Gulhan & Sahin, 2016; NRC, 2011; Seage & Turegun, 2020).

STEM education includes knowledge, skills, and beliefs formed by the intersection of more than one of the fields of science, technology, engineering and mathematics, and where interdisciplinary studies are applied holistically (Corlu et al., 2014; Gonzalez & Kuenzi, 2012). It is the process of gaining experience by using the disciplines of science, technology, engineering, and mathematics in designing a new product or revising an existing product, as well as producing through education, by coming up with relevant solutions to problems (Thomasian, 2011). Undoubtedly, STEM education is expected to train qualified individuals by integrating engineering- and technology-related skills into the fields of science and mathematics (Bakirci & Kutlu, 2018).

The current study was guided by Bybee's (2010a) *A Framework for Model STEM Units*, in which STEM disciplines are used in an integrated way in solving a problem (Figure 1). As seen in Figure 1, there is a daily life problem involving STEM disciplines at the center of the STEM education approach. This problem situation should attract students' attention and at the same time should be appropriate to the student's level. Students use the knowledge and skills of STEM disciplines while investigating the problem.

Figure 1

A Framework for Model STEM Units (Bybee, 2010a, p.33)



The educational needs of our age have come to such an unprecedented dimension that the importance of students' vital skills and knowledge has greatly increased. STEM education and related activities enable students to acquire 21st century skills (Bybee, 2010b; Bybee, 2010c; Honey et al., 2014; Kostur, 2017). These skills remove distances in the global world by enabling individuals from different cultures (Turner, 2013). Students are supposed to work in a planned and systematic way while producing solutions to a problem in the engineering design process of STEM activities (Bybee, 2011; Guzey et al., 2014; Mann et al., 2011). Likewise, while working on the design of a new product related to the solution of problems in this process, they may prompt a new and dissimilar engineering problem to emerge at the end of the process (Lederman & Lederman, 2013; NRC, 2012).

The fact that STEM is generally interpreted as science or mathematics and does not connote technology or engineering is an issue that needs to be resolved (Bybee, 2010a). Although some educators regard engineering as least relevant to K-12 students, STEM education is actually based on engineering (Basham & Marino, 2013). Engineering education can be provided by integrating the engineering field into the fields of science, technology, and mathematics with appropriate activities (NRC, 2010). In order to achieve such integration, the most suitable way is to carry out the activities within the scope of design-based learning (Felix & Bandstra, 2010). However, design-based learning, which supports STEM education and creates an efficient and constructive learning environment, enables students to become creative individuals who can reveal their knowledge and skills in the design process, analyze and evaluate the results in the application process, and share their opinions (Kolodner et al., 2003). Besides that, students become more creative as they present original, new, and distinct products during STEM activities (Charyton, 2015; Larkin, 2015). The reason for this is that creative thinking is included in the engineering design process in STEM activities (Court, 1998).

Design activities form the focus of design-based learning (Fortus, 2005). In the event that students draw on the concepts and skills of science and mathematics while solving engineering problems, it is more likely that they will be able to find solutions more easily (Ercan & Sahin, 2015). According to Crismond (2001), a design-based learning environment is a setting in which students can contribute positively to their problem-solving, decision-making, and collaborative working skills. In particular, it is well known that many mathematics topics are perceived to be generally abstract and difficult to grasp. For this reason, authentic activities are needed in order to teach abstract concepts by establishing a relationship with real-life learning (Acikgoz, 2006; Brown et al., 1989). Similarly, planning the Maths teaching process with design-based activities and performing concrete activities may improve teaching. Akgunduz et al. (2015) emphasized that interdisciplinary approaches should be adopted in teacher education and that curricula should be organized within the scope of STEM education.

The literature shows that research on STEM focuses mostly on science (Akgunduz, & Akpinar, 2018; Bakirci & Kutlu, 2018; Capraro & Slough, 2008; Gulen, 2016). Nevertheless, despite the presence of some studies on STEM in Maths education, it has still been emphasized that the number of such studies should be increased (Akaygun & Aslan-Tutak, 2016; Delen & Uzun, 2018). The development of 21st century skills along with metacognitive knowledge and skills is especially accentuated in the Maths curriculum (MoNE, 2018).

It is, therefore, of great importance for prospective Maths teachers to carry out performances related to STEM education. From this point of view, this study aimed to investigate the impact of the implementation process of design-based STEM activities developed by prospective secondary school Maths teachers on their problem-solving skills and scientific creativity. The prospective teachers' views were also taken at the end of the activity development process. To this end, the research question for this study is "How does the design-based STEM activity development process affect prospective Maths teachers' problem-solving skills and scientific creativity?" The sub-problems that were sought to be answered, in line with the problem statement of the study, are as follows:

- Research Question 1: How does the design-based STEM activity development process affect prospective Maths teachers' problem-solving skills?
- Research Question 2: How does the design-based STEM activity development process affect prospective Maths teachers' scientific creativity?

Problem-Solving Skills

The concept of "problem" is defined in various ways in many different sources. Yavuz et al. (2010) defined this concept as the difficulties faced by people with results which cannot be predicted. Dewey (1997), on the other hand, defined the problem as anything that preoccupies and challenges the minds of individuals. Considering the definitions for the "problem", these authors seem to have a negative connotation in human life. However, the real problem is not the problem itself, what matters is the act of coming up with a solution to the problem (Ozer et al., 2009).

There are various classifications of problems in the literature. However, the most used classification belongs to Jonassen and Kwon (2011), who divided problem types into well-structured and ill-structured. Well-structured problems are mostly questions at the end of units or chapters in Science and Maths lessons, whereas ill-structured problems are those frequently encountered in daily life (Yua et al., 2010). Because daily life problems are embedded in the lives of individuals, individuals try to cope with them and need to solve them (Tambychik & Meerah, 2010).

Problem solving is learned from a very early age, and problem-solving skills are developed at school age (Miller & Nunn, 2003). According to Heppner and Krauskopf (1987), problem-solving skills refer to developing cognitive, affective, and behavioral responses in order to adapt to internal or external stimuli. According to Dewey (1997), the problem-solving process starts with a problem and ends with defining the problem, giving suggestions to present possible solutions, collecting appropriate data, testing hypotheses, solving the problem, and reporting the results.

Individuals need to possess problem-solving skills in order to solve the problems they encounter throughout their lives (Ekici-İnel & Balim, 2013; Jonassen, 2002). Considering the importance of problem-solving skills in human life, it is necessary that such skills be taught to students at a very early age. In this regard, it is often emphasized that students are able to develop 21st century skills and solve problems related to daily life thanks to STEM education (Dewaters & Powers, 2006; Tseng et al., 2013). Capraro and Slough (2008) emphasized that STEM education enables students to learn and solve problems related to daily life.

A number of scales and tests exist in the literature to determine students' problem-solving skills (e.g. Ekici-İnel & Balim, 2013; Hawkins et al., 2009; Heppner & Peterson, 1982; Pekbay, 2017; Sezgin, 2011; Wakeling, 2007; Yaman & Dede, 2008). However, such scales are based on social problem-solving skills rather than daily, life-based problem-solving skills. In addition, it is seen that the most used scale about problem-solving in the literature is the Problem Solving Inventory (PSI) developed by Heppner and Peterson (1982).

Scientific Creativity

Creativity includes the process of creating an original product in every area where a problem needs to be solved (Cellek, 2002). In other words, individuals produce new and different products by coming up with solutions to existing problems (Gardner, 1997; Plucker et al., 2004). Wallas (1926) summarizes the creative process in four stages: preparation, incubation, illumination, and validation. In the preparation stage, which is the first stage of the process, individuals define the problem and try to seek solutions. They present new syntheses and ideas for the problem in the incubation stage. They come up with a solution to the problem in the illumination stage, and the solutions found to the problem are verified and the deficiencies are met during the verification, which is the last stage. Creativity is especially active while creating a new and original product, by drawing on the knowledge that exists in an individual during the problem-solving process (Dogan, 2011; Paulus, 2000; Torrance, 1968).

Creativity of individuals can be expressed as the ability to create original products at the end of a process or the creation process itself. However, if this skill aims to find a solution to a scientific problem in a process with certain limits, it denotes scientific creativity (Liang, 2002). Creativity and scientific creativity are regarded as different concepts in the literature (Liang, 2002; Lin et al., 2003). Scientific creativity refers to generating an original product in a field of STEM, or owning a scientific skill in the related field (Rawat, 2010). Hu and Adey (2002) emphasized that scientific creativity is a process that includes the practice of solving scientific problems. The authors stated that scientific creativity is a developmental process that includes scientific knowledge. Scientific creativity should not only embody a technical product made with scientific knowledge, but also a process designed to solve a scientific phenomenon or problem (Aslan, 1994; Atasoy et al., 2007; Hu & Adey, 2002). Aiming at coming up with a new and different solution to a scientific problem, individuals should use scientific methods, especially along with innovative solutions and scientific creativity (Harlen, 2004; Meador, 2003).

Hu and Adey (2002) proposed a creativity model in which scientific creativity is defined and criteria are specified. This model consists of three dimensions: creative process, creative character, and creative product. The creative process dimension of the model consists of divergent thinking and imagination. Divergent thinking is the ability to produce various answers with a multidimensional perspective in solving a problem. Imagination, which is the most significant feature of creativity, is to design a mental setting or phenomenon with known objects and ideas (Hu & Adey, 2002; LeBoutillier & Marks, 2003).

Whether or not an idea is the product of creative thinking can be understood by evaluating the dimensions of fluency, flexibility, and originality that define the character of the ideas (Hu & Adey, 2002). Fluency includes producing more than one idea, flexibility includes producing different ideas with the same stimulus, and originality refers to producing new and original ideas (Guilford, 1986; Hu & Adey, 2002; Torrance & Goff, 1989). In the dimension of fluency, individuals express their ideas verbally or in different ways by producing a large number of ideas and offering a variety of suggestions for possible solutions to a problem (Hu & Adey, 2002; Jaarsveldt, 2011).

On the other hand, in the dimension of flexibility, people can easily adapt to different situations or environments by evaluating the situation from different perspectives and producing different and exceptional ideas (Hu & Adey, 2002; Kontas, 2015). Whereas in the dimension of originality, individuals put forward an idea or product that has not been tried or produced before, make innovative attempts while looking for a solution to the problem, and offer an original solution that has not yet been produced either (Hu & Adey, 2002; Jaarsveldt, 2011). In the dimension of generating a creative product within the creativity model in science, the products to be made as a result of creative thinking should be technical products. Scientific knowledge in relation to such products must be set forth, must correspond to a scientific phenomenon, and must be designed to solve a scientific problem (Hu & Adey, 2002; Ustundag, 2014).

Combining the creative design process with the engineering design process is of particular importance in that it contributes to individuals' creative thinking skills (Hacioglu, 2017). Especially for the case of secondary school students, the engineering design process improves scientific creativity and problem-solving skills (Samuels & Seymour, 2015). STEM education also includes a process that contributes to students' creative thinking while seeking solutions to problems (Charyton, 2015; Havice, 2015). Hence, it is necessary to be open to innovations offered through activities and performances that develop students' creative thinking skills in teaching environments.

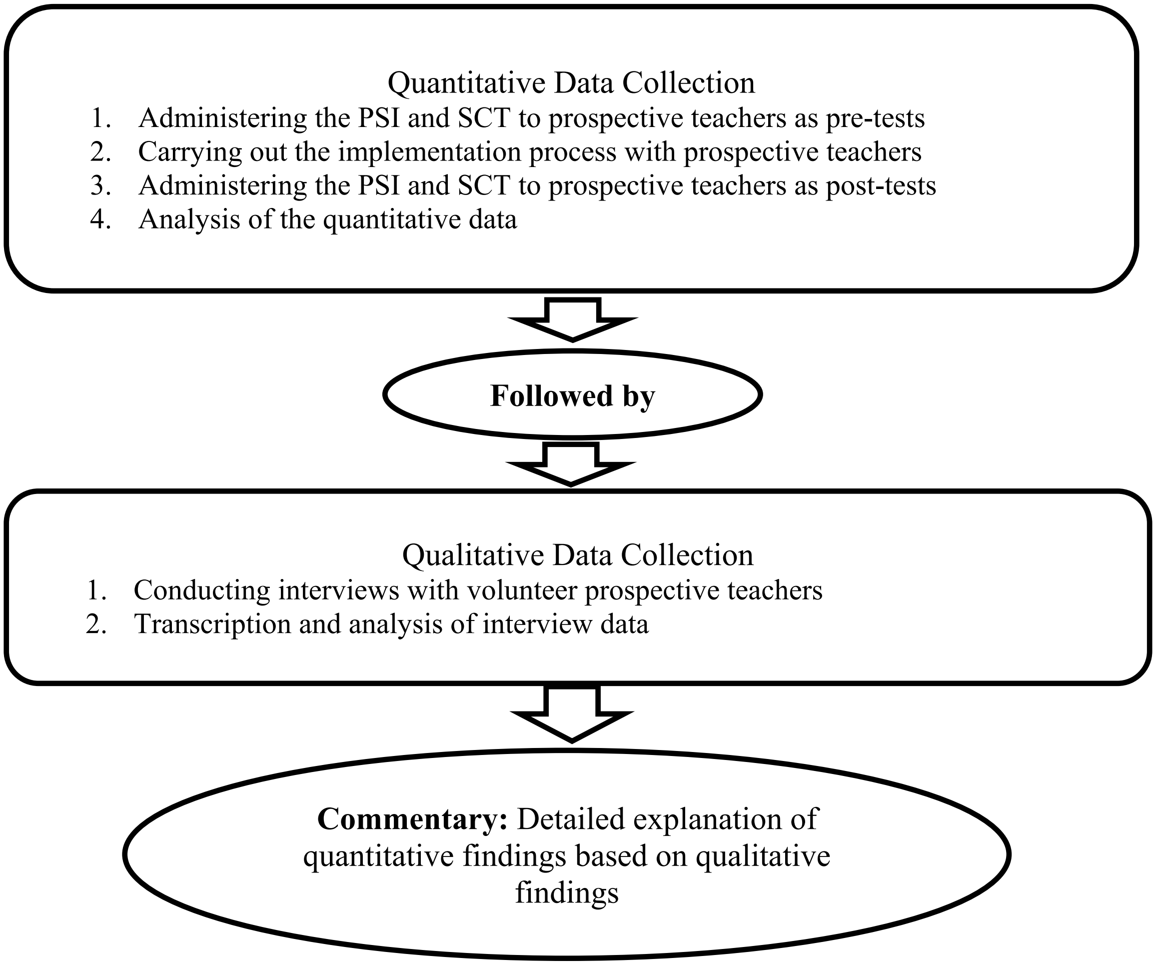
Method

Research Design

The present study involves the “explanatory sequential mixed methods design”, in which qualitative and quantitative data are collected in stages (Creswell & Plano Clark, 2011). In the first stage, quantitative data are collected and analyzed, while in the second, qualitative data are collected and analyzed. In fact, qualitative data are used to explain and support the interpretation of quantitative data. In social sciences, the use of either quantitative or qualitative approaches may prove insufficient, especially in defining complex problems, as well as concluding and interpreting data. In such cases, mixed methods research designs allow researchers to have a more detailed examination and explanation of the problems (Creswell, 2005). The reason for choosing a mixed methods design in this study is to explain the research problems in line with qualitative and quantitative data. Figure 2 shows the schematic representation adopted for this research.

Figure 2

Schematic Representation of the Research Method (This Figure was Adapted to the Current Research, Inspired by the Explanatory Sequential Mixed Method Design as Indicated by Creswell and Plano Clark (2011))



Quantitative Data Collection

1. Administering the PSI and SCT to prospective teachers as pre-tests
2. Carrying out the implementation process with prospective teachers
3. Administering the PSI and SCT to prospective teachers as post-tests
4. Analysis of the quantitative data

Qualitative Data Collection

1. Conducting interviews with volunteer prospective teachers
2. Transcription and analysis of interview data

Commentary: Detailed explanation of quantitative findings based on qualitative findings

Participants

The study was conducted with the participation of a total of 45 prospective secondary school Maths teachers (38 females, seven males) with an age range of 20-23, who were senior students at a state university in the West Black Sea Region in the academic year of 2018/19. Prospective teachers took the "Science, Technology, and Society" course for the first time and were not knowledgeable about integrated STEM education before. Participants from whom quantitative data were collected were selected using a purposive sampling method. The study group, in which the qualitative data of the research was collected, consisted of six pre-service teachers using maximum diversity sampling, one of the purposive sampling methods. The aim here was to create a relatively small sample and to reflect the diversity of individuals for the problem studied in this sample at the maximum level (Yıldırım & Simsek, 2011). The prospective teachers to be interviewed were selected according to the differences in their participation in the activity process. This method allowed for the obtainment of rich information and to investigate the situations in detail, depending on the purpose of the research (Buyukozturk et al., 2019).

Implementation Process

The implementation process of the research was carried out in the "Science, Technology, and Society" course taught as an elective in the Mathematics Teaching Curriculum. It was completed in a total of 14 weeks, three course hours per week, and the stages of the implementation are given in Table 1.

Table 1

Implementation Process and Stages for the Prospective Teachers

Week	Implementation
1	Getting to know you, introduction to the course, creating groups, and administering pre-tests
2	Informing about the concepts concerning STEM Education and its history
3	Informing about the curricula and STEM
4	STEM teaching-learning models: Explaining the 5E Learning Model
5	STEM teaching-learning models: Informing about Project-Based and Problem-Based Learning
6	Introduction to the engineering design process
7	Example Activity 1: Barbie Bungee Jumping
8	Example Activity 2: Rafting Competition
9	In-Class STEM Activities (implementation process for the prospective teachers)
10	In-Class STEM Activities (implementation process for the prospective teachers)
11	In-Class STEM Activities (implementation process for the prospective teachers)
12	In-Class STEM Activities (implementation process for the prospective teachers)
13	Presentation of Projects
14	Conducting post-tests and interviews

General information about the process was shared and the PSI and "Scientific Creativity Test" (SCT) pre-tests were administered in the first week (instruments described below) of the implementation process. The participants were given theoretical information about STEM education between the second and sixth weeks. The theoretical information about STEM is given according to

Bybee's (2010a) theoretical framework. At the same time a problem situation from daily life took place in the center, both in the activities carried out by the researchers and in the activities designed by the preservice teachers. In the seventh and eighth weeks, preservice teachers took part in the sample activities as a group, as planned by the researchers, within the scope of the engineering design process introduced by Hynes et al. (2011). In the seventh week, prospective teachers were informed about the requirement to prepare acquisition-oriented STEM activities in the following weeks in line with the secondary school mathematics curriculum, as presented in the sample activities. The STEM activity expected to be designed by prospective teachers was to include one or more acquisitions in the secondary school mathematics curriculum, and to prepare the activities as design-based. What was expected of the project was the design of a product that could solve a problem encountered by prospective teachers in daily life. The participants were also required to use the engineering design process introduced by Hynes et al. (2011), when designing their products.

This model is composed of a non-linear loop between the stages, in which there can be a transition from any stage to the next. Having been used in many fields, this model can also be adapted to the process of STEM activities. The engineering design process proposed by Hynes et al. (2011) consists of nine stages, for which the descriptions are given as follows.

1. *Identifying the need or problem:* This stage is important in that the problem is determined and the design is planned in detail (Atman et al., 2014). A list of necessary materials is created in line with the criteria or limitations specified for the product to be created during the planning process (English et al., 2017; Kolodner et al., 2003; Mentzer, 2011). It is indispensable to specify the limitations and criteria for the purpose of solving a problem and creating a product with the desired features, that is, coming up with a solution corresponding to the need (Brunsell, 2012). Students create a plan for solving a given problem at this stage of the engineering design process. They also plan an implementation process to create a product in consideration of the problem's limitations and criteria (Hynes et al., 2011).
2. *Researching the need or problem:* At this stage, students conduct research to develop different solutions to the problem. They explore what can be done to improve the solution they have come up with (Hynes et al., 2011; Kolodner et al., 2003). The limitations of the problem in relation to possible solutions are clearly determined (NRC, 2012). Students brainstorm and offer possible solutions to the problem.
3. *Developing possible solutions:* Here, the creativity of individuals stands out and individuals offer creative solutions (Wendell et al., 2010). Since there is more than one solution in the engineering design process, the students brainstorm about these solutions with their groupmates (Brunsell, 2012). The ideas put forward with the aim of solving the problem are evaluated. The solutions created are recorded with drawings or writings (Hynes et al., 2011).
4. *Selecting the best solution:* The students evaluate the solution proposals by taking into consideration the limitations and criteria, and come to a conclusion accordingly (Brunsell, 2012; NRC, 2012). The most suitable idea for the solution is selected while making a decision. However, in the case of the presence of ideas which do not meet the criteria, it is necessary to decide which criterion is more important or dispensable among them. In other words, the chosen proposal may not meet the solution exactly, yet the most appropriate one should be decided in accordance with the criteria (NRC, 2012). In this process, students can get help from their teachers before reaching a decision within the group (Hynes et al., 2011).
5. *Constructing a prototype:* A concrete prototype is created as a model or presentation for problem-solving. The prototype not only offers a solution to the problem, but also allows the implementation of theoretical knowledge (NRC, 2012). Students create a prototype product that corresponds to their specific solution. They also realize their mistakes so that they can develop their solutions while making their prototypes (Hynes et al., 2011).

6. Testing and evaluating the solution: The prototype is evaluated and tested according to the set criteria (Brunsell, 2012; Hynes et al., 2011; NRC, 2012). Students test and evaluate their designs with their teachers. Upon the evaluations, they improve and correct their prototypes in line with the given criteria so that they can successfully finalize their designs (Hynes et al., 2011).
7. Communicating the solution: The prototype and design process are shared. This sharing is important, both in terms of giving feedback to improve the prototype and promoting the product (Brunsell, 2012; NRC, 2012). Students present their designs to other classmates. Consequently, they can get feedback from their classmates to improve their designs. Thanks to such feedback, they receive suggestions from their classmates about the limitations and solutions of the problem (Brunsell, 2012; Hynes et al., 201).
8. Redesigning: The design is rearranged in line with the feedback given at the end of the submission of the solution. In addition, students work and make improvements to ensure that their designs are successful, and to eliminate the deficiencies in their designs (Hynes et al., 2011).
9. Completing the decision: Students decide that the design made is the most appropriate solution for the problem (Hynes et al., 2011).

Prospective teachers carried out the design-based STEM activities in groups of five to six students between the ninth and twelfth weeks with their classmates. In the thirteenth week, the projects prepared by each group were presented. In the last week, the PSI and SCT post-tests were re-administered and prospective teachers were interviewed voluntarily.

Data Collection Tools

In the present study, the PSI and SCT were conducted to collect quantitative data, and the participants were interviewed to collect qualitative data.

Problem-Solving Inventory

The PSI, developed by Heppner and Peterson (1982) and adapted into Turkish by Sahin et al. (1993), was used to measure prospective teachers' problem-solving skills. The scale consists of 35 items. Sahin et al. (1993) calculated the Cronbach's alpha reliability coefficient as .88 for the overall inventory. The scale was composed of six sub-dimensions, which include being impulsive, reflexive, avoidant, monitoring, problem-solving confident, and planful. The alpha coefficients of these subscales were found to be .78, .76, .74, .69, .64, and .59, respectively. In the present study, the Cronbach's alpha reliability coefficient of the problem-solving scale was found to be .89, with coefficients obtained for the sub-dimensions calculated as .74, .90, .70, .87, .86, and .80, respectively. The PSI was a six-point Likert type scale. According to the PSI, the low scores obtained from this scale indicated that the perception of problem-solving skills increased. The problem-solving levels indicated by the scores obtained from the scale were: Very high 1.00-2, High 2.01-3, Medium 3.01-4, Low 4.01-5, and Very low 5.01-6. Sample items are given below.

"When I have a problem, I try to think of all the ways I can solve it."

"I usually act on the first idea that comes to mind."

Scientific Creativity Test

The original form of the SCT was developed by Hu and Adey (2002), whereas its Turkish adaptation was made by Kadayifci (2008). The original test consisted of seven open-ended questions and was prepared in conformity with the dimensions of scientific creativity. The factor analysis of the original test indicated a single factor and the Cronbach's alpha reliability was calculated as .89. The test translated by Kadayifci (2008) was then administered to 57 students and the Cronbach's alpha reliability coefficient was found to be .74. In the present study, the Cronbach's alpha internal consistency coefficient of the scale administered to 45 prospective teachers was found to be .83. Based on the responses given in the SCT, the scores were evaluated according to the flexibility, fluency, and originality sub-scores. In the scoring of the SCT, the responses given by the students were determined as "raw ideas." Ideas pointing to the same issue, but expressed in different ways were combined to obtain "organized ideas." Analyses were made taking into account the "organized ideas", while creating the student scores. In scoring the questions, the researchers evaluated the raw ideas and the organized ideas together, and decided in collaboration to reach a consensus. Sample items are given below.

> Question 1: Write down the possible scientific uses of a piece of glass.
>
> Question 4: Imagine that there is no gravity and describe what the world would be like.

Interviews

In the present study, qualitative data were obtained from interviews conducted with the prospective teachers regarding the STEM activity development process following the implementation process. Interviews with the respondents were conducted in a semi-structured manner, as the questions were flexible, allowing the ability to ask additional questions to the interview questions (Merriam, 2009; Yildirim & Simsek, 2011). In order to ensure the content validity of the interview questions, two science education experts as well as an assessment and evaluation expert were consulted. The interviews aimed to reveal how the problem-solving skills and scientific creativity of the participants changed during the development of STEM activities. The sample question planned for the interview is presented below.

> Question: What are your views with respect to the STEM activities you performed during the implementation process?
>
> Alternative Question: What are your views with respect to the product designs you made during the implementation process?

Six prospective teachers who participated in the implementation process were interviewed in the face-to-face interviews, which were tape-recorded and then transcribed. The interviews lasted 30-40 minutes and were conducted on a voluntary basis. The participants were selected by using maximum variation sampling, taking into account the scores they received from the tests and their participation in the implementation process.

Data Analysis

The data obtained from the PSI and SCT were analyzed using IBM SPSS Statistics 21. In order to determine whether or not the data obtained from these tools showed a normal distribution, the data were analyzed with the Kolmogorov-Smirnov Test for normality. Since the *p* value was greater than .05 with the Kolmogorov-Smirnov Test for normality for the pre-test and post-test scores, it can be assumed that the groups have a normal distribution. According to these results, it can be considered that the scores obtained through the data collection tools show a normal distribution (Buyukozturk, 2011). In this context, a dependent *t*-test was used to examine whether or not there was a statistical difference between the pre-test and post-test scores obtained through the quantitative data collected from the group.

In the current study, the data obtained from the interviews with prospective teachers were analyzed with descriptive analysis. In the descriptive analysis method, the data are systematically grouped and explained clearly with cause-and-effect relationships, without the need for digitization or without any concerns for generalization (Yildirim & Simsek, 2011). In other words, researchers organize and interpret their questions within the framework of themes and concepts. In this regard, the data are interpreted and presented according to the themes specified before the analysis (Strauss & Corbin, 2015; Yildirim & Simsek, 2011). The present study applied a descriptive analysis process as explained by Yildirim and Simsek (2011) in four steps. The themes of the research were specified in the first step, while in the second step, the data were meaningfully correlated and organized within the scope of the themes. In this context, the conversations in the audio recordings, that is the interview data, were transcribed in written documents on paper. Sections that were irrelevant to the themes in the cited text were omitted. The data were explained in the third step, while they were interpreted through the findings in order to attach relevant meanings in the fourth step. In the commentary, direct quotations were included to emphasize the cause-and-effect relationship, and the plots were clearly presented. Common views and striking data were conveyed by including direct quotations, and all participants were given code names (S1, S2, S3,…). The raw data were analyzed with the joint decisions of the researchers, and the analysis process was carried out with their participation as well.

Validity and Reliability of the Research

Data were collected at different times and with different data collection techniques in order to increase the internal validity of the research. The internal consistency coefficient (Cronbach's alpha) calculations were made for the PSI and SCT scales to ensure reliability and validity in the quantitative part of the research. Because the study was carried out in an elective course in the curriculum, the participants were familiar with the researchers and regarded them as the experts of the course. The researchers already had previous academic studies on STEM and acted as a guide during the implementation process.

In the qualitative part of the study, participant confirmation was gathered in order to ensure reliability and validity, and to enable the transferability of the study, besides the researchers taking part together in the analysis of the data. It was made sure that there was long-term interaction to ensure the credibility of the research (Yildirim & Simsek, 2011). That is to say, the long-term interaction of the researchers with the participants increased the credibility. After the data recorded during the interview process were converted into written documents, the consent of the students who participated in the interview was obtained as to whether the data was correct or not. Besides that, the implementation process, the time of data collection, and the participants were described in detail in the research, and the interview data were presented with direct quotations.

Results

The results are presented in line with the sub-problems of the study.

Research Question 1: How Does the Design-Based STEM Activity Development Process Affect Prospective Maths Teachers' Problem-Solving Skills?

In the present research, a dependent *t*-test was used to examine whether there was a statistical difference between prospective teachers' PSI pre-test and post-test scores, and the results are given in Table 2.

Table 2

Dependent t-Test Results Related to PSI Scores

Variable	Measure	N	$\bar{x}$	S	SD	*t*	*p*
Problem-solving skills	Pre-test	45	2.70	0.53	44	1.30	0.20
	Post-test	45	2.58	0.63			

As can be seen in Table 2, no significant difference was found between the pre-test and post-test scores of problem-solving skills ($t_{(44)}$=1.30, p>.05). The post-test average scores of the participants regarding their problem-solving skills ($\bar{x}$=2.58) are lower than those scores indicated in their pre-tests ($\bar{x}$=2.70). Despite the lack of a significant difference between prospective teachers' post-test and pre-test scores, there ended up being a decrease, demonstrating that prospective teachers tended to improve their problem-solving skills at the end of the implementation process.

A dependent *t*-test was used to examine whether there was a statistical difference between the prospective teachers' scores obtained in the PSI in relation to the sub-dimensions, including being impulsive, reflective, avoidant, monitoring, problem-solving confident, and planful in the pre-tests and post-tests. Table 3 shows the relevant results.

Table 3

Dependent t-Test Results of the Sub-Dimensions of the PSI

Variables	Measure	N	$\bar{x}$	S	SD	*t*	*p*
Impulsive	Pre-test	45	3.10	0.76	44	0.77	0.45
	Post-test	45	2.90	0.81			
Reflective	Pre-test	45	2.2 9	0.90	44	0.38	0.71
	Post-test	45	2.21	1.06			
Avoidant	Pre-test	45	2.15	0.78	44	-0.22	0.83
	Post-test	45	2.18	1.12			
Monitoring	Pre-test	45	2.19	0.81	44	-0.08	0.94
	Post-test	45	2.20	1.06			
Problem-solving confident	Pre-test	45	2.46	0.86	44	1.38	0.18
	Post-test	45	2.22	0.92			
Planful	Pre-test	45	2.51	0.90	44	1.78	0.08
	Post-test	45	2.18	0.95			

As shown in Table 3, the sub-dimensions of the PSI include the following constructs: impulsive ($t_{(44)}$= 0.77, p>.05), reflective ($t_{(44)}$= 0.38, p>.05), avoidant ($t_{(44)}$= -0.22, p>.05), monitoring ($t_{(44)}$= -0.08, p>.05), problem-solving confident ($t_{(44)}$= 1.38, p>.05), and planful ($t_{(44)}$= 1.78, p>.05), with no significant difference between pre-test and post-test scores. In the sub-dimension of being impulsive, the pre-test scores ($\bar{x}$=3.10) are moderate, while the post-test average scores ($\bar{x}$=2.90) are high. Results show that in the sub-dimension of being impulsive, post-test mean scores ($\bar{x}$=2.90) are lower than the relevant pre-test scores ($\bar{x}$=3.10); in the sub-dimension of being reflective, post-test mean scores ($\bar{x}$=2.21) are lower than the relevant pre-test scores ($\bar{x}$=2.29); in the sub-dimension of problem-solving confidence, post-test mean scores ($\bar{x}$=2.22) are lower than the relevant pre-test scores ($\bar{x}$=2.46); and in the sub-dimension of planful approach, post-test mean scores ($\bar{x}$=2.18) are lower than the relevant pre-test scores ($\bar{x}$=2.51).

The difference between the prospective teachers' post-test and pre-test scores showed a decline in the sub-dimensions of being impulsive, reflective, problem-solving confident, and planful, though not statistically significant. These results show that prospective teachers tended to improve their skills in these dimensions at the end of the implementation process. On the contrary, in the sub-dimension of avoidance-approach, post-test mean scores ($\bar{x}$=2.18) were found to be higher than the relevant pre-test scores ($\bar{x}$=2.15), whereas in the subscale of monitoring, post-test mean scores ($\bar{x}$=2.20) were higher than the relevant pre-test scores ($\bar{x}$=2.19). The difference between the post-test and the pre-test scores in the sub-dimensions of being avoidant and monitoring showed a slight increase, although not statistically significant. In general, these results show that prospective teachers' tendency of improvement decreased in these dimensions at the end of the implementation process.

In the interviews, the prospective teachers emphasized that the implementation process positively affected their problem-solving skills, and that the activities carried out during the problem-solving process turned out to be fun and improved their problem-solving abilities since the fields of STEM were combined within the implementation process. In this context, S1 said:

> I believe that STEM education is an efficient process. It enables students to develop different solution strategies by learning to think in a uniform and certain pattern to solve problems with certain methods. I had a lot of fun, especially while thinking about the solution of the problems in the activities. During the activities, I created a hypothesis through trials. Afterwards, testing was a really exciting process.

Moreover, S5 said that the activities helped improve problem-solving skills while looking for solutions to the problems encountered in teaching abstract subjects of mathematics, given as follows:

> As Maths is a course comprising abstract expressions, adapting it to daily life problems and making concrete designs helped my problem-solving skills improve. In the process of developing an activity by associating the abstract topics of Maths with daily life, thinking about 'How can I do it? or What can I do?' had a positive effect on me since I had to solve the problem.

S3 emphasized that the practices affected the prospective teachers' perspective and ability to solve problems in the following statements:

> I think STEM aims to generate solutions to daily life problems by using science, technology, mathematics and engineering fields together. So, I think that my perspective on problems and my ability to solve problems have improved as a result of the activities we have done. During the design process of the activities, we constantly encountered problems that we had never thought of. We needed to find urgent solutions to those problems. Therefore, we always thought from a multi-dimensional perspective and came up with solutions.

Another respondent, S2 stated that STEM activities would contribute to the problem-solving abilities and other skills of not only prospective teachers, but also younger students and said:

> To me, coming up with solutions to daily life problems by using science, technology, mathematics, and engineering in the implementation process, helps develop necessary skills

> for creative thinking and problem solving, as well as engineering. I think I have improved myself especially when thinking about problem-solving. Since problems are often encountered suddenly, it is likely that the first system that comes to mind at that moment is developed in this framework. Testing whether the developed solution is suitable or not shows that the process should actually be planned. What is more, the use of these disciplines together in the education of young students and the fact that the problems include daily life problems enable them to both enjoy the lesson and think creatively.

Research Question 2: How Does the Design-Based STEM Activity Development Process Affect Prospective Maths Teachers' Scientific Creativity?

In the present study, a dependent *t*-test was used to examine whether or not there was a statistical difference between prospective teachers' pre-test and post-test scores obtained from the SCT. Results are given in Table 4.

Table 4

Dependent t-Test Results of Scientific Creativity Test Scores

Variable	Measure	N	$\bar{x}$	S	SD	*t*	*p*
Scientific	Pre-test	45	9.45	1.86	44	-2.88	.01
Creativity	Post-test	45	10.64	2.10			

As is seen in Table 4, the difference between prospective teachers' scientific creativity pre-test and post-test mean scores is statistically significant ($t_{(44)}$= -2.88, p<.05). Since the group's SCT post-test mean score ($\bar{x}$=10.64) was higher than that of the pre-test ($\bar{x}$=9.45), such a difference can be considered to be in favour of the post-test averages.

A dependent *t*-test was used to examine whether there was a statistical difference between the pre-test and post-test scores in the constructs of flexibility, fluency, and originality, which stand for the sub-scores in the SCI Test. Results are given in Table 5.

Table 5

Dependent t-Test Results of Scientific Creativity Test Sub-Scores

Variable	Measure	N	$\bar{x}$	S	SD	*t*	*p*
Fluency	Pre-test	45	3.02	.80	44	-1.87	.07
	Post-test	45	3.36	.85			
Flexibility	Pre-test	45	3.80	.88	44	-3.53	.00
	Post-test	45	4.44	1.05			
Originality	Pre-test	45	2.63	.56	44	-1.78	.08
	Post-test	45	2.84	.53			

As can be seen in Table 5, the difference between the pre-test and post-test mean scores of prospective teachers in terms of flexibility ($t_{(44)}$= -3.53, p<.05) sub-score is significant on the side of the post-test, yet the difference between those scores for the fluency ($t_{(44)}$= -1.87, p>.05) and originality ($t_{(44)}$= -1.78, p>.05) was not significant. Nevertheless, the fluency post-test mean score ($\bar{x}$=3.36) of the group was found to be higher than that of the pre-test ($\bar{x}$=3.02), the flexibility post-test mean score

($\bar{x}$=4.44) was higher than that of the pre-test ($\bar{x}$=3.80), and the originality post-test mean score ($\bar{x}$=2.84) also turned out to be higher than that of the pre-test ($\bar{x}$=2.63).

In the interviews, prospective teachers stated that the STEM activities-based implementation process helped improve their scientific creativity by offering them a different perspective. Regarding this, S2 said:

> We were able to integrate different areas and observe the effect of these four different areas on each other, which gave me a different perspective since such a process revealed creative ideas, enabling me to think of different ways while creating new designs. We developed many ideas while designing the activities. During the implementation, I gained experiences that I can apply to improve the creativity of students, especially in my future teaching career.

In an attitude to support such views, S1 said:

> STEM activities enable and develop skills such as creative thinking, self-expression, and entrepreneurship. It also stimulates a sense of doing research and curiosity. When I become a teacher in the future, I will definitely use them because they will develop both my students' creativity and my own creativity as well as other skills.

In addition, S4 emphasized that STEM activities, in a way, represent normlessness; that they are original and a process which triggers the power of thinking, thereby supporting creative thinking:

> I can say that STEM activities improved my creativity. If I had to describe the implementation process, I can say that learning how to design is different and interesting, besides being partly out of norms. You feel inadequate when you fail to produce new ideas. Permanent learning takes place as it leads you to think creatively. It has also contributed to our own self-improvement, as we develop activities that generate solutions to problems especially by using the power of thinking. I mean, it is a unique, different, and solution-oriented process.

S6 pointed out the idea that STEM activities developed imagination as well as creativity, and taught how such applications should be done:

> The blending of mathematics, engineering, science and technology fields and the way they are used in education gives the opportunity to develop imagination and work in these fields. By establishing an effective bond in these areas, I saw how I could use my imagination in activities and my imagination could develop even at this age. While carrying out our activities in the classroom, we were able to come up with much more creative products without being bound by a specific directive.

Furthermore, S5 stressed that creative solutions to problems can be produced by thinking multi-dimensionally during the activities, and said:

> This process showed me that planning and doing an activity is not difficult, and that students can learn permanently and produce creative solutions to problems. During the implementation process, I both had fun and learned to produce practical solutions. Work sharing in group work enabled me to improve my skills for thinking multi-dimensionally and to approach events from different perspectives. It also had a significant and positive impact on my analytical and practical thinking.

Discussion and Conclusion

This study examined the implementation process of some design-based STEM activities, particularly developed by prospective secondary school Maths teachers, in terms of the impact of those activities on the problem-solving skills and scientific creativity of prospective teachers. As a result of the development process of STEM activities in this study, no statistically significant difference was found between the prospective teachers' pre-test and post-test scores for problem solving skills. In spite of the lack of a significant difference between the PSI pre-test and post-test scores, the clear decline in the post-test scores indicated that the participants' problem-solving skills had improved. Similarly, considering the impulsive, reflective, avoidant, monitoring, problem-solving confident, and planful approaches, which are the sub-dimensions of the PSI, it was concluded that there was no significant difference between the pre-test and post-test scores. However, the decline between the post-test and pre-test scores in the sub-dimensions of the PSI including the factors of being impulsive, reflective, problem-solving confident, and planful indicated that the participants showed improvement in these dimensions at the end of the implementation process. However, the increase observed between the post-test average scores and the pre-test scores in the avoidant and monitoring approaches within the inventory denotes that the development of prospective teachers in these dimensions decreased at the end of the implementation process. One of the reasons for such results could be the readiness of prospective teachers' problem-solving skills being at a high level.

Problem-solving skills can be learned and affected by interpersonal communication (Heppner & Petersen, 1982). The reason why the problem-solving skills of prospective teachers showed no significant improvement could be attributed to the lack of communication within or between groups, since this research was carried out in a crowded classroom. The results of this study indicated a similarity to those results reported by Acar (2018) and Nagac (2018) in their studies conducted with secondary school students and prospective teachers. These studies also revealed that STEM activities showed no positive impact on students' problem-solving skills. Similarly, Elliott et al. (2001) investigated the effect of STEM education on university students' critical thinking skills, problem solving skills, and attitudes towards Maths. At the end of the study, while a positive increase was found in students' attitudes towards mathematics, there was also a slight increase in their critical thinking skills, yet no increase in their problem-solving skills. Contrary to the results of this paper, Delen and Uzun (2018) reported that the process of using design-based STEM activities developed by prospective secondary school Maths teachers had a positive effect on both their problem-solving skills and their views about the process. Moreover, Ceylan (2014), concluded in a study conducted with secondary school students that STEM education had a moderate effect on students' problem-solving skills.

Different studies conducted with different age groups concluded that the activities related to STEM education improved students' problem-solving skills (Akcay, 2019; Akgunduz & Akpinar, 2018; Bal, 2018; Cho & Lee, 2013; İnce et al., 2018; Nagac, 2018; Pekbay, 2017; Ozcelik & Akgunduz, 2018; Vatansever, 2018). In addition, studies in the counselling literature have shown that design-based activity practices also positively affect students' problem-solving skills (Barak & Assal, 2018; Ceylan, 2014; Cooper & Heaverlo, 2013; Crippen & Antonenko, 2018; Dewaters & Powers, 2006; Elliott et al., 2001; Lin et al., 2015; Pekbay, 2017; Sarican & Akgunduz, 2018). A study conducted by Avsec and Kocijancic (2014) reported that engineering-based activities developed within the scope of inquiry-based learning improved students' problem-solving skills as well as their learning capacity.

Despite the lack of any statistically significant differences in the PSI, the findings obtained from the interviews with prospective teachers support the increase in the problem-solving skills of prospective teachers. Participants emphasized that their problem-solving skills improved in the process of developing design-based STEM activities. They also indicated that the activities contributed, especially in terms of problem-solving skills, gaining a different perspective, creativity, and the ability to make use of them while teaching, and that STEM education is interdisciplinary as a whole. They also emphasized that it is a practical preparation, in which different disciplines are integrated and solutions are produced, for different problems.

Generally speaking, prospective teachers stated that STEM education is a process, design, or product that integrates different disciplines (technology, science, mathematics, and engineering as a whole), requires problem-solving skills, and finds solutions to current problems and needs. In particular, students' designing with materials they may encounter in daily life enables them to establish direct relationships with daily life (Ceken, 2010). Thus, students' awareness of the environment increased during the implementation process, which they stated they associated with the topics and concepts with daily life. Similarly, Ozcakir Sumen (2018) reported that the use of STEM activities in lessons contributed to establishing an increased relationship between mathematics subjects and daily life. Additionally, Kayalar (2018) asserted that STEM activities can be conducted using simple, cheap, and recyclable materials. The author also stated that STEM activities are intertwined with daily life and that they need to be planned to meet the needs of individuals. In a similar manner, Harkema et al. (2009) noted that science and engineering exist in an integrated way in daily life, and that STEM activities should also have an emphasis on daily life.

Prospective teachers stated that the process was remarkable in that they generated concrete solutions in relation to the subjects of the activities during the implementation process. In other words, this process ensures that an individual is kept active in the learning process by doing and experiencing. Another study supporting these results was conducted by Dare et al. (2017) on the use of STEM activities in teaching physics concepts with sixth grade students. In this context, they used the engineering design process to solve possible problems in STEM activity plans. As a result of that study, the authors reported that student-centered approaches motivated students who found STEM activities attention-grabbing and that making designs for the field of physics made it easier for students to establish a relationship between physics and daily life in such a way that they could learn the subject well. Many studies on STEM education have concluded that STEM has a positive effect on students' conceptual and theoretical learning levels (Gulgun et al., 2017; Robinson et al., 2014; Yoon et al., 2014).

Another result of our study is the statistically significant difference in favour of the post-test, which was found between the participants' pre-test and post-test scores with respect to scientific creativity as a result of the STEM activities development process. Based on this, it could be assumed that STEM activities, conducted with the participation of prospective teachers, contribute to their scientific creativity. Similarly, there was a statistically significant difference in favour of the post-test between the pre-test and post-test scores in the flexibility sub-score of the scientific creativity test. As opposed to this, no statistically significant difference was found between the pre-test and post-test scores in fluency and originality sub-scores. However, these sub-scores were found to be higher in the post-tests than in the pre-tests.

In the STEM activity processes, the prospective teachers associated their daily life experiences with the field knowledge they had already acquired. During the implementation of the activities, they followed the changes in their ideas, commented on different ideas, and came to a conclusion by discussing the correctness and applicability of their ideas, a process which contributed to the scientific creativity of the students. The results of some studies in the literature are also similar to the results of the present study (Ceylan, 2014; Cho & Lee, 2013; Ciftci, 2018; Dogan & Kahraman, 2021; Dong-Ju et al., 2016; Kahraman, 2021; Knezek et al., 2013; Pekbay, 2017; Ryu & Lee, 2013; Siew et al., 2015; Senturk, 2017). The results of the study conducted by Ciftci (2018) with seventh grade students also indicated that STEM activities positively affected students' scientific creativity levels. Similarly, STEM activities integrated into the subject of acids and bases were found to boost students' creativity (Ceylan, 2014) and that STEM activities, especially those associated with abstract concepts, also improved students' scientific creativity (Senturk, 2017).

Given the results of the present study, the reason why the post-test results of scientific creativity as well as of its sub-scores of fluency, flexibility, and originality were high could be attributed to the use of engineering design process steps in the STEM activities conducted during the procedure. Associating the problem scenarios used in such activities with daily life experiences, and creating a solution to an existing problem can play an important role. The reason for this is that students create new products and designs by using the engineering design process and skills at the stage of producing solutions for the given problem (Bybee, 2011; Lederman & Lederman, 2013). Mauffette et al. (2004) asserted that the scenarios used in learning environments, and the problems contained in those scenarios, establish a connection in attracting students' attention, determining the boundaries of the relevant subject, and associating such experience with daily life.

In the interviews, the prospective teachers emphasized that STEM-based practices support scientific creativity and that creative ideas are put forward, since the implementation process encourages individuals to think multi-dimensionally. The STEM activity development process enabled participants to offer different solutions on the basis of original ideas. Therefore, it can be said that the problem-solving process exposed the creativity of the prospective teachers. It can also be concluded that the implementation of the activities in the classroom environment prepared the prospective teachers for their future teaching profession by enabling them to acquire the necessary skills such as relevant experience, making presentations, planning the process, classroom management, and self-confidence.

In the counselling literature, it is stated that STEM-based activities improve problem-solving skills and creativity of individuals, and their self-confidence in STEM fields (Akgunduz et al., 2015; Gulen, 2016; Moore et al., 2015; Naizer et al., 2014; Wendell, 2008). In addition, Gokbayrak and Karisan (2017) emphasized that such activities with students contribute to their mental development. For this reason, it is extremely important that the activities carried out in the teaching environments are instructive and that educational activities allow students to establish interdisciplinary relationships.

In the present study, participants found the activities conducted in relation to STEM education interesting and fun. Participants also emphasized that the activities supported learning by doing and experiencing, besides heading them towards multi-disciplinary thinking by offering different perspectives. Similarly, in many other studies, students stated that STEM-based practices are fun, enjoyable, and interesting (Cinar et al., 2016; Ozbilen, 2018). In addition, as students carry out the activities actively throughout the implementation process, they are able to use their field knowledge to solve a problem (Cepni, 2017). In this way, the students are actively involved in the process, thereby restructuring the knowledge themselves as they gain experience through learning by doing (Daniel,1993; Jones et al., 2003; Wheatley, 1991).

In the current study, the participants stated that STEM activities improved their imagination by influencing their abilities to be able to make predictions and think analytically within group work, Moreover, participants were able to associate mathematics with daily life, which provided permanent learning that was educational. Various studies in the literature also indicated that STEM-based activities encourage students learn cooperatively and develop their effective communication skills (Ceylan, 2014; Choi & Hong, 2013; Cepni, 2017; Eroglu & Bektas, 2016). Having investigated the effects of out-of-school STEM activities on students, Sahin et al. (2014) reported that students are influenced by each other and contribute to each other's development as they cooperate.

Considering the results of the research in teacher education, it is thought that there is a need for teaching environments in which individuals will actively take part in the learning process, where they can offer various solutions to the problems they encounter, where they can make original and innovative designs, and display their creativity. This study presents an innovative perspective on STEM-focused science and mathematics education teacher preparation. It is thought that the application process and results of the study will contribute to the field.

Recommendations

The following recommendations can be made based on the results obtained from this research: In this study, the designs for the relevant activities were created in the classroom environment by making use of the materials available, and within the time limit for which the activities were being conducted. Similar activities can be conducted with the participation of students in the form of assignments, or projects as an out-of-school activity, so that there will be no limits in terms of time and materials. The activities within the scope of this research were carried out in the classroom environment, which was organized in accordance with the activities throughout the implementation process. However, another important factor is that STEM activities should be easily implemented and suitable environments should be arranged for students to work in groups. In this context, workshops or laboratories can be organized in schools for the implementation of STEM activities. Thus, students can be provided with suitable settings where they can create their own designs and products.

This study was carried out in a crowded classroom with 45 prospective teachers. In the future, further studies can be conducted in classes or in groups with fewer people. In addition, this study was carried out with prospective Maths teachers only. The content of the study can be used to conduct other studies with prospective teachers studying in different departments with updated curricula. Thus, it will be possible to achieve interdisciplinary work with a variety of prospective teachers. The applicability of STEM activities developed by prospective teachers can be tested using quantitative and qualitative methods. Also, more STEM education courses can be prepared and offered to prospective Maths teachers. In-service professional development on STEM education can be provided for Maths teachers. This study examined prospective Maths teachers' problem-solving skills and scientific creativity. Many other skills may be examined in future studies, and different tests may be used to measure the problem-solving skills and scientific creativity of prospective teachers.

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Centering Students in Transdisciplinary STEAM Using Positioning Theory

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ABSTRACT

Integrated STEAM instruction continues to be a major focus of K-12 education. In effort to better understand STEAM education, we reviewed existing frameworks for implementing integrated STEAM in classrooms. We found that existing frameworks largely focused on the lens of the teacher, thus leaving the student perspective of STEAM learning experiences out of conversations centered on both research and practice. The purpose of this theoretical paper is to center STEAM education on students' rights, obligations, and duties within integrated STEAM instruction as a way to refine understanding of students' positions in STEAM learning experiences. We use theoretical considerations and evidence to explore new ways for transdisciplinary STEAM to be conceptualized from a student perspective. We conclude with considerations and implications for future STEAM education research.

Keywords: elementary STEAM, positioning theory, student repositioning, transdisciplinary

Introduction

K-12 schools have increasingly focused on science, technology, engineering, art, and mathematics (STEAM) education (Liao, 2019) due to the perceived benefits of an integrated learning experience. While some research has been conducted related to understanding students' experiences in STEAM instruction (e.g., Bush et al., 2020) much of the literature in STEAM education remains focused on teachers' understanding or implementation of integrated STEAM instruction (e.g., Herro & Quigley, 2016; Jacques et al., 2019; Quigley et al., 2019). The purpose of this theoretical paper is to center STEAM education on students' rights, obligations, and duties within integrated STEAM instruction as a way to refine understanding of students' positioning in STEAM learning experiences. We use positioning theory (van Langenhove & Harré, 1999) to explore how students are positioned during STEAM inquiries and focus specifically on how some inquiries invite or limit students' potential positions and shape their opportunities for transformative learning. Through the exploration of student positioning in STEAM, we highlight how specific disciplinary integrations lend themselves more naturally to repositioning students towards transformative learning experiences.

While STEAM and science, technology, engineering, and mathematics (STEM) education have been a focus of policy makers and administrators (Liao, 2019) for decades, they have different roots that have ultimately positioned students in different ways. Because STEM has its roots in workforce development, students receiving STEM education are positioned with the tools needed to prepare them for eventual jobs or to meet the needs of a global market economy (National Research Council, 2011). STEAM literature adds another element to this aforementioned lens by integrating art education into STEM as a way to engage more learners (Ahn & Kwon, 2013; Bequette & Bequette, 2012; Wynn & Harris, 2012). The addition of "A," shifting from STEM to STEAM, recognizes the role that aesthetics, beauty, and emotion play in arriving at solutions to problems (Bailey, 2016). STEAM specifically focuses on students solving authentic problems by positioning them to make their worlds better (Bush & Cook, 2019). Integrated STEAM instruction draws on creativity, aesthetics, and personal expression, while positioning students to design solutions for others (Cook & Bush, 2018). An important component of integrated STEM and STEAM is the role of empathy in solving problems for others (Bush et al., 2022; Bush et al., 2020; Edelen et al., 2020; McGee & Bentley, 2017; Sun, 2017). The inclusion of empathy offers a catalyst through which students can both begin to realize why disciplinary knowledge is needed to make sense of the situation under investigation, as well as generate new and novel solutions (Bush et al., 2022; Cook & Bush, 2018).

While several frameworks exist for integrated STEAM education, the role of students within STEAM learning experiences is left largely out of the conversation. Curricular ideas for how to better understand, conceptualize, and develop the highest quality STEAM learning experiences include ideas about best practices in STEAM inquiry design and implementation, but do not address how the students are positioned within the learning, nor what can make STEAM a transformative experience for students.

In this paper, we build from several existing frameworks in the field (e.g., Bush & Cook, 2019; Hwang & Taylor, 2016; Quigley et al., 2017; Yakman, 2011) to focus on different integrated approaches to STEAM instruction (i.e., multidisciplinary, interdisciplinary, and transdisciplinary), while drawing clear connections to student authority within such integrations. We first discuss existing STEAM conceptual frameworks and then highlight the inclusion of empathy as a key component to STEAM. We then propose a new conceptual framework for integrated STEAM instruction from a student perspective.

Existing STEAM Conceptual Frameworks

During the past decade, frameworks have been developed to inform and guide components of integrated STEM education theory and practice (e.g., Bybee, 2010; Falloon et al., 2020; Honey et al., 2014; Kelley & Knowles, 2016; Lee & Nason, 2012; Reider et al., 2016; Tan et al., 2019; Yata et al., 2020), which are summarized in more detail by Jackson and colleagues (2021). In science education, the National Research Council (NRC, 2012) calls for teachers to guide students in understanding and grappling with ethical and moral implications as well as the human context of science. Frameworks such as the Science, Technology, and Society (STS), Science, Technology, Society and Environment (STSE), and Socio Scientific Issues (SSI) have provided structures and considerations for teachers to engage students with the impacts science has on society. Chowdhury (2016) explains that the "STS/STSE and SSI integrated approach may help to focus more holistically on the humanisation and socialisation aspects of science practices; and can increase the awareness of social implications" (p. 35). Our work complements these and other frameworks that have emphasized the importance of the humanistic elements of learning. And, while these frameworks have helped push the field of integrated instruction forward in important ways, this paper specifically focuses on integrated STEAM.

Therefore, we now take a closer examination of existing integrated STEAM frameworks.

One integrated STEAM framework, *STEAM: A Framework for Teaching Across the Disciplines* (Yakman, 2011), focuses on the general integration of the STEAM disciplines using a pyramid to showcase that as you move up towards the top of the pyramid from content and discipline specific silos to a more integrative STEAM approach, this leads to "more engaging and deeply embedding ways within the already well-established realm of education" (Yakman, 2011, p. 3). A second framework, *Interdisciplinary Approach to STEAM Education for Students with Disabilities*, by Hwang & Taylor (2016), focuses on STEAM for students with disabilities and includes the integration of the disciplines in STEAM, real world contexts/authentic problems, and generalizability.

Quigley and colleagues (2017) developed a STEAM framework, *STEAM Teaching Model*, but this frame focuses specifically on a teaching model for STEAM and includes two domains (instructional content and learning context) and six dimensions (problem-based delivery, discipline integration, problem-solving skills, instructional approaches, assessment practices, and equitable participation). The STEAM Teaching Model is derived from extensive work with middle school teachers and centers on (a) real-world applications that have no definitive solution; (b) the need for multiple disciplines to address the problem; and (c) the need for students to use collaborative skills in finding a solution. A fourth framework, Equitable STEAM Education by Bush and Cook (2019) focuses on equity in STEAM and identifies three essential elements for equitable STEAM education: 1) providing access to each and every student, 2) implementing reform practices in mathematics and science teaching in STEAM instruction, and 3) exploring meaningful and authentic problems through STEAM. We have provided Table 1 to aid in summarizing across each of the frameworks.

Table 1

Frameworks in STEAM

Framework	Authors and Year	Focus
STEAM: A Framework for Teaching Across the Disciplines	Yakman, 2011	General integration of STEAM subjects from a siloed approach to an integrative approach to teaching
Interdisciplinary Approach to STEAM Education for Students with Disabilities	Hwang & Taylor, 2016	Teaching STEAM for students with disabilities. Focuses on integration of subjects and using real world contexts
STEAM Teaching Model	Quigley et al., 2017	Focuses on a teaching model of STEAM. Includes two domains (instructional content and learning context) and six dimensions (problem-based delivery, discipline integration, problem-solving skills, instructional approaches, assessment practices, and equitable participation)
Equitable STEAM Education	Bush & Cook, 2019	Focuses on attending to equity in STEAM through access, reform practices, and using meaningful and authentic problems.

These four frameworks presented provide important guidance to the field regarding different aspects of STEAM education and during the past decade, based on publication dates, there is a clear trajectory towards new learning and more sophisticated ideas related to STEAM education. In this paper, we complement and expand on these ideas about STEAM teaching and learning by a) adding a key component of empathy to the discussion; and b) recentering the focus of STEAM education on a student's perspective of their STEAM learning.

The work of Bush and Cook (2019) informs our next steps as they argue that the foundation of STEAM education is a commitment to transcending disciplinary boundaries through equity, empathy, and experience. Specifically, they approach *equity* as access to STEAM instruction for each and every student (rather than STEM or STEAM instruction being available only after school or in an advanced program, for example). Whether through a laboratory setting, where STEAM instruction is the primary focus, or a traditional classroom setting, every student deserves access to the meaningful learning STEAM approaches provide such as rich discourse, collaboration, risk-taking, authentic problem solving, and connections to their community and self. Equity does not mean every student enters the STEAM conversation the same way, but that every student has the opportunity to access the conversation with their voices and lived experiences valued. The *experience* of STEAM, rich in expression, collaboration, exploration, authenticity, and innovation pushes educators to do whatever is necessary to fully engage students in the content. Finally, *empathy* grounds the STEAM experience in the "why." Empathy positions students to be change agents for the betterment of not only their realities but to also think deeply about how they might meet the needs of others in an effort to improve lives. From the educators' perspective, empathy refocuses the attention from a product only inquiry to encouraging their students to be charged with observing and engaging in more mindful, meaningful, and insightful ways in the service of others.

The Importance of Empathy in the STEAM Experience

Smith and Paré (2016) argue that incorporating empathy through the arts in STEM instruction addresses the need for an affective connection for students to grasp difficult concepts and ascribe importance to them. The inclusion of empathy through the arts makes STEAM different from STEM, and intentionally grounding STEAM in equity, experience, and empathy (Bush & Cook, 2019) differs from other movements in elementary science and mathematics education. Maxine Greene (1988) makes the following argument, connecting "art forms" and empathy to transformation.

> For those authentically concerned about the 'birth of meaning,' about breaking through the surfaces, about teaching others to 'read' their own worlds, art forms must be conceived of as ever-present possibility. They ought not to be treated as decorative, as frivolous. They ought to be, if transformative teaching is our concern, a central part of curriculum, wherever it is devised. (p. 131)

What Greene suggests as an "ever present" sense of empathy through the arts is uniquely positioned to truly transform instruction in concert with whatever content students encounter. Approaches rooted in empathy cannot be relegated to the sidelines or included only as a means of checking off a list. Greene (1995) notes "if the significance of the arts for growth, inventiveness and problem solving is recognized at last, a desperate stasis may be overcome" (p. 382).

Land (2013) points to potentially transformative uses of the arts in this way, specifically musical compositions, kinetic art, product design, prototype development, and performance art as ways to connect people. Additionally, Land (2013) explores how the inclusion of empathy through the arts as part of STEAM might affect student outcomes. Sharapan (2012) points to the famous pop culture icon Fred Rogers and his show Mister Rogers' Neighborhood as a model approach for how empathy through engagement with the arts might be fully included and valued in broader elementary science and mathematics research and pedagogical conversations, naming students as "magical thinkers" in their educator-facilitated explorations of the world around them through music, dance, descriptive language, building, making, and connecting with others. For students highlighted in this research, embracing empathy through the arts allows for creative liberation and broadening of content knowledge. For educators, embracing the arts allows students to "collaborate with different subject teachers [to] relieve teachers' burdens and save more time to acquire new pedagogies" (Ahn & Kwon, 2013, p. 1859). When educators collaborate, not only do they benefit logistically (as workloads are often shared), but also educationally as professional knowledge is shared and professional capacities are enhanced.

Elementary science and mathematics reform documents (e.g., Larson, 2017; National Council of Teachers of Mathematics, 2014; 2020; NRC, 2012; President's Council of Advisors on Science and Technology, 2010) and the incorporation of empathy through the arts encourage elementary educators to find new ways of thinking and to invite students to embrace possibilities. The inclusion of empathy represents an opportunity to look beyond the past towards better futures, futures which include equal distribution of resources, futures without discrimination based on gender identity, race, sexual orientation, being inclusive of each and every person. The Arts, a pathway for empathetic engagement, are more than merely the incorporation of simple visualizations but focused on a broader more forward-thinking, idealistic vision for what was possible. Greene (1995) suggests educators free and unleash the arts to empathize with others. According to her, doing so provides enrichment for both students and educators and brings purpose to what can be too heavy a focus on a rigid and non-emotional scientific and technological progress that can overshadow personal and social growth. In short, adding the A to STEAM and focusing on empathy brings about the opportunity to refocus on more transformative instruction.

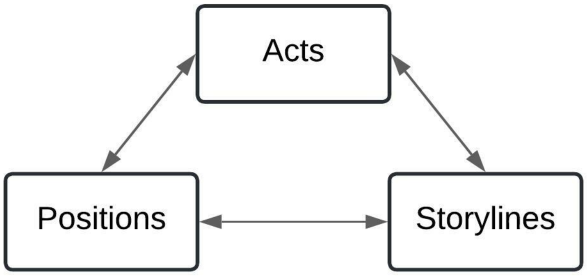
Theoretical Framing

To articulate the role of empathy and the potential it has in positioning students to transcend disciplinary boundaries, we draw from the work of van Langenhove and Harré's (1999) positioning theory. We use positioning theory as an explanatory theory (Green et al., 2020) to highlight and describe the observable and unobservable details of interactions that comprise social life. In particular, positioning theory encapsulates the positions that define storylines enacted by actors in social contexts. In this paper, we will use each of the vertices in the *Positioning Triangle* from Harré and Moghaddam (2003) to explore the social life and contexts of an elementary school classroom. Within the triangle (see Figure 1; inspired by Harré & Moghaddam, 2003), *positions* are the potential rights and duties performed within certain social situations. Importantly, a position limits what is possible for an actor to say or do in a social situation. The second vertex of the triangle, *acts*, refers to the social actions that are performed by actors in the social situation, and thus are contextually significant. The third vertex within this triangle encompasses *storylines*, which are the ways in which social situations play out due to positions, social acts, and narrative conventions. Because storylines do not unfold in random ways, but instead follow a practiced and established pattern of interactions, locating the positions of actors (e.g., students, teachers, principals, paraprofessionals) in social situations is a means to illuminate the rights, duties, and responsibilities of each person in a particular context.

For the purposes of this paper, positioning theory helps situate the exploration of classroom structures in order to gain insights into the negotiations of authority, status, and power within STEAM instruction. In this paper, we purposefully explore beyond the simple binaries of student identities in STEAM contexts (e.g., power/powerless) to engage in the complex storylines enacted by the actors (e.g, teachers and students) involved in STEAM inquiries.

Figure 1

Example Positioning Triangle

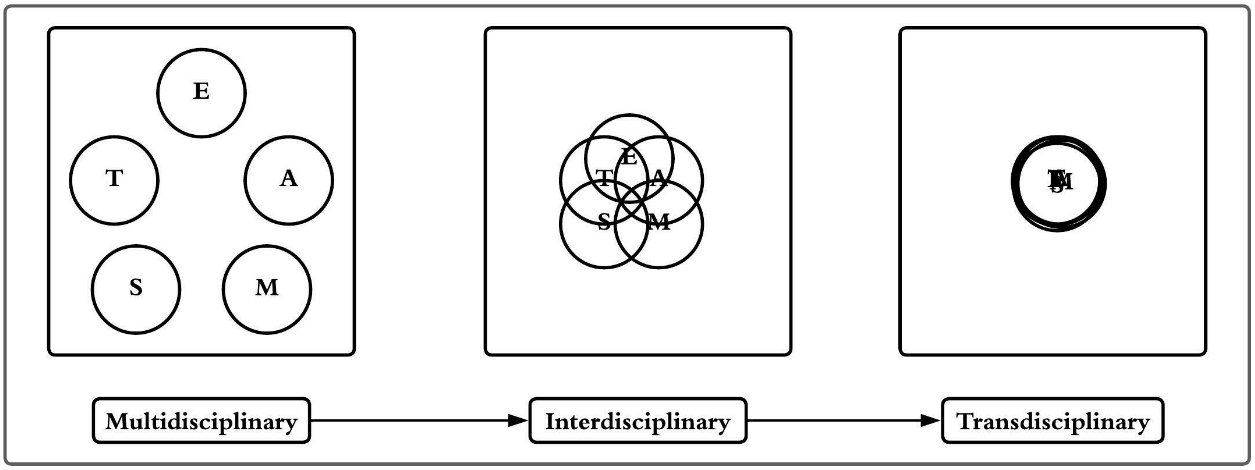


Transcending Subject Boundaries

Within STEAM, there is much discussion regarding the ways in which and the extent to which the STEAM disciplines are integrated. Three different types of STEAM integration can be best visualized on a continuum (see Figure 2, adapted from Jensenius, 2012).

Figure 2

STEAM Disciplinary Integrations Continuum



Note. Adapted from Disciplinarities: Intra, cross, multi, inter, trans by A. Jensenius, 2012, March 12, https://www.arj.no/2012/03/12/disciplinarities-2/ and Don't forget the profession when choosing a name (p. 69) by E. F. Ziegler, 1980, *Academy Papers.*

On the left side of the continuum are multidisciplinary integrations. Here, the disciplines are integrated to focus on a problem or an issue without integrating knowledge of each discipline (Choi & Pak, 2006; Kaufman et al., 2003; Herro & Quigley, 2016). In essence, students might study a singular phenomenon, but in departmentalized classroom settings or with clear disciplinary approaches (e.g., science component, then mathematics component, etc.). In the center of the continuum are interdisciplinary integrations. Interdisciplinary learning is the integration and interaction between disciplines of thought or practice (Stentoft, 2017). Interdisciplinary refers to the incorporation of two or more disciplines that are integrated to allow students' utilization of knowledge from multiple disciplines in observation of an object of study or problem under investigation (Choi & Pak, 2006; Klein, 2006). Interdisciplinary is different from multidisciplinary in that subjects are integrated in a way that builds upon the disciplinary connections; therefore, disciplines complement each other as a means to explore phenomena through a connected disciplinary lens. On the right side of the continuum is transdisciplinary integrations. Within transdisciplinary integrations, students move beyond the constraints of one discipline, such as mathematics or science, to formulate new and novel solutions (Nicolescu, 2005; 2010). In a transdisciplinary investigation, students become so enthralled in the problem that they use previous knowledge and acquire new knowledge from multiple subject areas to generate a solution (Cook & Bush, 2018). Transdisciplinary integration becomes nebulous when it is put into practice, as educators seek to discover the catalyzing force through which students might transcend subject boundaries. In the following section, we offer a framework to conceptualize the importance of student positionings in transcending subject boundaries.

Repositioning Students in STEAM Inquiries

While there are several ways to integrate the disciplines in STEAM inquiries, we contend that integrated STEAM should be focused on student experiences, and the ways in which students are positioned within this learning. Maintaining a focus on students allows for a repositioning of traditional roles in integrated STEAM learning. Through this repositioning, we critically examine the positions of actors (e.g., students and teacher) in STEAM settings. For the purpose of this paper, we will examine those actors who have the authority to define the rights and duties of the positions associated with learning in integrated STEAM.

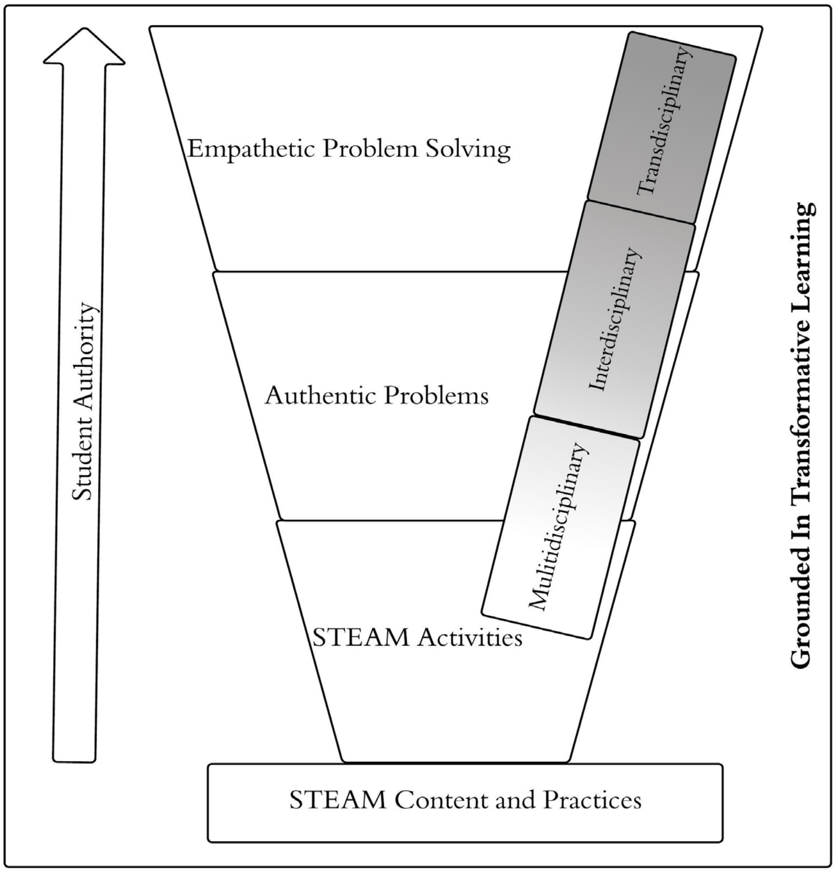
Bush and colleagues (2020) determined that there were three hierarchical levels of STEAM learning experiences, as found by student perceptual data: a) STEAM activities, b) authentic problems, and c) empathetic problem solving. The first level of the hierarchy, *STEAM activities*, are defined as STEAM challenges that students identified as being fun or challenging, but that had no deeper connection to the mathematics or science content and practices. The second level, *authentic problems*, are defined as problems that position students to connect an authentic or real-world integrated STEAM problem to science and mathematics content and practices. The third and highest level of the hierarchy, *empathetic problem solving*, is defined as inquiries that position students to connect with other peoples' (or animals', or the environments') needs. In these experiences, students use integrated STEAM to better inform their understanding of the social situation under investigation, with a deep connection to science and mathematics content and practices. While the hierarchy highlights key practices and a way to evaluate the quality of STEAM inquiries, we wish to better articulate the positions of students in the context of integrative STEAM learning.

Student Repositioning: Transdisciplinary STEAM Framework

It matters how students are positioned in STEAM inquiries. To articulate this phenomenon, we present a framework to illustrate the positions of students within integrated STEAM inquiries. Within this framework, transformative learning (Mezirow, 2009) is presented as the orienting theory for STEAM and is highlighted in Figure 3 as the backdrop for each component. We use transformative learning because it centers students in an effort to shift students' perceptions of their worlds and shape their understandings and beliefs (Cranton & King, 2003; Mezirow, 2009). Ultimately, STEAM learning inquiries should result in students making better sense of their worlds. Importantly, there is a key distinction that undergirds our framework; transformative learning greatly depends on students' frames of references, or the ways they view their worlds. These frames of reference are shaped both by their experiences, as well as the sociocultural worlds in which they have experiences (Mezirow, 2000; 2009). Thus, for transformative learning to occur, STEAM learning inquiries must create opportunities for students to make sense of their worlds in an effort to continually shape and reshape their frames of reference.

Figure 3

Student Repositioning: Transdisciplinary STEAM Framework



However, not all STEAM inquiries have the same impact on students, as indicated in the three levels presented in our framework (i.e., STEAM activities, authentic problems, and empathetic problem solving). Within the hierarchy, we have included the approaches to disciplinary integrations (multidisciplinary, interdisciplinary, and transdisciplinary) to note how we conceptualize the progression of student experiences within STEAM content. Importantly, our framework is built on the foundation of STEAM content and practices. STEAM content comprises the core subject's disciplinary knowledge (i.e., science, technology, engineering, arts, and mathematics), while STEAM practices are made up of the practices associated with the disciplinary knowledge used during STEAM inquiries (i.e., Mathematical Practices [National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010], Science and Engineering Practices [NGSS Lead States, 2013]). In our framework, the disciplinary integrations cross the hierarchy levels to indicate which STEAM learning inquiries (activities, authentic problems, and empathetic problem solving) naturally lend themselves to each integrative approach.

As transformative learning is based on extending frames of references for students engaged in the learning opportunity, the ways in which students are positioned must also be considered. Within transformative learning, students have a strong tendency to reject ideas or claims that are not easily viewed through their frames of reference (Mezirow, 2009). To honor students' rich frames, STEAM learning must offer opportunities for students to shape and build upon their lived experiences. Because frames of reference are cultivated through students' culture and language in use (Mezirow, 2009), each student will have different opportunities offered to them based upon the STEAM learning inquiry and they will approach those learning opportunities through different lenses. Importantly, student repositioning in STEAM learning must provide opportunities for students to redefine their rights and duties in the learning event, so that students can explore how STEAM might be used in their worlds.

Within our framework, we use student authority to point to the opportunities students are offered to extend upon, reshape, or use to redefine the STEAM learning event. Here, authority is defined through a positioning theory lens to identify which actor (teacher or student) has the power to redefine their positions within STEAM learning. In the following sections, we build on this concept to clearly outline the importance of student authority; more specifically, we focus upon the rights and duties that are associated with different levels of STEAM integration.

Positions in STEAM inquiries

While other frameworks focus on the instructional moves that teachers make to transcend subject boundaries within STEAM (e.g., Bush & Cook, 2019, Hwang & Taylor, 2016; Quigley et al., 2017; Yakman, 2011), the *Transdisciplinary STEAM Framework* privileges the student at the center of the. We propose that educators cannot ultimately determine what is transformative for students. Within our framework, there are three possible levels of inquiry across multidisciplinary, interdisciplinary, and transdisciplinary integrations. We use positioning theory to discuss the positions, rights, and duties available to students to act within based upon storylines in each of the levels. During STEAM inquiries, there are many ways in which students can be positioned to act; however, we will focus upon three: teacher(s), problems under investigation, and STEAM content.

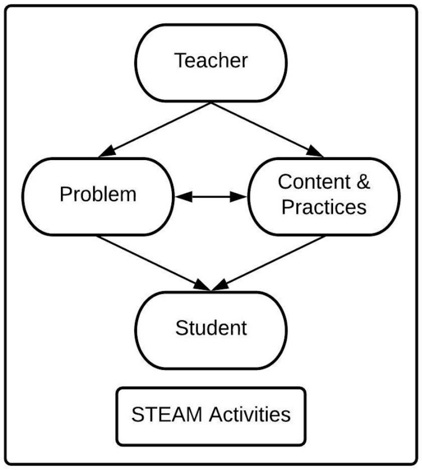
In the subsections that follow (STEAM activities, authentic problems, and empathetic problem solving) we offer conceptual representations of the organization of positionings within each of these STEAM inquiry levels. To help the reader visualize each level, we use the traditional integrated STEAM inquiry of building and designing a garden (commonly known as the garden inquiry) to further explore the rights and duties of students within each of the levels.

STEAM Activities

Within this level, an important question must be asked, *Who has the authority to define the rights and duties associated within STEAM inquiries?* Typically, the storylines available to students are clear due to how they are positioned within STEAM activities. Here, students are positioned as receivers of knowledge because they do not have the authority to design the learning event. While these learning situations make up those activities that students might indicate as fun, they lack a larger connection to a problem under investigation or for a greater purpose. As such, students do not have the authority to outline their learning event; thus, integrations are seen as top down and teacher directed. Within this level, students might experience multidisciplinary integrations in which STEAM subjects are integrated, but with clear disciplinary boundaries. In Figure 4, the three ways in which students are positioned are outlined. The teacher is at the top of the positioning map, demonstrating how the inquiry or activity is designed by the teacher. Teachers maintain this position because they develop what students might learn about (e.g., the content and the problem). In this regard, the content and problem directly positions the student and the ways in which they may act, as well as the storylines available to them. In returning to transformative learning, the content and problem directly position the ways in which students use their frames of reference to solve and make sense of the STEAM learning experience. Thus, students lack authority to explore learning outside the storylines that are presented to them. As indicated below, the problem and content created by the teacher directly position the storyline so that students are able to enact in the context of the STEAM situation. Therefore, the teacher indirectly positions students through the design of the STEAM content, integrations, and problem under investigation, as they control what is being investigated and how the content is to be integrated.

Figure 4

Positionings in STEAM Activities



In using positioning theory, potential storylines that students have the opportunity to enact are limited due to clearly defined roles and duties: student as receiver and teacher as generator of knowledge. Students within these integrations and activities are not granted the right to authorize themselves past the current learning event due to the ways in which students are positioned.

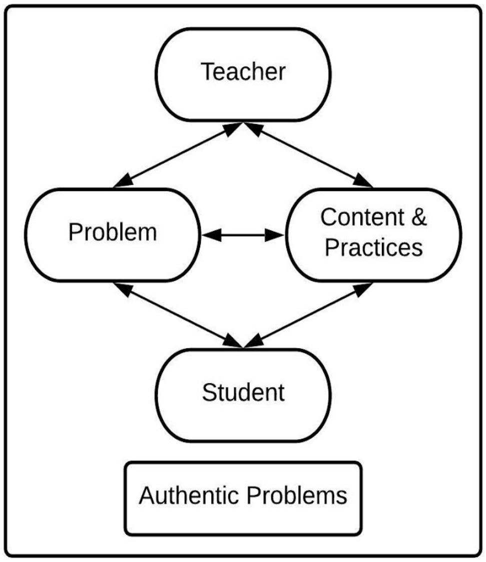
Using the garden inquiry, we can further make visible how students could be positioned within this level. As STEAM activities are generated by the teacher and lacking a larger connection to students' frames of reference, the garden inquiry may typically be outlined as follows. The garden inquiry would be centered around students visiting a school or community garden to learn about each or some of the STEAM disciplines. Importantly, the teacher would decide how each of the subjects were to be explored by the student, and thus the storylines available to students as they explore the garden inquiry would be limited. For example, students might use mathematics to find the total area of the garden. They might use scientific thinking and exploration to document living and non-living things. Students could use technology to chart differences electronically in plant species. They could also be asked to draw a specific plant as an art component. Students might also use engineering to explore certain structures that aid plants' growth in the garden. Each of these components would be teacher-directed, multidisciplinary in nature, and remain siloed due to the lack of disciplinary integrations. In this specific garden inquiry, students would only be positioned as receivers of knowledge; the storylines in this type of inquiry would direct students to play out the obligations associated with the teacher directed content. New mathematics and science content and practice learning would be limited and certainly not transformative in nature within this level (Bush et al., 2020). Although some learning could take place, essentially, the inquiry would not allow for students to reposition themselves to redefine their rights and duties.

Authentic Problems

Within this level, the storylines available to students become more nuanced because there are more possibilities for repositioning of student rights and duties, as compared to STEAM activities. However, student acts, as determined by student positions, are more informed by the problems students are investigating. Figure 5 outlines the indirect and direct positionings of students and displays how students are still positioned to act as receivers of knowledge. In this level, the teacher is still positioned to maintain authority to generate and delineate STEAM content to students. In the position mapping, the teacher is at the top of the map (similar to STEAM activities) because they generate the content and the problem to be explored. Because the teacher generates the inquiry, the storylines for students to act within are predetermined, and thus their positions lack the authority to renegotiate to better use their frames of reference. However, within this level, students can inform the content and the problem under investigation, as seen in Figure 5. This figure outlines the ways in which the teacher directly positions the problem and the content for STEAM inquiries; ultimately, the teacher clearly defines how and in what ways disciplines should be integrated. Figure 5 is different from Figure 4 in that the arrows are bidirectional to account for how students might position the content and problem based upon the integration. There are two types of integrations within this level: multidisciplinary and interdisciplinary. Within multidisciplinary integrations, students do not have the same potential to explore the connections between disciplines. However, as inquiries become more interdisciplinary, students have the potential to authentically explore how disciplines might be connected; they therefore have more authority to explore the content and the problem under investigation. Importantly, within this level, meaningful mathematics and science content and practice learning can occur for students (Bush et al., 2020).

Figure 5

Positioning in Authentic Problems



One of the defining features of authentic problems is that the problem under investigation still has clear disciplinary boundaries. This distinction means that students might be positioned to see the connections across disciplines, but these connections are defined by the problem under investigation and the person who designed the problem. Thus, this type of integration ultimately outlines the rights and duties of students in the STEAM learning inquiry.

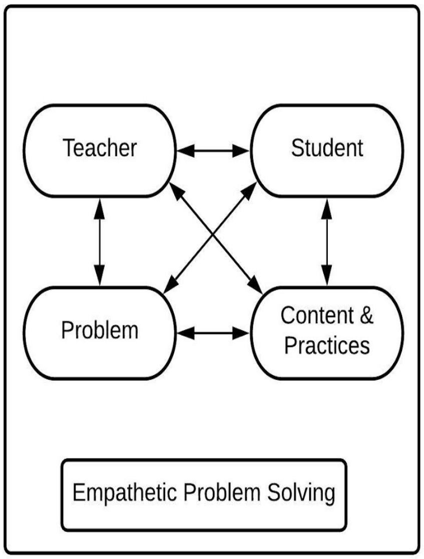
To further explore this integration, we return to the garden inquiry as an interdisciplinary example. As indicated previously, a defining feature of this level focuses upon an authentic problem for students to explore; thus, the authentic problem in this example could center around building a garden for the students' school. In the garden inquiry at this level, students could be working to design and build a garden. However, the teacher would design the disciplinary parts that the students would explore. For example, students might use mathematics to design the garden to scale on paper first to ensure their plans would fit within the constraints of the inquiry. They might research different plants and the growing cycles to determine what should be planted in the garden. They might explore different engineering designs of raised beds to use in their plans or decorate and color their plans to denote key characteristics of their included plants. Students might also use design software to develop their 3-D plans. While students might clearly see the connections between the subjects, they are still positioned as the receivers of knowledge in this level. While they gain the authority to describe connections between disciplinary content and the problem under investigation, they do not have the authority to reposition themselves to act out different storylines other than those that have been pre-determined by the plans of the teacher as generator of the inquiry.

Empathetic Problem Solving

Within this level, the possible storylines and positionings become muddled as new possibilities are introduced due to the empathetic component of the problem. Including an empathetic component into STEAM inquiries changes the rights and duties of students, thus changing their positions. Figure 6 outlines this phenomenon.

Figure 6

Positionings in Empathetic Problem Solving



In Figure 6, students are moved from receivers of knowledge to constructors of knowledge because they are positioned alongside the teacher. Students are no longer solving the problem only for content understanding. They also are not solving the problem to align themselves more closely to the thought processes of the teacher. Instead, they are actively working to solve the problem for someone else or to make their worlds better. Learning within this level has the most potential for being transformative for students (Bush et al., 2020).

The inclusion of an empathetic component allows for students to reposition themselves to better use frames of reference because teachers alleviate their own authority. This alleviation creates an opportunity for students to renegotiate their obligations for learning. In this situation, the storylines available to students differ from the others because of the grounding in the empathetic component; thus, students may take on a new role of evaluator, solver, problem generator, or STEAM expert. In this context, students have the authority to redefine their rights and duties in STEAM situations. Here, we extend on the garden inquiry by including an empathetic component.

In this example, students could design a local community garden. To do so, they would begin their inquiry by trying to understand the needs of the community through building empathy for members in the community. Students might interview, research, and contact community members to better understand the specific needs of those that live in the area in which the garden would be built. Instead of prescribed disciplinary content from the teacher, the students are now potentially authorized to decide on the content and practices they need to apply to be able to best meet the needs of the community. For example, students might learn that the community lacks access to a grocery store. In this context, students would try to better understand the situation and the community's needs, thus students have the potential to explore the inquiry alongside their teacher because they must work together to best meet the needs of the community.

Here, students could be repositioned as an engineer, when they work to design a produce stand for the community to receive fresh produce from the garden. Students could be architects, as they meet with the community to try and learn the constraints of where the garden could be built. Once students begin to explore why there is not a grocery store in the community, students could become social justice advocates and use mathematics to model recent trends in grocery store locations around the community. Students might also be positioned as nutritionists when they explore what produce to plant in the garden based upon the communities needs and wants. Here, the arts integration can position the students as artist if they were to collaborative paint a mural depicting the community.

We also extend this to include the humanistic or empathetic part of solving problems, in that students are not solving a problem for content understanding or because they have been positioned as receivers of knowledge, but instead one of empathy and a desire to improve the world around them. Notice that the storylines for students to act out are much more open for students to decide upon the position they might occupy during the inquiry. In particular, students have the authority to transcend the disciplinary constraints of any single subject to explore a problem in an effort to better understand the community in need, but also use their frames of reference to intentionally build new knowledge. In the end, this transcension actually leads to deeper science and mathematics content and practice understanding, and connections.

In short, how students are positioned in STEAM inquiries matters. For students to transcend subject boundaries, they must be given the authority to reposition themselves to better understand the problem under investigation. Each level in our framework demonstrates a clear connection to the student positions and the storylines in which they have the obligations, or non-obligations, to act out in the inquiry. By including an empathetic component, teachers can potentially allow for new storylines to be enacted in STEAM inquiries. Empathy repositions students within the positioning mappings to gain the authority to explore and redefine the rights and duties of the inquiry. It is through this repositioning that transdisciplinary learning can occur for students. In our framework, empathy is the catalyst to generate opportunities for authorizing students.

Opportunities for Future Research

In the following sections, we explore new directions for STEAM education to highlight the importance of a student repositioning approach to both learning but also research and collaboration.

Exploring the Role of Research in Positioning

Cannella and Lincoln (2011) propose a more ethical research stance as one that focuses on research with people and a thorough examination and analysis of "competing power interests" (p. 97), with Foucault (1994) affirming and zeroing in on work requiring "self-criticism that historically examines the constitution of self" (p. 91). When we approach research in STEAM through a qualitative lens and as "the reconceptualized, broad-based critical social science that addresses institutionalized, policy-based, intersecting forms of power" (Cannella & Lincoln, 2011, p. 93), we can build alliances and work towards a more just elementary school and, perhaps, society at-large. So, to pursue research as solidarity and to honor participants, beneficence, and justice, it is key to select approaches, agendas, and research paths that reveal power structures and "attend first and foremost to the needs of participants and to the goals of social change" (Kincheloe et al., 2017, p. 247). Examining positionings allows researchers to move forward with the guiding notion that empowered (including the researcher) and disempowered people exist in the same space. In a school, especially, there are visible and invisible structures that perpetuate injustices and reinforce the status quo.

Research that firmly positions students at the center of the work invites students to participate in a humanizing way in which they see themselves as useful individuals with freedom of thought and ability. The exploration of that participation helps us link social phenomena to wider sociohistorical events and expose prevailing systems of domination, hidden assumptions, ideologies, and discourses with the goal of redefining experiences. Exploring the positions of students is an opportunity for exploration in the STEAM research conversation (and research in general). Often discounted because of arbitrarily-placed age or developmental constraints, research verifies that elementary school-aged students are able to "think critically about the world around them…deepen strategic thinking, abstract thinking, empathy and taking the roles of others, temporal and causal ordering and metacognition" (Mitra & Serriere, 2012, p. 745). It is essential to center student experience in research related to potentially impactful student learning initiatives. Exploring where and how students exist in STEAM contexts, contexts through which we often ask students to engage in their learning in a deeply personal way, provides additional insight into our selected curricula and our individual and collective pedagogies. It also provides space for students to make connections with how their school life intersects and informs the rest of their lives, and vice versa.

Exploring the Role of Discourse in Positioning

To truly understand the impact of student and teacher positioning in the learning and teaching space of integrated STEAM learning, it is important to consider specific nuances which might inform that understanding. Of particular interest is how students and teachers use language in connection to their positions in integrated spaces. Specifically, in this paper, we used positioning theory to show the potential storylines that were available to students. However, these are more stagnant relationships. To gain a deeper understanding of how certain integrations position students, we need to research the in-the-moment positionings within STEAM spaces. In order to better understand the student experience in STEAM, researchers must begin to explore the role of language and language usage in STEAM, as these can be interpreted as the social acts associated within student positionings.

To explore the role of language usage, future research might focus on discourse, defined as the way humans use language at particular moments and the differences in how language is used from one time and place to another (Holland & Leander, 2004). As a key example, Barwell (2016) focuses on relational meaning in his research on mathematics education, which has implications for other disciplines and the integrated spaces. From Barwell's perspective, mathematics discourse exists in relation to other types of discourse and multiple voices, perspectives or intentions are present in every mathematics utterance. Barwell notes: "When students talk about mathematics, they must use words that precede them, and these words carry overtones or undertones of the previous history of these words" (p. 336). Barwell also notes that Bakhtin's theory of language includes a "continual tension between a centripetal force towards uniformity…and a centrifugal force towards heteroglossia" (p. 336). If Bakhtin's theory of language is applied to teaching and learning in mathematics, suggests Barwell, it demonstrates how students must constantly navigate traditional and progressive models of both content and teacher instructional methods. Barwell asserts that from a Vygotskian perspective (a prevailing cognitive framework of STEM/STEAM teaching), students are being socialized into understanding through careful teacher-guided lessons, where the teacher replaces the student-constructed responses with socially, agreed-upon standard language. Alternatively, and more powerfully, Barwell asserts, is a Bahktian perspective where students work on expanding their "discursive repertoires, giving them a wider range of ways to make meaning in different mathematical situations" (p. 343). In the former, the path is set – there is a formalized mathematical language students must eventually internalize. In the latter, the path is less clear – students must build mathematical language. Barwell suggests that his research shows that if we do not learn, speak, interact, or communicate in a vacuum, why then, would we do mathematics in a vacuum?

There are powerful implications for STEAM research and practice in Barwell's work. If applied to and during the development of a theoretical/philosophical STEAM framework, as in this work, a Bahktian perspective could be transformative. Barwell's work seems to further justify the facilitation of student generated knowledge, positioning students as the drivers of knowledge, with the teacher as guide instead of sage, as the ideal integrated classroom experience.

Student-to-Student Positionings

Within this paper, we discussed students as a whole entity in relation to the role of the classroom teacher. Research should also begin to explore the student-to-student positionings and repositionings in STEAM inquiries to better understand how some inquiries might be transdisciplinary for some, while remaining interdisciplinary for others. In order to develop a more robust understanding of the transcension of discipline boundaries in STEAM, research must place greater emphasis on individual experiences and how such learning events are constructed from a student perspective.

Concluding Thoughts

In this paper, we have articulated the importance of repositioning students to be at the center of the transition of subject boundaries in STEAM. Building from previous frameworks in STEAM education research, we theorize new framework from the perspective of students. Using positioning theory, we demonstrated how not all STEAM experiences are the same for students involved in the learning event. From that perspective, we contend that we should not be asking what allows for the transcension of subject boundaries, but instead how can we position our students to transcend the boundaries of the STEAM disciplines and reposition their experiences and connections to be at the center of the STEAM inquiries. Throughout this paper, we have elucidated how STEAM education allows for multiple storylines in which students have differing obligations as a learner; thus, attention must be given for how different storylines and positions can be afforded to students to better their understanding of not only content, but increase their sense of belonging in STEAM. However, in order for students to have transformative learning experiences in STEAM, we must position them to be able to enact storylines that are based on their frames of reference. Our framework, *Transdisciplinary STEAM Framework,* outlines the role of empathy in repositioning our students to transcend subject boundaries. The intent of STEAM education is to foster and cultivate students of whom have a desire to make the world a better place, we must also acknowledge that our students come to us with many diverse experiences. Empathy has the potential to better position students to be the problem solvers of tomorrow; however, we need to ensure we position them to authentically use empathy to drive their learning experiences towards a transformative outcome.

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