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Exploring Elementary Student and Teacher Perceptions of STEM and CS Abilities

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ABSTRACT

Curriculum, legislation, and standards across the nation are quickly evolving to incorporate computer science and computational thinking concepts into K-12 classrooms. For example, many states have passed legislation requiring computer science to be included in every school's curriculum. Most states, however, report high shortages of qualified computer science teachers, meaning, teachers without extensive training will be required to integrate these concepts into their classrooms—a daunting task for most teachers without the necessary background and experiences. This paper reports the impacts of a thirteen-week intervention in a local elementary school designed to introduce computational thinking skills to 4th and 5th grade students. This intervention involved the first two authors working with a teacher and her students to introduce a project-based activity into the traditional curriculum. As students worked to design, build, and automate a model clubhouse, they incorporated foundational construction concepts as well as computational thinking skills. Our findings shed light on the potential for such a project to influence student and teacher's perceptions of related fields, and abilities, and student's perceptions of related professions.

Keywords: Computer science education, STEM education, computational thinking, elementary education

Technological advancements have given rise to pressure on districts, schools, and teachers to incorporate Science, Technology, Engineering, and Mathematics (STEM) and Computer Science (CS) into their classrooms (Nager & Atkinson, 2016). While the effects of this integration have generally been lauded (Martín-Páez et al., 2019) and demonstrated positive outcomes for students (Stohlman et al., 2012), teachers are not always comfortable integrating these concepts into their classrooms (Margot & Kettler, 2019). This can be especially true when it comes to CS concepts – sometimes referred to as computational thinking (CT; Barr & Stephenson 2011) skills when taught as broader ideas outside of programming language specifics (Yadav et al., 2016). While CT and CS are multi-faceted fields that include a variety of concepts, practices, and perspectives, this effort sought to explore the impact of exploratory, and introductory, STEM/CS activities in an elementary school classroom. Understanding how to best assist teachers and students in learning these STEM/CS/CT skills is vital if additional efforts in this vein are to be successful – especially when it comes to younger grade levels where teachers report the least confidence in adding these concepts to their classrooms (Ketelhut et al., 2020).

Project-based Learning & STEM Education

STEM education is an effort to integrate the subjects of Science, Technology, Engineering and Mathematics so that the traditional barriers between these subjects are removed (Kennedy & Odell, 2014); in this way the focus becomes the applied process of designing solutions to contextual problems using tools and technologies. Kennedy, & Odell (2014) suggest the interdisciplinary nature of STEM requires pedagogical approaches that differ from the traditional approaches used within schools, stating that "STEM Educators must use problem-based and project-based learning with a set of specific learning outcomes to support student learning (p. 256)."

In this context, project-based learning (PBL) can be used as a means of providing an authentic experience for students through scaffolded learning and connections within science, technology, engineering, and mathematics. This process is described by Capraro, Capraro, & Morgan (2013, p. 2), who argue that an "advantage to integrating STEM and PBL is the inclusion of authentic tasks (often the construction of an artifact) and task-specific vocabulary." They further go on to define STEM PBL as "an ill-defined task within a well-defined outcome situated with a contextually rich task requiring students to solve several problems which when considered in their entirety showcase student mastery of several concepts of various STEM subjects" (Capraro et al., 2013, p. 2). In this light, PBL extends beyond completing traditional summative assessment projects at the end of learning units; rather, PBL is seen as shifting learning so that students explore, learn, receive formative feedback and complete summative assessments all while pursuing real-world solutions in the form of long-term projects (Markham, 2011). The freedom and challenge presented to students leads to higher levels of engagement in course content, as well as engagement with ethical, aesthetic, and collaborative concerns (Kokotsaki et al., 2016). These projects can also allow students to focus on problem solving and to employ critical thinking skills (Markham, 2011).

Computer Science Education & the Micro:bit

As Computer Science (CS) grows in its global influence (Bureau of Labor Statistics, 2020), an emphasis on teaching CS principles has grown at all levels of education (Hambrusch, 2018). The history of CS begins with computers created by industry labs like IBM; in these settings, CS training was first provided to students through graduate programs (Wood et al., n.d.) in preparation for industry jobs. However, as the field of computing grew, CS education (CSE) shifted towards an emphasis on broader computing principles which were then added to undergraduate university programs (Wood et al., n.d.) before eventually extending down into high school classrooms (Turner, 1985). In recent years, government and institutional expectations of CS offerings in schools have greatly increased (Code.org Advocacy Coalition, 2019) and CSE has found its way further down into K-12 classrooms (Google Inc. & Gallup Inc., 2016).

The increased emphasis on CSE has been followed by an increase in the adoption of CS standards across many states; for example, a 2019 report noted that 34 states have formal CS standards, and five more have standards currently in progress (Code.org Advocacy Coalition,

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2019). This number represents over a 550% increase in states that have CS standards from 2017 (Code.org Advocacy Coalition, 2019). In light of these recently developed requirements, the availability of both physical and curriculum resources have become increasingly important (Prottsman, 2014). For example, while the state of Indiana has had K12 CS Standards since 2016, Indiana recently passed legislation SEA 172 (Office of Teaching and Learning, 2018) which requires every school to include CS in its K12 curriculum by 2021. This integration is intended to address standards with benchmarks such as: creating software to control systems (K-2.DI.3), using algorithmic problem solving to design a solution to a problem (3-5.DI.1), and implementing a solution using a block-based visual programming language (3-5.PA.3)(Office of Teaching and Learning, 2018).

However, while there is an increased push for organized implementation of CS activities (Prottsman, 2014) and availability for targeted elementary schools (Waterman et al., 2020), there is still limited access to resources and implementation of training for elementary teachers. Further, many educators are being asked to implement CSE with limited or no formal training, resulting in gaps in content knowledge and understanding of the complexities of the field (Blikstein, 2018). These gaps are especially prevalent in line with gender differences in participation, perseverance, and employment in CSE and CS fields (Charlesworth & Banaji, 2019). For example, only 19% of AP Computer Science test takers are female and even less (18%) persevere through college to earn a degree in computer and information sciences (NCWIT, 2012). While a variety of research efforts (Abbate, 2017; Vitores & Gil-Juaarez, 2015; Bennett, 2011) into understanding, and potentially levelling this gap have been implemented, little progress has been made (Charlesworth & Banaji, 2019).

In tandem with the standards and benchmarks that teachers are required to implement in classrooms, there are a myriad of technology devices, software programs, websites, and other mediums that can be used to facilitate CSE (e.g., Arduino, RaspberryPi, Scratch, and AppInventor). The abundance of options, mediums, and processes often result in frustration for teachers (Sentance & Csizmadia, 2017). However, one technology device, the *Micro:bit (microbit.org)*, has been increasingly adopted at the elementary level with high levels of success (Schmidt, 2016). The *Micro:bit,* is a hardware computing platform that includes a processor as well as input and output devices. *Micro:bit* integrates with several program editors including one block-based visual programming platform called Blockly (Schmidt, 2016) and relies on a web-based interface for programming and downloading code. Developed in the United Kingdom in 2016, the *Micro:bit* originated with the intent of assisting students to receive an easy first introduction to physical computing with limited prior experience (Teiermayer, 2019). Current research regarding the effectiveness of the *Micro:bit* itself, and block-based programming in education more largely, is inconclusive but the use of these learning tools is growing in popularity (Brown et al., 2016).

The intervention described in this paper emphasizes student exposure to event listeners, conditionals, and loops as part of the larger block-based programming options available at makecode.org for the *Micro:bit*. Although learning these techniques in a block-based environment includes simplifications of loops and Boolean elements that may result in student misconceptions (Grover & Basu, 2017), block-based programming has been shown to improve students' future capacity to learn more advanced programming skills, including increased speed of learning new concepts and higher cognitive levels of understanding (Armoni et al., 2015).

Research Objective

Legislation, mandates, and other educational reform efforts (e.g., Indiana Senate Bill 172 requires that every public school, beginning July 1, 2021, include computer science in the school's curriculum for students in grades K-12) have increasingly focused on integrating CSE at younger and younger grade levels (Code.org Advocacy Coalition, 2020). However, the comfort, abilities, and readiness of teachers to implement such changes to their curriculum is in doubt (Sentance & Csizmadia, 2017). Therefore, in an effort to 1) assist teachers with legislative mandates by modeling a CS-focused unit, and 2) understand the implications of such an intervention, we determined to test and study the impacts of an in-class PBL unit with local elementary school students. Specifically, given the research findings into wide gender disparities in CSE, we were interested in the implications of such a unit broadly on perceptions among students, as well as more narrowly in terms of gender. This unit engaged students in applying acquired knowledge as they designed, built, and automated a model clubhouse. Our research aimed to explore ideas around teaching CS principles, engineering and technical concepts, and whether an educational intervention might influence teacher and students' perceptions of STEM and CS. The guiding research questions for our investigation were:

1. What are the impacts, if any, of the SMART Clubhouse unit on teacher and student perceptions of STEM and CS?
2. What insight does this activity provide into students' perceptions of, and abilities related to CS and related careers?
3. What are the impacts, if any, of the SMART Clubhouse unit on student perceptions of gender capabilities in STEM and CS?

Methods

This research intervention took place during one semester of school in a public elementary school (grades K-5; ages 5-12) serving approximately 600 students in the state of Indiana. The classroom for this study was a high ability, multi-age classroom, composed of 24 fourth and fifth grade students (10 females, and 14 males, ages 9-11). The teacher was recommended for participation in the study by the school principal, based on expressed interest in including more STEM and CS content in the classroom. Following consent from the teacher to participate, all students enrolled in the multi-age class were invited to participate, and both consent from parents and assent from the students was obtained. All students (n = 24 students) enrolled in the class were included in the outlined intervention, but the data presented in this paper includes information only from those with both consent and assent obtained (n= 22 students, 1 teacher).

The thirteen-week intervention, referred to here as the *SMART Clubhouse Unit*, consisted of pre-questionnaires, clubhouse design, building, automation activities, post-questionnaires, and semi-structured interviews with randomly selected students and the classroom teacher. The details of the intervention are described in further detail below.

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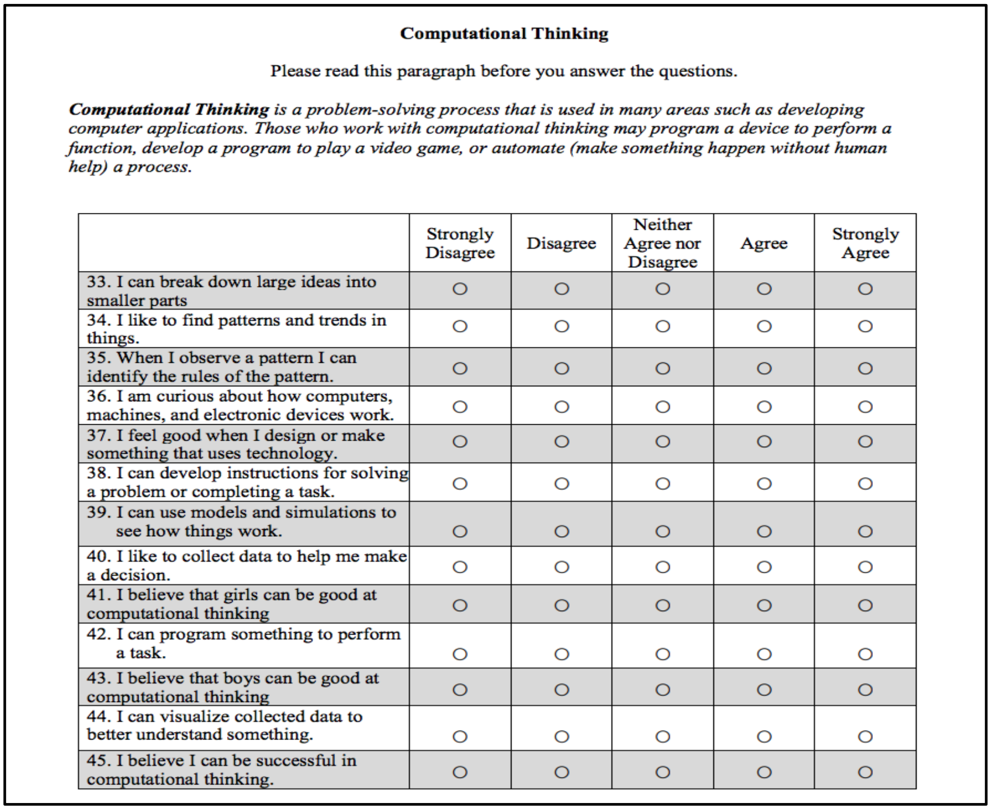
Procedure

The research team prepared the necessary Institutional Review Board (IRB) forms and developed all other required materials prior to implementing the intervention within the classroom. Specifically, instructional materials —including worksheets and a booklet (for students), PowerPoints, and physical design and build supplies for each student—were prepared for each of the topics covered (including setup, architecture/construction, computational thinking and automation, manufacturing, and finishing touches). Additionally, the measurement instruments were developed during this time based on the Student Attitudes toward STEM survey (S-STEM; Friday Institute for Educational Innovation, 2012). The S-STEM survey, which collects data pertaining to students' thoughts and feelings regarding STEM subjects and related careers, was modified for this research to include a section related to computational thinking in line with the research objectives (see Appendix A). Further, minor edits were made to questions to improve clarity and comprehension for elementary students (e.g., the existing question "I can handle most subjects well, but I cannot do a good job with math." was changed to "I can understand most subjects easily, but math is difficult for me."). Lastly, the researchers added two questions to each section of the S-STEM survey specifically related to gender (e.g., "I believe that boys can be good at computational thinking") based on the research into the gender gap in CSE (Charlesworth & Banaji, 2019). These questions also aligned well discussions with the classroom teacher where it became evident that perceptions of competence across genders was an area of potential interest to the teacher. The final administered questionnaire (see Appendix A) consisted of 45 questions regarding student's perceived abilities in, and perceptions of STEM, CS, and related career fields.

Intervention

The first day of the intervention was used to introduce the teacher and students to the project, including its purpose and an overview of activities. The research team distributed supply kits to students that would be used for the duration of the intervention and showed the teacher and students a fully automated clubhouse (created prior to the intervention by one of the researchers) to give them a better sense of the scope of the project. Additionally, this time provided the researchers with a chance to obtain assent from students and send consent forms home to parents.

On the second day of the intervention, consent forms were collected and the modified S-STEM Survey (Appendix, A; based on Friday Institute for Educational Innovation, 2012) was administered to all students. The directions and example questions were read to students prior to taking the questionnaire to ensure that students were familiar with the five-point Likert used within the questionnaire. Each page of the questionnaire provided students with a paragraph outlining specific concept definitions and information related to possible careers within the field (see Figure 1). Students were asked to respond to the 45 questions independently but were allowed to ask questions if they were unfamiliar with any of the terms or had questions regarding the questionnaire. In order to protect the identity of students throughout the intervention, the teacher created unique identifiers for each student which were used on all student questionnaires, worksheets, clubhouses, interviews, and consent and assent forms. These unique identifiers were known only to the teacher and were used throughout the intervention.



Computational Thinking

Please read this paragraph before you answer the questions.

***Computational Thinking** is a problem-solving process that is used in many areas such as developing computer applications. Those who work with computational thinking may program a device to perform a function, develop a program to play a video game, or automate (make something happen without human help) a process.*

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
33. I can break down large ideas into smaller parts	○	○	○	○	○
34. I like to find patterns and trends in things.	○	○	○	○	○
35. When I observe a pattern I can identify the rules of the pattern.	○	○	○	○	○
36. I am curious about how computers, machines, and electronic devices work.	○	○	○	○	○
37. I feel good when I design or make something that uses technology.	○	○	○	○	○
38. I can develop instructions for solving a problem or completing a task.	○	○	○	○	○
39. I can use models and simulations to see how things work.	○	○	○	○	○
40. I like to collect data to help me make a decision.	○	○	○	○	○
41. I believe that girls can be good at computational thinking	○	○	○	○	○
42. I can program something to perform a task.	○	○	○	○	○
43. I believe that boys can be good at computational thinking	○	○	○	○	○
44. I can visualize collected data to better understand something.	○	○	○	○	○
45. I believe I can be successful in computational thinking.	○	○	○	○	○

Figure 1. Sample page from the Measurement Instrument

Following the completion of the initial questionnaires, the research team visited the classroom for a total of 21, 90-minute class periods over the course of thirteen weeks. The intervention consisted of instruction and activities related to the topics mentioned previously. An outline of the schedule is included in Table 1.

In addition to the questionnaires and outcomes from the daily activities (e.g., worksheets), the student researcher kept field notes for each visit. These notes related to class discussions, progress, observations, and insights shared by the students related to the intervention. These field notes were saved for use in conjunction with the survey data analysis as a means of triangulating findings with both the quantitative data from the questionnaires and the qualitative data collected from students through the semi-structured interviews.

Finally, following the thirteen weeks of classroom activities, all students once again completed the modified S-STEM questionnaire. All previously used protocols were again used during the administration of the modified S-STEM Survey and the unique identifiers for each student were used to match pre- and post-questionnaires. Following completion, all student data points were matched, and the collected data were conditioned for analysis. This process involved coding responses numerically (i.e., "Strongly Disagree" responses were coded as "-2," "Disagree" responses were coded as "-1," "Neither Agree nor Disagree" responses were coded as "0," "Agree" responses were coded as "1," and "Strongly Agree" responses were coded as "2") and removing missing data points. This conditioning facilitated analysis of data by allowing the researcher to investigate any changes in students' responses (i.e., from disagree [-1] to agree [1] etc.) from the pre- to post-questionnaires.

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Table 1.
Classroom schedule for the intervention

Topic	Day	Class Schedule
Introduction/ Setup	1	• Introduce project, overview/ purpose, show clubhouse, • Consent/assent forms
	2	• Pre-Questionnaires, Smart Homes (architecture, trends, needs) • Brainstorming Ideas- what could my clubhouse look like?
Architecture / Construction	3	• What's the process of creating a building from start to finish? • What are blueprints? • Scaling activity, Floor Plans
	4	• Proper Wall framing guidelines- why do we have building codes? • Framing basics (wall, window, door), Wall Framing stations
	5	• Model supplies, scale, plans • Begin framing base
	6	• Wall Workday
	7	• Wall Workday
	8	• Wall with Door Workday
	9	• Wall with Window Workday
	10	• Finish building & Erect Structure • Wall framework assessment
Computer Programming & Automation	11	• Programming basics • Robot cup stacking activity • Directions Packet o conditional statements (if/then)
	12	• Components (physical) o LEDs, Motors, Wires, Sensors & circuits
	13	• Micro:bit basics o Start/Wait, Loops, Conditionals (if/then), High/low (on/off), input/output & variables
	14	• Programming Doorbell o Touch sensor o Buzzer/Tone
	15	• Programming LED Light o Light sensor o LED
	16	• Programming Thermostat and Fan o OLED screen o Fan o Temperature sensor
	17	• Introduction to Nesting
	18	• Programming Workday
	19	• Programming Workday
Manufacturing	20	• Manufacturing processes, materials, & automation • Home manufacturing: Siding, brick, finishing • Workday Thingiverse / TinkerCAD
Wrap-Up	21	• Review project- what did we learn? • Post Questionnaires • Interviews

Interviews

At the conclusion of the study the participating classroom teacher was interviewed in line with our stated research objective of understanding the impact of this intervention on teacher's perceptions of areas such as STEM and CS. This interview followed protocols and procedures outlined for interviews by Berg (2009) and was guided by a list of questions (see Figure 2), with follow-up questions to explore comments made by the teacher during the interview. The semi-structured interview was conducted at the school and lasted approximately 20 minutes.

1) What did you like/ about the intervention?
2) What observations did you make?
    - What did students learn?
    - What was difficult for the students?
    - What was difficult for you?
    - What surprised you?
3) Would you ever do this project again?
    - Would you do something similar?
    - Why or why not?
    - What are your takeaways?
4) What STEM concepts do you feel the students learned?
    - How did this activity help with these concepts?
    - Did the activity help tie into what you were doing in your class? How?
5) What is your confidence level in this content?
    - What is your confidence level in this activity?
    - What is your confidence level in your ability to do this activity/ similar activity?

Figure 2. *Semi-structured interview questions for the teacher*

Additionally, individual interviews were conducted using semi-structured interview procedures as outlined by Berg (2009) with nine randomly selected students. These randomly selected students were notified of the interviews and additional assent (student) and consent (parental) was obtained prior to participating in the interviews. Students were asked several open-ended questions (see Figure 3) in an effort to better understand their experience related to the intervention and determine their perceptions of STEM, CS and related topics (e.g., construction). Clarifying questions were also asked by the research team to further explore information surrounding the students' experiences. Each interview was conducted at the school and averaged approximately 6 minutes. Students were informed that their interviews would be audio recorded and later transcribed, but no identifying information would be used in the analysis (students were instructed that personal information [e.g., name] was not to be shared during the interview).

1) Tell me about your experience with the SMART clubhouses project
2) What did you like, dislike, etc.?
3) What was hard, easy, fun, exciting, challenging?
4) What did you learn about **Science** while working on this project?
5) What did you learn about **Math** while working on this project?
6) What did you learn about **Technology** while working on this project?
7) What did you learn about **Engineering** while working on this project?
8) What did you learn about **Computer Science** while working on this project?
9) What did you learn about **Construction** while working on this project?
10) Would you consider a career in any of these fields after an experience like this?
11) Is there anything else you would like to share with me about this experience with the Smart Clubhouses?

Figure 3. *Semi-structured interview questions for students*

Following the collection of all interview audio recordings, the interviews were transcribed using a third-party transcription software and all responses to the interview questions, from both the teacher and students, were organized and analyzed using Holistic coding techniques (Saldaña, 2013) to explore the experiences of those involved with the intervention. Specifically, key trends, themes, and/or ideas were parsed out for further analysis and potential triangulation with other findings identified in the quantitative data analysis.

Findings

The findings, taken from both the quantitative and qualitative data collected during this study, are presented here in alignment with the corresponding research questions. We present here the results from all associated data sources—both quantitative and qualitative—as well as the implications for the overarching investigation. Our research questions centered on exploring the impacts, if any exist, of the Smart Clubhouse activity on teacher and student perceptions of STEM and CS as well as those related to gender. In light of the exploratory nature of this work we determined to use an alpha level of $p<.10$ to determine significance. Fully recognizing the limitations associated with a higher alpha level, in addition to the potential presence of any number of lurking and outside variables during the course of our lengthy intervention (thirteen weeks), these results are shared with the intent of exploring our questions and fostering further research, effort, and conversation around these topics.

Qualitative Findings: Teacher interview

The teacher was interviewed to explore the impacts, if any, of the intervention on their perceptions of STEM and CS. We were specifically interested in exploring the teacher's comfort level with the STEM and CS content in light of the noted legislation and other CS requirements. This exploration was accomplished through the semi-structured interview and associated holistic coding of the teacher's responses. Several themes emerged which provide insight into the teacher's experience; these are shared below with illustrative examples of each.

Holistic Idea 1: The teacher underestimated the student's abilities in STEM and CS. The teacher made several remarks highlighting that she was "surprised that they did as well as they did" and that she felt she "underestimated particular student's ability in [STEM] area[s]." The teacher noted the high-level of difficulty in the project but also talked about the benefits, to both her and the students, of such a project:

> It also showed me good and bad, but resiliency among my students, what kids really have that because even if they didn't know how to do it, I could see how do they problem solve? How did they get help? What were their strategies? So that was interesting, and I think for some of them it was interesting too because they're used to things being relatively easy for them, and I try to challenge them, but I think the whole process, there was never a part where they were like, Oh, this is going to be easy.

Holistic Idea 2: The teacher felt more comfortable, after the project, in pursuing future STEM and CS projects. The teacher mentioned multiple instances of being "uncomfortable" or "not knowing the answers to the student's questions" during the course of the project but also noted that her own comfort level had increased as a result. She shared:

> ...there were a lot of points where I'm like, I can't answer that question because I don't know what I'm doing. Especially with coding, but I haven't done any... I've never coded. It's been something I wanted to try, especially with this group of kids. So it was good for me, kind of forced me to try some things as well. But it was also hard not to know how to help them…
>
> I think I learned programming as well. I think I learned to be more comfortable with that and that process. I think I'd be more confident to go use the maker space by myself because I'm like, well, we all survived that. So, I think I could probably make this work… But I think I learned that would probably be the biggest takeaway I have is just being more comfortable with that process and that space in our building.

Holistic Idea 3: The teacher connected the project with lessons within her classroom. The teacher made several remarks highlighting how the project tied into other standards or topics that she had taught throughout the year. For example, she stated:

> I will say that some of the things that were covered, like you talked about circuits and needing a complete circuit and even similar work with fractions, those are things that I am going to try to cover, or a concept that we can refer back to this project when those things come up.
>
> And since I teach a two-year cycle, I don't get to electricity every year. So this is a good way to cover something like that, in a different way rather than the unit that I particularly always do because now they've had exposure to all that and on testing they would be able to answer the necessary questions without having been taught it from me.

Holistic Idea 4: The teacher viewed this project as an authentic programming opportunity. The teacher mentioned that she and her students had been provided with limited prior experience programming, but not at the level provided by this project. The teacher mentioned the following in her interview:

> I did have Makey Makeys in my other school, which they involve some minor programming, but I never delved really deep into that because you could make the Makey Makeys do all sorts of sounds when different things happen. But I never really was comfortable or confident enough to try that. So we did a lot of preexisting, pre-created

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> programs with them…this was way different[from Scratch programming] and way more complex. So I think they got a taste of, I know it gets way more complicated, but a tastes of how much more in depth coding can be…the programming component of nesting I thought was really fascinating. A lot of them hadn't done that. They could with relative ease, do programming pieces like singular. But when they had to put them all together and explain why certain things had to be nested where I think it made sense, but they hadn't really thought through it like that.

Quantitative Findings: Student survey responses.

While the perceptions of the teacher have significant impacts on student learning, it is also useful for teachers to understand the effects of these activities on students' perceptions in order to better support student development. In order to investigate the impacts of the intervention on student perceptions of STEM and CS, a paired samples t-test was conducted using the student pre- and post-study responses to the modified S-STEM questionnaire. While the majority of responses did not reveal any statistically significant difference between the pre- and post-study survey responses, the analysis revealed specific questions demonstrating significant differences in student responses. These questions, from the modified S-STEM survey, and the associated statistical results, are shared herewith.

Question 18. I can understand most subjects easily, but science is hard for me to understand. There was a significant difference in student responses to this question before (M= -.75, SD= 1.19) and after the intervention (M = -1.22, SD= .99), *t* (22) = -2.0057, *p* = 0.057. Students, overall, disagreed significantly more with this question after the intervention. The change in student responses to this statement following the intervention, which is negatively weighted, suggests that they did not agree with the idea that other subjects were easy to understand while science was difficult.

Question 19. In the future, I could do harder science work. There was a significant difference between student pre- (M= .95, SD= .93) and post-study responses to this question (M = 1.43, SD = .66), *t* (22) = 2.5543, *p* = 0.018. Students' responses shifted significantly in a positive direction suggesting their belief that they could do harder science work in the future grew.

Question 21. I believe that girls can be good at science**.** There was a significant difference between students' responses about girl's aptitude for science before (M=1.65, SD = .65) and after the intervention (M= 1.39, SD = .99), *t* (22) = 1.8166, *p* = 0.083. Significant change in student responses was negative suggesting the students felt significantly less confident in girls' ability to be good at science following the intervention

Question 32. I believe that girls can be good at engineering and technology. Similar to question 21, our analysis showed a significant difference between students' responses (M= 1.65, SD =.65) and after the SMART clubhouse unit (M= 1.43, SD = .95), *t* (22) = 2.011, *p* = 0.057. As with question 21, the students' confidence in girls' abilities in engineering and technology were significantly less following the intervention than before.

Question 41. I believe that girls can be good at computational thinking. Finally, when asked about girls' capacity in computational thinking, the student analysis showed a significant difference between pre- (M= 1.65, SD = .65) and post-study responses (M= 1.39, SD = .99), *t* (22) = 1.8166, *p* = 0.083. Like science, technology, and engineering, the responses suggest students felt significantly less confident in girls' ability to be good at computational thinking following the intervention.

Qualitative Findings: Student interviews.

In addition to the quantitative survey data, the findings from the semi-structured interviews with the students were used to explore our research questions. Holistic coding approaches were used to investigate student perceptions of a variety of topics focused on within the intervention (see Figure 2); this coding approach entails applying a single code to a larger unit of data, which captures the overall essence/idea of the contents (Saldaña, 2013). The findings, obtained through this investigative approach to the interview responses, are shared below with illustrative examples of each.

Holistic Idea 1: Student either liked building or programming, but not both. When asked what they liked/disliked about the project, the students made an interesting distinction - drawing a line between the "building" portion of the project and the "coding" portion. While almost all students interviewed noted that all aspects of the assignment were challenging, four out of the nine interviewed explicitly stated that they liked either building or coding and disliked the other. For example, Student 1 stated: "I think I liked the coding and I didn't really like the building" and Student 9 said:

> I really liked building it, but I didn't really like nesting [an aspect of the coding portion], because I think it was just really hard and complicated.

Perhaps unsurprisingly, when asked later about the potential for pursuing careers in these fields the student interviews suggested that they were interested in a career field related to the aspect of the assignment they enjoyed. Student 9, who liked the building but not the programming, remarked:

> I really want to be an engineer when I grow up and I want to build things and make things. And I think [this project will] really help me.

Alternatively, some students had preference for one portion (e.g., coding or building) but saw the potential for pursuing a career in either field. Student 12 indicated:

> I really liked building, because it was a little challenging at first but then you caught on those steps and it was really fun. And then I kind of dislike some of the programming, because it was really hard.

When asked about potential career options in the future, Student 12 touched on both building and programming:

> [Coding] was very fun and like it was different than... I'd never done something like this before. I've never built my own little house. I would definitely think about maybe I would be a programmer, like more working with technology and all of that. Maybe I would do building, not sure about [that].

This difference suggests that teachers may be able to help students by discussing the differences between these skills and how they connect to potential career paths.

Holistic Idea 2: Students accurately connected the assignment to STEM fields. When asked about potential connections between the project and STEM content areas the interviewees provided many examples. Students linked "housing (Student 1)" and "electricity and computers

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(Student 21)," to Science and "electrical current (Student 1)," and "computers (Student 21)" to Technology. However, the most common response from students for both "Science" and "Technology" was "coding."

When asked about "Engineering," student responses centered on "building things." For example, when asked about any potential connections between the project and "Engineering," Student 7 responded:

> The building and all the steps. I didn't even know that there was studs in a wall. I thought they just put a bunch of sticks in there and then put the wall together.

Similarly, Student 12 answered this question about engineering by stating:

> You have to scale everything down and that was definitely engineering. And then you have to build, of course you have to like get all the right placements, have the right spacing, make sure that doors like in the right proper little pieces.

Some students connected Mathematics with "variables" and "distances." However, the majority of student comments related to Mathematics centered on "scaling." This was perhaps unsurprising as scaling was a central aspect of the assignment and required significant effort on the student's part (see Table 1). Students' comments included ideas such as "the dimensions had to be perfect or else it wouldn't work" (Student 7) and

> Sizing down, like to get that, even that little or little ruler you use to size everything down (Student 12)

> To equal the size of this miniature house to the big house because we had to divide everything by fractions, and we had to make it a smaller version (Student 20)

The knowledge that students are able to accurately connect the applied tasks they are completing to STEM concepts can provide teachers with confidence that these activities support students' learning progressions.

Holistic Idea 3: Students were proud of their effort in doing something difficult. Consistently, throughout the interview responses, the students demonstrated pride in tackling difficult tasks – usually identified as either the building or the coding portions. Teachers can authentically reenforce these feelings to further increase student self-efficacy. Several comments illustrate this overarching sense of pride; for example, students commented:

> I thought it was easy and like JavaScript was like, 'Hm, I could probably learn that in a day or something.' But now that I've seen the whole thing of things you could use and how to program a house, I feel it's a lot more difficult. But I feel like it's a little bit easier for me to get through the difficult stuff because of this (Student 20).

> [my dad] was an engineer growing up, so he always knew all this fancy stuff and I didn't know any of it and my sister knew a little, but I never knew anything. So, I got to learn everything. And now my dad is proud of me, because I actually know some stuff he does... I like the different studs sometimes like or like building just in general. I tell him all the stuff I build. Like if I finished building something today, I'll tell my parents and he gets really excited. I finish coding something, I'll be also really excited (Student 12).

> It was really hard, but it was fun and I always had people who were there to help me. And it ended up being fun and now I know a lot more than I did when we started (Student 18).

Discussion

This research set out to explore the potential impact of an educational intervention—which centered on building and automating a scaled clubhouse—on student and teacher perceptions of STEM and CS fields. Further, we sought to investigate the impacts, if any existed, on these perceptions relative to gender among the students. Findings were derived from both quantitative and qualitative sources of information from both the students and teacher.

Following a 13-week intervention, consisting of more than 30 hours of class time, activities, worksheets, and lessons, there were notable impacts on the teacher or student's perceptions of STEM and CS (as collected through the interviews and modified S-STEM survey). The teacher, when interviewed, shared two important insights: 1) the students could do more than she had initially believed and 2) this intervention was an effective way to help her feel comfortable implementing STEM and CS activities in her classroom. The teacher was impressed with what the students were able to accomplish and noted the difficult nature of the assignment, she shared:

> And it was never, I think overwhelming because you introduced it all slowly over time. But there was never a stage where they could just go on cruise control. They had to really be on the whole time. So that was fun to watch. I love to hear how exhausted they were at the end. Every time that we worked, they're like, "Oh, my brain hurts so bad." Which is awesome. I mean, brain science shows that that's how you grow your brain. So I think they probably grew their brains quite a bit.

The teacher also noted that, although she was uncomfortable with the content at the beginning, by the end she was prepared to implement future STEM and CS activities. This finding suggests that the approach noted in this article, namely a hands-on classroom intervention with guidance, may be a feasible approach to future professional development. Additional research into the implications and potential of such an approach is needed – especially considering the mounting pressures on K-12 educators to integrate such content into their classrooms.

Findings derived from the student interviews were generally positive as well; students were proud of their capacity to "do something hard" and they were able to accurately connect the classroom intervention activities with associated STEM and CS fields. Additionally, we noted that students were generally inclined towards either "building" or "coding" but not both. Students who explicitly mentioned liking one (building or coding) almost always mentioned not liking the other – this was interesting as STEM and CS both draw on skills contained in both "building" and "coding." Perhaps students had preconceived notions of their own abilities (i.e., I am good with my hands or I am good with computers) and these carried over into their own experiences with the clubhouse. Alternatively, it is possible that the thinking required for the coding was different enough from that required for designing and constructing a physical model that some students were naturally more gifted or inclined than others. It was interesting to note that these preferences (e.g., building or coding) were not gender-specific, with both males and females similarly identifying one or the other as their preference.

Despite questions about gender and STEM or CS fields, very little significant information was derived from the students – in either the interview or questionnaire. Students were asked specifically about their perceptions of males or females and the various fields with very few significant responses. While we wondered if the presence of the female student researcher may be significantly impactful on student perceptions, few significant positive gains were found. However, we also recognize the possibility that negative perceptions could have been solidified or

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fostered regardless of the makeup of the research team – these ideas and the potential implications deserve further exploration, especially considering the pressures on integrating these concepts into K-12 classrooms.

Of those questions on the survey that revealed significant differences in student answers before and after the intervention, the majority demonstrated a negative impact, suggesting the students were less confident after the intervention than before. Specifically, the student's perceptions of girl's ability to do science, engineering and technology, and computational thinking were all significantly lower following the intervention. This finding may be attributed to a variety of things but highlights an important idea: just because students participate in an activity successfully does not mean their perceptions of their own, or their classmates, capabilities will increase. We noted that all female students in the class were successful in the project. Further, we noted that the student researcher was a female and served as an example for students of success in these STEM and CS fields; finally, the classroom teacher was also female and demonstrated many of the associated activities for her students. Despite these examples, the overall perceptions of students in the areas noted, decreased significantly during the course of the 13-week intervention. Further investigation into this finding is needed to adequately understand why such a decrease occurred, especially in light of the generally positive qualitive interview findings.

Positive statistical significance was found for two questions related to science – in both cases the students were more confident in their abilities to do science following the intervention. Although the intervention revolved around STEM and CS in general, and did not specifically center on Science, these were the only two questions demonstrating significant positive increases following the intervention. Recognizing the potential for a variety of external factors to influence these perceptions, we also posit that the activities associated with this intervention may have exposed students to new ideas, concepts, and processes and thus positively influenced their own perceptions. Additional research into the implications of these findings is needed to clarify the connection, or lack thereof, between the project and student's science perceptions.

Further, we noted that while these findings were significant in providing valuable information, they did not provide sufficient information to explain the reason for the associated data. Further investigation of these ideas, findings, and the shared research questions is worthy of pursuit. Specifically, we note that robust research—both qualitative and quantitative—may yield further explanation around these ideas. For example, following a review of the data, we hypothesized that as students' computational thinking capabilities improved their perceptions of STEM and CS also shifted. However, data should be collected before any concrete conclusions are reached and shared. Use of an interview instrument to measure computational thinking could determine if computational thinking acts as a mediator between student experiences and student ability perceptions in STEM and CS. Additional, or different, quantitative instruments may also shed additional light on different facets of this experience.

Conclusion

Given the mounting pressures, discussions, and legislations surrounds the integration of computer science into K-12 classrooms there is a need for robust research into both *what* should be done and *how* it can be effectively accomplished (Nager & Atkinson, 2016). We presented the findings from one educational outreach initiative with elementary students and their classroom teacher. We hypothesized significant positive gains in student STEM and CS interest and were especially interested in the potential for increases in perceptions surrounding females in light of the presence of a female student and teacher. However, most of our significant findings were negative in direction – we found it especially intriguing that perceptions of female students to "be good at" Science, Engineering and Technology, and Computational Thinking were all significantly less confident following the intervention despite the presence of multiple female role models (e.g., the teacher and student) for the duration of the project.

We identified several questions from this research which we feel are important areas for exploration in light of the myriad of efforts around STEM and CS. For example, maybe there were outside influences that caused such a decrease? Perhaps the intervention was difficult enough that it dissuaded students—who were initially fairly confident in their abilities—from future endeavors? Is it possible that a different project, approach to coding, or age range would produce different findings? Future research in this area can build on the findings from both the quantitative and qualitative efforts in this work and explore potential avenues and approaches for elevating students' perceptions of, and abilities in, STEM and CS fields.

References

Abbate, J. (2017). *Recoding gender: women's changing participation in computing*. The MIT Press.

Armoni, M., Meerbaum-Salant, O., & Ben-Ari, M. (2015). From scratch to "real" programming. *ACM Transactions on Computing Education* (TOCE), 14(4), 1-15.

Barr, V., & Stephenson, C. (2011). Bringing Computational Thinking to K-12: What is Involved and What is the Role of the Computer Science Education Community? *ACM Inroads*, 2(1), 48–54. https://doi.org/10.1145/1929887.1929905

Bennett, C. (2011). Beyond the leaky pipeline: Consolidating understanding and incorporating new research about women's science careers in the UK. *Brussels Economic Review*, 54(2), 149–176.

Berg, B. (2009). *Qualitative research methods for the social sciences*. New York, NY: Pearsons://doi.org/10.1145/2677087

Blikstein, P. (2018). *Pre-College Computer Science Education: A Survey of the Field*. https://services.google.com/fh/files/misc/pre-college-computer-science-education-report.pdf.

Brown, N. C., Mönig, J., Bau, A., & Weintrop, D. (2016). Panel: Future Directions of Block-based Programming. *Proceedings of the 47th ACM Technical Symposium on Computing Science Education - SIGCSE '16*. https://doi.org/10.1145/2839509.2844661

Bureau of Labor Statistics, U.S. Department of Labor. (2020). *Computer and Information Research Scientists: Occupational Outlook Handbook*. https://www.bls.gov/ooh/computer-and-information-technology/computer-and-information-research-scientists.htm.

Capraro, R. M., Capraro, M. M., & Morgan, J. R. (2013). STEM project-based learning. *An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach*, *2*.

Charlesworth, T. E. S., & Banaji, M. R. (2019). Gender in Science, Technology, Engineering, and Mathematics: Issues, Causes, Solutions. *The Journal of Neuroscience,* 39(37), 7228–7243. https://doi.org/10.1523/jneurosci.0475-18.2019

Code.org Advocacy Coalition. (2019). State of Computer Science Education Retrieved from https://advocacy.code.org/

https://ir.library.illinoisstate.edu/jste/vol57/iss1/8
DOI: 10.30707/JSTE57.1.1664998343.93078

Code.org Advocacy Coalition. (2020). State of Computer Science Education: Illuminating Disparities. Retrieved from https://advocacy.code.org/

Friday Institute for Educational Innovation (2012). *Student Attitudes toward STEM Survey-Upper Elementary School Students,* Raleigh, NC: Author.

Google Inc. & Gallup Inc. (2016). Trends in the State of Computer Science in U.S. K-12 Schools. Retrieved from http://goo.gl/j291E0

Grover, S., & Basu, S. (2017). Measuring Student Learning in Introductory Block-Based sProgramming. *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education*, 267–272. https://doi.org/10.1145/3017680.3017723

Hambrusch, S. (2018). *NAS Report Investigates the Growth of Computer Science Undergraduate Enrollments*. Computing Research News. https://cra.org/crn/2017/11/nas-report-investigates-growth-computer-science-undergraduate-enrollments/

Kennedy, T. J., & Odell, M. R. L. (2014). Engaging students in STEM education. *Science Education International*, *25*(3), 246-258.

Ketelhut, D. J., Mills, K., Hestness, E., Cabrera, L., Plane, J., & McGinnis, J. R. (2020). Teacher change following a professional development experience in integrating computational thinking into elementary science. *Journal of science education and technology*, *29*(1), 174-188.

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools*, *19*(3), 267–277. https://doi.org/https://doi-org.erl.lib.byu.edu/10.1177/1365480216659733

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: a systematic literature review. *International Journal of STEM Education*, *6*(1), 1-16.

Markham, T. (2011). Project based learning A bridge just far enough. *Teacher Librarian*, 39, 38-42. Retrieved from http://erl.lib.byu.edu/login/?url=https://www-proquest-com.erl.lib.byu.edu/magazines/project-based-learning-bridge-just-far-enough/docview/915254354/se-2?accountid=4488

Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education*, *103*(4), 799-822.

Nager, A. & Atkinson, R.D. (2016). The Case for Improving U.S. Computer Science Education. *Social Science Research Network*. http://dx.doi.org/10.2139/ssrn.3066335

NCWIT (2012). *Technology Is Everywhere, But Where Are the Girls? Statistics from NCWIT.* National Center for Women & Information Technology. Retrieved on March 22, 2021 from: https://www.ncwit.org/infographic/3435.

Office of Teaching and Learning. (2018). *Computer Science*. Indiana Department of Education. https://www.doe.in.g ov/wf-stem/computer-science.

Prottsman, K. (2014). Computer science for the elementary classroom. *ACM Inroads, 5*(4), 60 63. doi:10.1145/2684721.2684735

Saldaña, J. (2013). *The coding manual for qualitative researchers* (Second ed.). London: SAGE.

Schmidt, A. (2016). Increasing Computer Literacy with the BBC micro:bit. *IEEE Pervasive Computing*, *15*(2), 5–7. https://doi.org/10.1109/mprv.2016.23

Sentance, S., & Csizmadia, A. (2017). Computing in the curriculum: Challenges and strategies from a teacher's perspective. *Education and Information Technologies*, *22*, 469–495. https://doi.org/https://doi.org/10.1007/s10639-016-9482-0

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research (J-PEER)*, *2*(1), 4.

Teiermayer, A. (2019). Improving students' skills in physics and computer science using BBC Micro:bit. *Physics Education*, *54*(6). https://doi.org/10.1088/1361-6552/ab4561

Turner, A. (1985). Computer science in secondary schools: Curriculum and teacher certification. *Communications of the ACM, 28*(3), 269-279. doi:10.1145/3166.3168

Vitores, A., & Gil-Juárez, A. (2015). The trouble with 'women in computing': a critical examination of the deployment of research on the gender gap in computer science. *Journal of Gender Studies*, 25(6), 666–680. https://doi.org/10.1080/09589236.2015.1087309

Waterman, K.P., Goldsmith, L. & Pasquale, M. (2020). Integrating Computational Thinking into Elementary Science Curriculum: an Examination of Activities that Support Students' Computational Thinking in the Service of Disciplinary Learning. *Journal of Science Education and Technology* 29, 53–64. https://doi.org/10.1007/s10956-019-09801-y

Wood, B., Aiken, H., & Brooks Jr., F. P. (n.d.). The origins of computer science. Retrieved March 07, 2021, from http://www.ibm.com/ibm/history/ibm100/us/en/icons/compsci/

Yadav, A., Gretter, S., Hambrusch, S., & Sands, P. (2016). Expanding computer science education in schools: understanding teacher experiences and challenges. *Computer Science Education*, *26*(4), 235-254.

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APPENDIX A

ADMINISTERED STEM QUESTIONNAIRE

DIRECTIONS: There are lists of statements on the following pages. Please mark your answer sheets by marking how you feel about each statement. For example:

Example 1:	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I like engineering	○	○	○	○	○

As you read the sentence, you will know whether you agree or disagree. Fill in the circle that describes how much you agree or disagree.

Even though some statements are very similar, please answer each statement. This is not timed; work fast, but carefully.

There are no "right" or "wrong" answers! The only correct responses are those that are true for you. Whenever possible, let the things that have happened to you help you make a choice.

PLEASE FILL IN ONLY ONE ANSWER PER QUESTION.

Math

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1. Math has been my worst subject.	○	○	○	○	○
2. When I'm older, I might choose a job that uses math.	○	○	○	○	○
3. Math is hard for me.	○	○	○	○	○
4. I am the type of student who does well in math.	○	○	○	○	○
5. I can understand most subjects easily, but math is difficult for me.	○	○	○	○	○
6. In the future, I could do harder math problems.	○	○	○	○	○
7. I can get good grades in math.	○	○	○	○	○
8. I am good at math.	○	○	○	○	○
9. I believe that boys can be good at math	○	○	○	○	○
10. I believe that girls can be good at math	○	○	○	○	○

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Science

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
11. I feel good about myself when I do science.	○	○	○	○	○
12. I might choose a career in science.	○	○	○	○	○
13. After I finish high school, I will use science often.	○	○	○	○	○
14. When I am older, knowing science will help me earn money.	○	○	○	○	○
15. When I am older, I will need to understand science for my job.	○	○	○	○	○
16. I know I can do well in science.	○	○	○	○	○
17. Science will be important to me in my future career.	○	○	○	○	○
18. I can understand most subjects easily, but science is hard for me to understand.	○	○	○	○	○
19. In the future, I could do harder science work.	○	○	○	○	○
20. I believe that boys can be good at science	○	○	○	○	○
21. I believe that girls can be good at science	○	○	○	○	○

Engineering and Technology

Please read this paragraph before you answer the questions.

***Engineers** use math and science to invent things and solve problems. Engineers design and improve things like bridges, cars, machines, foods, and computer games. **Technologists** build, test, and maintain (or take care of) the designs that engineers create.*

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
22. I like to imagine making new products.	○	○	○	○	○
23. If I learn engineering, then I can improve things that people use every day.	○	○	○	○	○
24. I am good at building or fixing things.	○	○	○	○	○
25. I am interested in what makes machines work.	○	○	○	○	○
26. Designing products or structures will be important in my future jobs.	○	○	○	○	○
27. I believe that boys can be good at engineering and technology	○	○	○	○	○
28. I want to be creative in my future jobs.	○	○	○	○	○
29. Knowing how to use math and science together will help me to invent useful things.	○	○	○	○	○
30. I believe I can be successful in engineering.	○	○	○	○	○
31. I am curious about how electronics work.	○	○	○	○	○
32. I believe that girls can be good at engineering and technology	○	○	○	○	○

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Computational Thinking

Please read this paragraph before you answer the questions.

Computational Thinking *is a problem-solving process that is used in many areas such as developing computer applications. Those who work with computational thinking may program a device to perform a function, develop a program to play a video game, or automate (make something happen without human help) a process.*

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
33. I can break down large ideas into smaller parts	○	○	○	○	○
34. I like to find patterns and trends in things.	○	○	○	○	○
35. When I observe a pattern I can identify the rules of the pattern.	○	○	○	○	○
36. I am curious about how computers, machines, and electronic devices work.	○	○	○	○	○
37. I feel good when I design or make something that uses technology.	○	○	○	○	○
38. I can develop instructions for solving a problem or completing a task.	○	○	○	○	○
39. I can use models and simulations to see how things work.	○	○	○	○	○
40. I like to collect data to help me make a decision.	○	○	○	○	○
41. I believe that girls can be good at	○	○	○	○	○

computational thinking					
42. I can program something to perform a task.	○	○	○	○	○
43. I believe that boys can be good at computational thinking	○	○	○	○	○
44. I can visualize collected data to better understand something.	○	○	○	○	○
45. I believe I can be successful in computational thinking.	○	○	○	○	○

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Online Interdisciplinary STEM Education: A Case of Co-teaching for Social Justice

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ABSTRACT

This paper presents the process two professors engaged in to develop a co-taught model for two online graduate courses taught concurrently as part of a justice-oriented STEM education curriculum. Students in the courses, who are k-12 teachers, contributed to the development of the courses across iterations through feedback and discussions with the professors. Our previous co-teaching experiences in face-to-face courses supported by literature on co-teaching in higher education online environments were instrumental in preparing for the initial semester and ongoing development of these two co-taught courses. Development of the courses also relied on extensive cogenerative dialogue that resulted in a merged calendar tool and revised discussion assignment strategies. Integration of content across STEM disciplines was enacted and modeled in both courses, in part through assignments that were connected across the two courses.

Keywords: STEM, online education, social justice, ecojustice, co-teaching, interdisciplinary learning

The University of West Georgia is a large producer of education graduate degrees in the state and serves as a leader in many other areas of interest. We are located in a relatively suburban area, with close access to two major cities in the southeast; as with most institutions, especially after COVID-19, graduate programs are offered primarily online with little to no on-campus expectations. As with many graduate programs that are housed online, we tend to serve students throughout the state. Our department within the College of Education offers several different types of degrees at the graduate level along with several endorsements of interest to the k-12 classroom teacher and administrator. We developed two courses in different, related content areas which we have taught collaboratively through shared goals and related readings, activities, and assessments for three years within a STEM Education Endorsement. The endorsement is the product of our combined specialties and a mission of a department that includes others who are directly invested in STEM education for a more socially just society. Table 1 presents the course descriptions for our two courses.

The STEM Education Endorsement was designed to immerse teachers in STEM issues relating to social justice, as evidenced in the course descriptions above. Graduate-level students who hold a teaching certificate are eligible to enroll in the endorsement, which consists of a series of four courses taken over a calendar year with common goals, readings, activities, and assignments designed to meet the specific content and relate to STEM and social/ecojustice. We share readings and activities, in the appendix, that are established in research-based literature as directly related to social-justice, but there are many others that could also be used in courses such as these that are subjective to the instructor perspective. Students take a summer introductory course focused on STEM in the community prior to our co-taught science for ecojustice and math for social justice courses. The final course, what is considered a capstone, ties together concepts addressed in each of the previous semester syllabi into a community-based effort to bring meaningful STEM to others. The information detailed in this manuscript is intended to illustrate how we adapted two online courses in an effort to model content integration and simultaneously address integrative co-planning and implementation of a justice-oriented STEM curriculum.

Table 1
Course Descriptions

Science for Ecojustice	Math for Social Justice
Students will be introduced to research in science education that promotes awareness for multiple perspectives and considers diverse aspects of STEM efforts within the community. Through a focus on ecojustice issues, the student will develop skills necessary to contextualize science instruction for effective community-based STEM initiatives as well as the dispositions, knowledge, and skills needed to teach integrated STEM lessons to students in P-12.	Concepts and materials which are appropriate for mathematics education integrated with science, technology, and engineering for P-12 children will be investigated. In addition, STEM education is considered through the lens of social justice, equity, and community-based learning. This course is a prerequisite for Designing Community-Based STEM Education.

Literature on STEM Education

As part of the process of developing courses and key assessments for the STEM Education Endorsement, we focused on an interdisciplinary approach to STEM, as defined by Vasquez (2014): “Students learn concepts and skills from two or more disciplines that are tightly linked so as to deepen knowledge and skills” (p. 13). This is a challenge that k-12 STEM teachers are called to meet: to implement a STEM curriculum integrated across content areas with rich tasks that address real-world concerns. STEM teachers may find that their backgrounds in only one or two content areas have left them underprepared for integrative planning (Al Salami et al., 2017; Radloff & Guzey, 2016). Indeed, many never experience a truly interdisciplinary course as a student in a college setting during their teacher preparation training (Nowikowski, 2017). We realized if we wanted our students to truly understand the interdisciplinary approach to STEM teaching and learning, they would need to experience it first-hand in our classes. This led to our initial discussions of integrating the two courses so that our candidates would develop a more comprehensive understanding of STEM as a truly integrative discipline. Our preparatory research indicated that many people talk about the importance of STEM education, but few actually address it holistically or address the balance of the individual disciplines within the framework of justice (Bybee, 2010; Garibay, 2015; Hudley & Mallinson, 2017). Breiner and his colleagues (2012) found that many university educators viewed STEM in terms of separate content areas without

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connections. We knew planning for the integration of our course content would necessitate that we first overcome our own internal notions on siloed content before assisting our students in overcoming this struggle.

To design our co-taught online courses, we relied on our own experiences co-teaching outside of online environments as a starting point in addition to guidance found in the literature (Ericksson et al., 2020; Harter & Jacobi, 2018; Moore, 2016), and we turned to the literature for guidance on co-teaching in online environments (Heath & White, 2013; Morelock et al., 2017; Pharo et al., 2012, Tobin, 2006). While there is not a great amount of literature on co-teaching in post-secondary environments, some pointed to important themes and aspects of co-teaching in university settings that provided guidance as we built our courses. Harter and Jacobi (2018) found in their quasi-experimental study of two undergraduate communications courses, one co-taught and one not co-taught, that students believed they benefited from co-teachers' differing perspectives on content topics and different teaching methods and styles. On the other hand, students reported that the course structure was sometimes confusing and some were uncomfortable with a departure from a traditionally structured class. From the perspective of the instructors, one advantage of co-teaching includes the potential for each instructor to focus on different areas of expertise. Shared planning, which brings the strengths of two instructors to the process, is also a positive aspect of co-teaching; however, this is balanced by the disadvantage that this type of co-planning is time-consuming (Ericksson et al., 2020, Morelock et al., 2017). In a large-scale teacher network formed to co-teach college courses focused on an interdisciplinary environmental topic, Pharo and her colleagues (2012) found that co-teaching created an enhanced sense of community in those online courses but that it required additional workload for the instructors to collaborate. Among the collaborative tasks required of those co-teaching online are planning for assessment in a way that is consistent between the two instructors, discussing assignment expectations and building rubrics during the planning phase, sharing comments between co-teachers before sharing with students, and making content or assessment revisions during the course (Heath & White, 2013, Tobin, 2006). Moore (2016) emphasized that students in online classes in particular, whether those classes are co-taught or not, need a sense that their instructors are present and engaged in the online class environment in a way that scaffolds student experiences but does not interfere with the self-directed nature of online learning. Being explicit about email response time expectations, including technology intentionally in course assignments, and creating student/student and student/instructor interaction opportunities are some of the methods that contribute to student perceptions of instructor engagement in online classes (Moore, 2016).

As mentioned in distance education literature, there is a heavy emphasis on maintaining a presence in the online class for the teacher as well as encouraging student participation (Moore, 2016). Our planning and course-coordination needed to be transparent for ourselves, but also for the students so that they would see an equitable partnership for instruction that was fully-integrated and inclusive. In the process of planning and implementing these two, integrated online courses we discovered that communication was the essential element, including open dialogue between professor and professor, students and professors, and students and students.

Framing Methodology

Through the use of cogenerative dialogue, the researchers were able to read, reflect, discuss, and navigate a more seamless way of teaching diverse courses with similar intended outcomes. We ascribe to the approach defined by Tobin (2006) where cogenerative dialogue is the shared process of identifying outcomes and working together to attain common goals. Obviously, communication is a large component of cogeneration and allowed a better iteration of the courses over semesters as we gained feedback from our students but also from each other. An additional benefit of cogenerative dialogue is that our students were aware of the constant communication between us as professors and this, in-turn, demonstrated value in collaboration and positioned each content area as equally meaningful. Admittedly, one of the professors works from a big-picture perspective and has lofty ideas that may not always seem completely attainable; the other tends toward being systematic and intentional in her actions, with goals that are more explicit and easier to explain. Together, through self-analysis and constant communication regarding completed student work and feedback, we were able to develop a co-taught pair of courses that were truly co-created and collaborative in content and goals, while expressing the directive that STEM is not dependent on any "one" area more than another. The material presented in this manuscript has the benefit of going through three iterations; we have successfully taught our respective courses for three years. While the notion of success is subjective, we deem success as student feedback provided throughout the semester as well as evidence of student application of concepts covered in the courses, while in the courses and after. We viewed success as students' abilities to create authentic assignments that connected multiple STEM components while considering community and justice-based issues. Examples within this set of courses include identifying a local or relevant current issue and the aspects of Science Technology Engineering and Mathematics involved, identifying the social implications of how that impacts a community, and developing approaches to teaching STEM through that lens. Student "success" is also examined in the capstone course as the students are required to enact a community-based project with their k-12 students. Specific examples include projects that established a food pantry for their community, created blankets from plastic bags to distribute to local homeless populations, and developed school-based gardens that could supply fresh produce to families in need.

At the beginning of each semester before the courses, we have open and extensive dialogue regarding what worked for us and the students and what changes need to be implemented. This process includes our students' perspectives as their feedback and understanding is, and should be, what drives our instructional practice. What we present relies heavily on how we began the structure that enabled our current approach to interdisciplinary STEM education, an approach that respects the function of all integrated content and aligns with issues of justice. Since one of the professors teaches the capstone course, we utilize examples from that course as well as feedback from students that has been included on the course evaluations to help refine the courses so they become more focused on approaching STEM education through a justice-focused lens.

Design and Planning

The professors met several times prior to the first fall semester to develop a plan of action, outline course assignments, and to establish a list of key articles and activities that would be required to satisfy their original course syllabi and common objectives for the two courses. Since the first iteration of the courses, we have been able to negotiate assignments that aligned with both of our respective course expectations while maintaining a focus on STEM for social justice. In developing these two online content-specific STEM methods courses (Math for Social Justice and STEM for Ecojustice) for the endorsement, the conversation was extended to make sure that readings did not overlap and students did not have repetitive assignments. We believe that the result was an intense "course" that addressed what we perceived as the larger goal revealed in the

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literature. We deemed the larger goal as one contextualizing the role of STEM in disenfranchising people and places; our responsibility became one of helping our students make better decisions in how they teach concepts and for what purpose instruction exists. Both courses included a common set of objectives, a sample of which are included in Table 2.

Table 2
Common Objectives

The candidates will demonstrate the ability to engage students in STEM reasoning that reveals how STEM professionals think and solve problems.
The candidates will demonstrate the ability to effectively engage students in engineering design processes to solve open-ended problems or complete design challenges.
The candidates will demonstrate the ability to effectively engage students in fostering a learning environment which encourages risk taking, innovation, and creativity.
The candidates will demonstrate the ability to effectively engage students in facilitating student-led learning.
The candidates will demonstrate the ability to effectively engage students in applying skills to novel, relevant, and authentic situations.

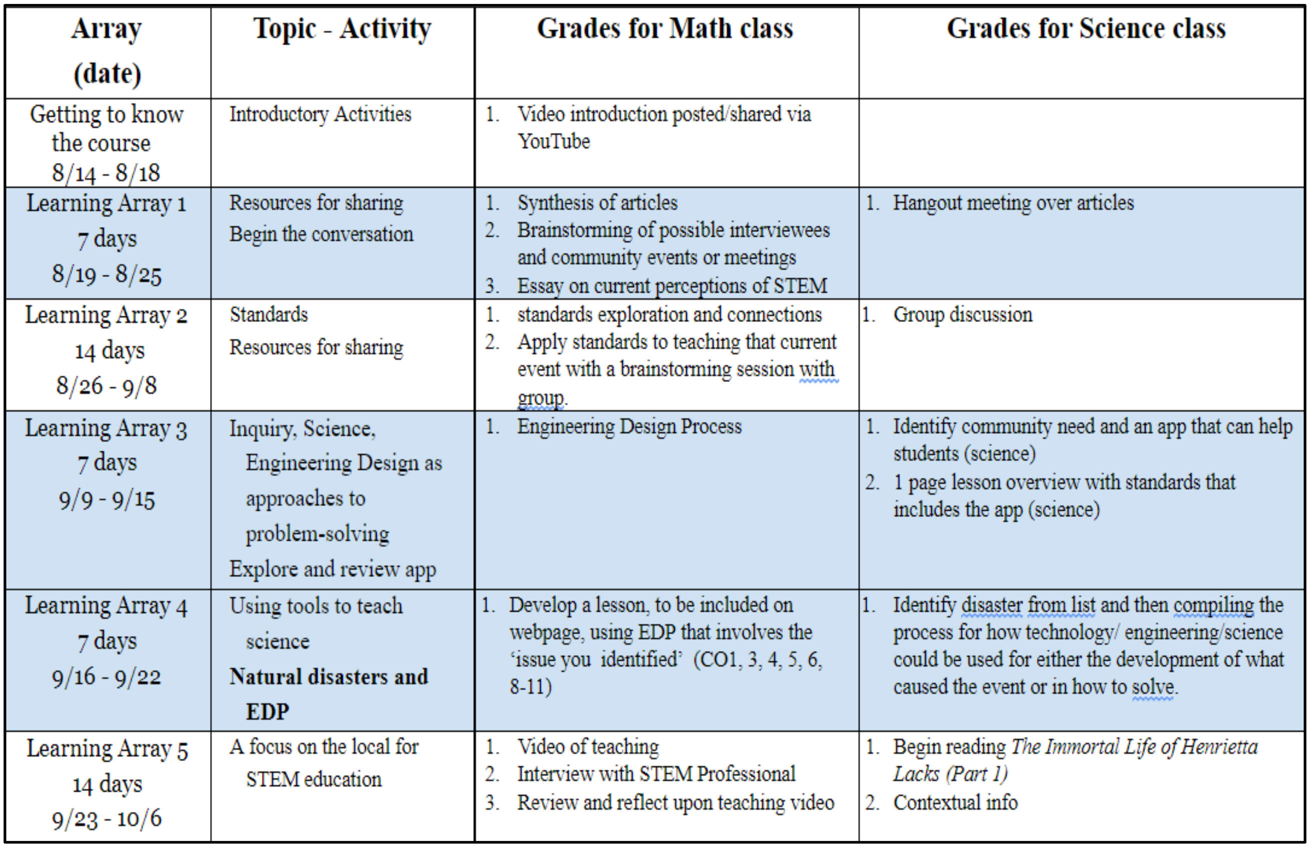
We settled on the idea that our two courses, covering different content areas, should be taught concurrently and intertwined as one online class within the STEM Education Endorsement. The very intentional decision to join our content was beneficial to our students, but even more so to our individual growth as professional academics. The context of our collaboration is critical, with a math educator who is highly linear in thinking, and a science educator who works with a much more abstract approach, both with a background and passion for sociocultural issues. Our combined voice was instrumental in helping the students navigate the role of "justice" in STEM education and more importantly, the value of their own voice in community-based issues that impact the disenfranchised. We dedicated our instruction to teaching processes, with the integration of readings that placed *justice as the context for change* and knowledge building in the area of STEM education. A partial readings list is included in the Appendix.

Planning to Co-teach

The online nature of these courses required us to consider the organization of our learning platform, the type of assignments and discussions which would take place, as well as the frequency of interactions that would be mandatory between teacher and student. We felt that a more hands-on approach would be beneficial in the beginning, not knowing the experiences of our students, who were working teachers, enrolled in the courses. Both of us were familiar with online learning and had taught courses before that required us to develop weekly/bi-weekly "modules" as a way to organize material and help students navigate the resources. With this fall grouping, we followed our experience and developed learning "arrays" as a way of structuring student thinking and to bring in terminology that would connect content across both classes. As we planned for the first iteration of the course series, we focused on a common calendar, discussion expectations, and assignments that were integrated into each course with common goals and expectations.

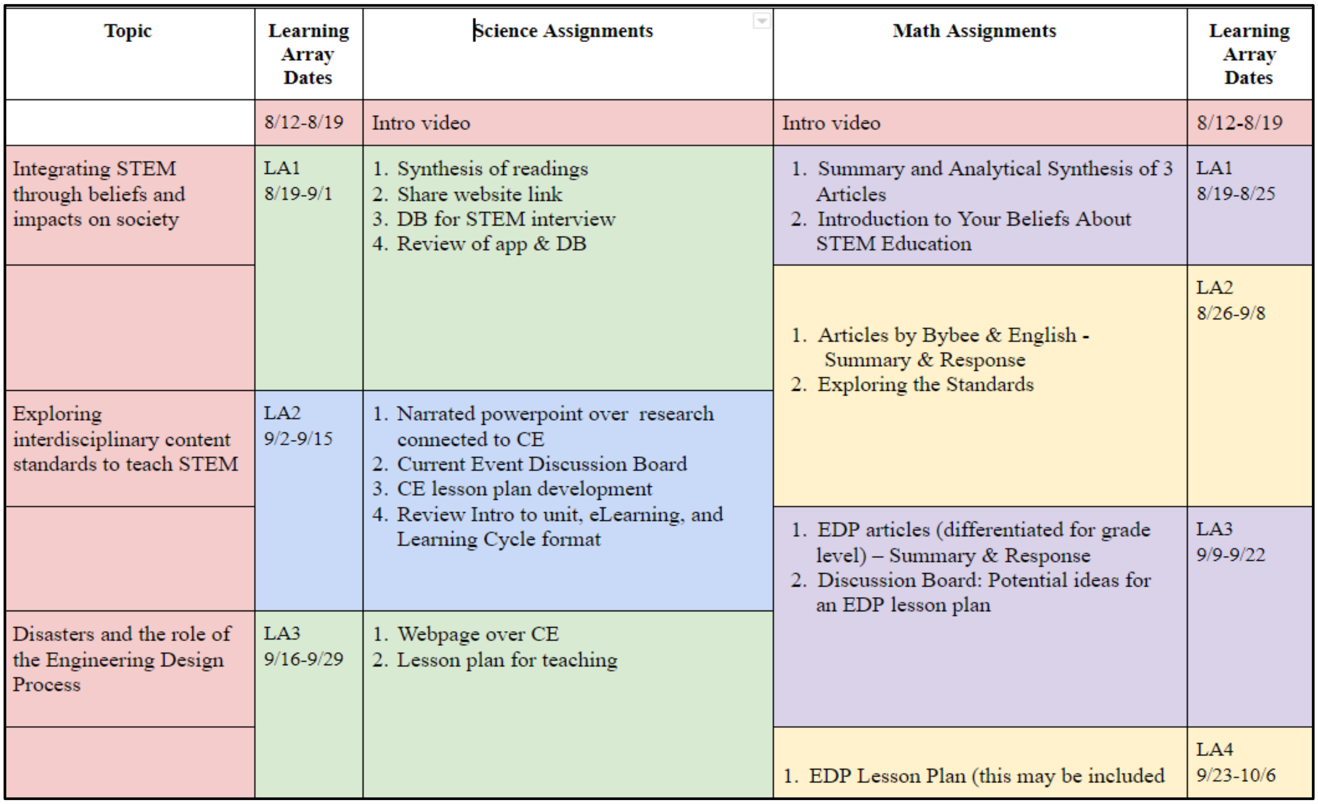
Common Calendar

It was decided that a working calendar would be most effective in helping us, as well as the students, maintain organization and equitable inclusion of content in assignments across the courses. After several iterations of the course series (Figure 1), we have altered the structure of the calendar (Figure 2) but remain true to the original goal of equitable representation of content. These calendars represent, for the students, how each course builds on the other and integrates STEM across math and science. Each of the courses includes assignments that require students to consider other content areas involved in STEM.



Array (date)	Topic - Activity	Grades for Math class	Grades for Science class
Getting to know the course 8/14 - 8/18	Introductory Activities	1. Video introduction posted/shared via YouTube	
Learning Array 1 7 days 8/19 - 8/25	Resources for sharing Begin the conversation	1. Synthesis of articles 2. Brainstorming of possible interviewees and community events or meetings 3. Essay on current perceptions of STEM	1. Hangout meeting over articles
Learning Array 2 14 days 8/26 - 9/8	Standards Resources for sharing	1. standards exploration and connections 2. Apply standards to teaching that current event with a brainstorming session with group.	1. Group discussion
Learning Array 3 7 days 9/9 - 9/15	Inquiry, Science, Engineering Design as approaches to problem-solving Explore and review app	1. Engineering Design Process	1. Identify community need and an app that can help students (science) 2. 1 page lesson overview with standards that includes the app (science)
Learning Array 4 7 days 9/16 - 9/22	Using tools to teach science **Natural disasters and EDP**	1. Develop a lesson, to be included on webpage, using EDP that involves the 'issue you identified' (CO1, 3, 4, 5, 6, 8-11)	1. Identify disaster from list and then compiling the process for how technology/ engineering/science could be used for either the development of what caused the event or in how to solve.
Learning Array 5 14 days 9/23 - 10/6	A focus on the local for STEM education	1. Video of teaching 2. Interview with STEM Professional 3. Review and reflect upon teaching video	1. Begin reading *The Immortal Life of Henrietta Lacks (Part 1)* 2. Contextual info

Figure 1. Fall 2019 Schedule: Grades are divided per content course, but work for each course occurred over the same time period and addressed common topics.



Topic	Learning Array Dates	Science Assignments	Math Assignments	Learning Array Dates
	8/12-8/19	Intro video	Intro video	8/12-8/19
Integrating STEM through beliefs and impacts on society	LA1 8/19-9/1	1. Synthesis of readings 2. Share website link 3. DB for STEM interview 4. Review of app & DB	1. Summary and Analytical Synthesis of 3 Articles 2. Introduction to Your Beliefs About STEM Education	LA1 8/19-8/25
			1. Articles by Bybee & English - Summary & Response 2. Exploring the Standards	LA2 8/26-9/8
Exploring interdisciplinary content standards to teach STEM	LA2 9/2-9/15	1. Narrated powerpoint over research connected to CE 2. Current Event Discussion Board 3. CE lesson plan development 4. Review Intro to unit, eLearning, and Learning Cycle format		
			1. EDP articles (differentiated for grade level) – Summary & Response 2. Discussion Board: Potential ideas for an EDP lesson plan	LA3 9/9-9/22
Disasters and the role of the Engineering Design Process	LA3 9/16-9/29	1. Webpage over CE 2. Lesson plan for teaching		
			1. EDP Lesson Plan (this may be included	LA4 9/23-10/6

Figure 2. Fall 2020 Schedule: Math and Science schedules were staggered, but still related to common topics.

Integrated Assignments

Each professor felt it was important to provide assignments that included content from ALL STEM areas when possible, and opportunities were created to encourage students to make those cross-curricular connections as well. Throughout each course, we use the same terminology and have cross-over activities: the science course focuses on context (either place or community) while in math, the student looks at approaches to instruction (problem or project based); STEM standards are addressed in one class but used in both; both require an e-Learning module addressing multiple components of STEM; unit plans and individual lessons produced for both courses require the same format and require integrated content. The only assignment that seems unrelated in the beginning involves the assigned reading for science; students are required to read *The Immortal Life of Henrietta Lacks* and develop STEM related lesson ideas based on the resource. Both professors agreed on the inherent value in incorporating this publication into the curriculum, as it so eloquently allows connections to be made visible between medicine and science, technology and humanity, as well as the advances we have made through technology, medicine, engineering and human rights. The link between human rights and STEM is ever-present and allows for thoughts to shift as we encourage deeper analysis and reflection on how these issues currently impact our own communities. Given this overlap, we encourage students who are in both courses to make connections between not only the individual content areas, but also across other STEM disciplines in connection with social issues.

We often introduce an idea in one class, continue with related content in the other, and then bounce back to expand it with additional lessons or activities in the original class. The best example of this begins in the science section where students are required to select a current event from a professor-identified list of natural or man-made disasters. These topics are chosen based upon both the societal and STEM-based contributions they may have for potential student learning. The "current event" project involves a list of topics/incidents that have happened in the last decade and are connected to STEM. Within the science course, students conduct research on how STEM exists within the "event" while amassing science content-specific knowledge that allows them to put together a narrated presentation aligning with local and national standards for their grade level. The next math learning array requires them to use the engineering design process (EDP) to solve problems. The instructor for the math course encourages students to use the current event topic as a springboard for developing their EDP lesson plan. While they are working on the EDP, they are asked to develop a webpage in science that asks them to put together the content understanding with newly acquired knowledge from math, technology and engineering and look at the topic from a social perspective. Students sign up for the topic of their choice and conduct research on what, why, how, where, and when, along with what that event meant for society and the community in which it occurred. The current event is assigned as a science course activity, but leads into the engineering design process learning array that takes place in math. The very next science array then requires the student to take the information gained from researching the current event and turn it into a webpage that includes components connecting STEM to society.

In selecting topics for the current event, both professors work together to discuss things that would align well for instruction in each course while encapsulating a social justice concern. We attempt to include topics that are comprehensive and will have some connection to all aspects of STEM but specifically impact a local community; sample topics for the current event have included: Hard Rock Hotel Collapse in New Orleans, LA; Georgia droughts of 2016; Flint River, MI water crisis; cave flooding and scout rescue in the Philippines; various hurricanes and wildfires in the recent decade; the COVID-19 impact on the economy; logging in the Brazilian rainforest; Michigan dam collapse of 2020. As new events occur globally and locally, we continue to update the list. We encourage discussion about which topic is a best fit, and we often include issues that come up in the local news that might be relevant to the students and represent STEM as a social issue. The assignment descriptions for the natural disaster webpage as well as the EDP are provided in the appendix.

An example of the connections made between the current event topic selection and webpage developed in the science course and the engineering design process lesson plan developed in the math course can be illustrated by work focused on Hurricane Michael, which made landfall in the Florida Panhandle as a category 5 hurricane on October 10, 2018. First introduced by a student via a narrated presentation in the science course during an assignment about natural and current events, our student explained potential classroom connections to STEM concepts and the impact of Hurricane Michael to students in the local community. Elaboration was provided on wind damage to homes and buildings in Florida, Georgia, and Alabama, and the potential to develop lesson plans that incorporate hurricane proof building design. In Table 3, an excerpt of the engineering design process lesson plan that was subsequently developed for the math course in which students design houses to withstand wind loads, is presented.

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Table 3
An Excerpt from an Engineering Design Process Lesson Plan in the Math Course

Engagement

The teacher will begin the learning activity by reading a story about the three little pigs. Students will be given time to think and discuss why the houses made of straw and sticks fell apart. This discussion will help to transition the students onto the topic of force, and how different forces, like wind, are able to act upon structures, such as the pigs' houses. The teacher will also show the students real-life examples of how forces can affect building structures (images of destruction following Hurricane Michael). The teacher will then present the design challenge to the students and pass out the design briefs. Students will need to work with their team to design, create, build, and test a new house for the pigs to live in that will be able to stay standing against the wolf's huffing and puffing.

Explore

Each group will be given a cardboard box lid, five index cards, and a strip of masking tape. The students will be told that they are not to spend five minutes to work with members of their group to begin observing and brainstorming ideas about how to use these materials to construct their house. The students will be required to record their observations and initial ideas on the Initial Observation/Brainstorming page of their design briefs. Using the observations that were made during this initial exploration phase, groups will create and build their own designs for the pigs' houses.

Explain

The groups will share their individual designs. During this time, the students will need to fully explain their idea and justify why they made the design choices they did. Before starting this part of the activity, the teacher will remind the students about what it means to give constructive criticism and will explain to the students how they can use the observations they have made as evidence to support why they are for or against certain aspects of the designs. While the students are sharing, the teacher will be walking around the room, stopping to probe and question the groups as necessary. After groups finish sharing, the groups will bring their models over to the wind test area, which will simulate the Big Bad Wolf's huffing and puffing, or real-life connection to high powered wind storms. The wind test will be conducted by having the students place their model three feet away from the fan. The fan will then be turned on at full power. If the model can withstand the full power of the fan at the three-foot mark, the teacher will move the model closer to the fan in six-inch intervals. Each group will make observations about what is happening to their model during the test and will record how close the model was able to get to the fan before being blown over. These observations will be recorded on the Wind Test Observations page in the design brief.

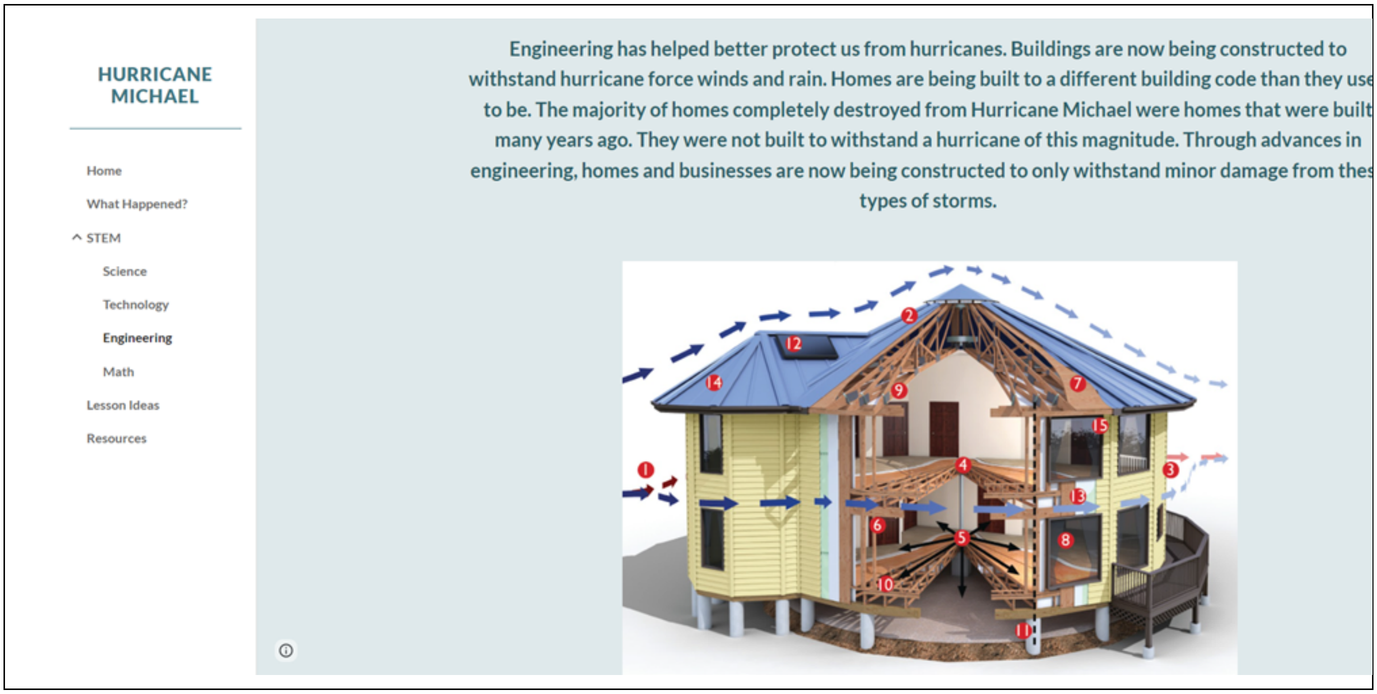
Extend

Once all of the groups have been given the opportunity to test the houses they designed, the teacher will gather the students in a whole group setting. The teacher will then ask the students to share and discuss what they noticed and learned from completing this activity. The teacher will use the class discussion about what happened to the housing models to allow the students to be able to see the connection between this project and the destruction that occurred in the Florida panhandle in the wake of Hurricane Michael. The teacher will explain that after a storm, communities have to assess the damage and use that information to help them rebuild. Groups will have time to redesign their models. Students will be challenged to think about how they used materials the first time and how they could utilize these materials in a better way. The students will sketch and record their new group design on the Redesign page of their design brief. When groups have completed construction of the new design, they will test it using the same procedures as before. During this round of testing, students will make and record observations about how this new design performed during the wind test. The students will record these observations on the Wind Test Observations Take-Two page of the design brief.

Evaluation

Once all of the groups have finished testing their new designs, the students will gather as a whole group to share what they learned from this experience. The teacher will use this discussion as a way to informally assess the students' understanding of the concepts presented during this activity. The students will independently complete the Student Reflection page in the design brief. Once finished, the students will turn in their completed design brief which will be used to formally assess students on their understanding of addition and subtraction, how forces can impact structures, and the Engineering Design Process. As part of this reflection, the students will also complete a self-assessment rubric evaluating how they were able to work through the steps of the Engineering Design Process.

Later in the semester during the science course, our student developed a natural event webpage based on Hurricane Michael and shared her webpage with her classmates via discussion board. The purpose of this assignment was to educate her fellow classmates about the event, to provide additional resources about it, to explain how each aspect of STEM has real-world connections to it, and to suggest lesson planning ideas that incorporate the event. As seen in Figure 3, connections to the engineering design process lesson plan assignment completed for the math course are evident.



Engineering has helped better protect us from hurricanes. Buildings are now being constructed to withstand hurricane force winds and rain. Homes are being built to a different building code than they use to be. The majority of homes completely destroyed from Hurricane Michael were homes that were built many years ago. They were not built to withstand a hurricane of this magnitude. Through advances in engineering, homes and businesses are now being constructed to only withstand minor damage from thes types of storms.

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LESSON IDEAS

TEST YOUR BUILDING

Have your students evaluate and research different buildings that were destroyed during Hurricane Michael. Students should begin to brainstorm the materials used in these structures. Within those list of materials students should begin to research their ability to withstand certain wind speeds, storm surge, and pressure.

After looking into these materials, students should begin to create a sketch of a building they feel could withstand a storm of Hurricane Michaels magnitude. To develop the sketch students should ask themselves these questions: Could my building hold up against a category 5 storm? Is my building's design incorporating a design that is built to hold up against a hurricane? What materials are able to withstand these high wind speeds, storm surge, and pressure?

After creating the sketch, students should work with their peers to gain feedback to make their design better. Students then can create a replica of their model and be prepared to present how their building would be able to withstand a category 5 hurricane.

Figure 3. Clips from Hurricane Michael Webpage in the Science Course

Integrated Projects in the Classroom

One of the main goals, as stated previously, was to help teachers begin the process of implementing integrated STEM content rather than teaching STEM as siloed subjects. In addition to these projects occurring in each class over the course of the semester, students were required to develop unit plans that integrated STEM content through community-based approaches and a problem/project based format. These unit plans often identified a local issue and worked to help solve problems in the classroom, but they also expanded many of the lesson ideas that may have been created for basic classroom assignments. Table 4 below indicates how a pre-K teacher planned to address issues of green space in her community with her students. As evidenced in her lesson outline, various aspects of STEM were included along with additional content needed for classroom instruction. One interesting component is the formative and performative nature of the included assessments, and another is the specific objectives that demonstrate the teacher’s plan for students to be able to apply knowledge about abstract concepts to concrete solutions. This same type of outline is included in the appendix to represent a fifth-grade teacher who used her natural disaster project to frame the second week of her unit while addressing multiple, integrated STEM components, including video game design that incorporated historical events related to natural disasters.

Table 4

Connections between Objectives, Assessment and STEM Content for Pre-K

	Lesson 6	**Lesson 7**	**Lesson 8**	**Lesson 9**	**Lesson 10**
Include objective, essential questions (must have 2+ content daily)	Students will describe roles and responsibilities of a variety of occupations. Students will demonstrate understanding of more complex vocabulary through everyday conversations. Students will match sets of objects with the same number.	Students will make real-world connections between stories and real-life experiences. They will identify the importance of participating in activities related to health.	Students will understand how people effect their environment. Students will explore the use of technology and understand its role in their environment.	Students will create simple representations of their school environment. Students will match sets of objects with the same number. Students will recognize and name common two-dimensional shapes; they will combine these shapes to form new ones.	Students use objects to function as simple machines to enhance child directed play. Students will work and play cooperatively with peers and show respect for peers.
What aspects of STEM are addressed?	Math, Technology & Science	Engineering & Technology	Science, Technology & Engineering	Math, Technology & Engineering	Math, Technology & Engineering
Anticipated outcomes - assessment type	Video recording of the exploration and extended activity.	The class chart of ideas for the playground.	The classroom video that the students make.	Notes from students' participation. Matrix on the students' use and understanding of two-dimensional shapes.	Video of the students during the lesson.

Conclusion

Since the start of our STEM Endorsement, we have had 35 students who are teachers in grades k-12, most of whom teach in elementary school settings, complete the endorsement. We have learned from them and from one another what makes our co-taught courses more successful. While we have no way of knowing for certain how these objectives are enacted within schools after our teachers have graduated the program, it is our hope that they continue implementing the practices they developed in our courses to grow a more community-based, socially aware STEM curriculum within their own classrooms and schools. It has been our experience that creating student to student connections and student to professor connections have been the keys to encouraging student engagement in content that most of them have not encountered in the integrated format we have developed. Having smaller classes has also allowed us to spend more time emphasizing the social

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aspects of STEM and helping students see the local connections that exist where they live. The continued work in the capstone course allows us to "see" the rewards of student understanding and how they begin to further engage with the community. The process has been rewarding and we feel that the changes have made us, as well as the program, better. We are constantly redefining what better means, in regard to the endorsement and what is happening in the world and will likely do that as long as we are responsible for these series of courses. Because our vision of co-teaching relies on collaborative planning based on student feedback and our own analysis of past semesters of our integrated courses, this effort is a work in progress that will continue through future iterations of our co-taught courses.

References

Al Salami, M.K., Makela, C.J., & de Miranda, M.A. (2017). Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. *International Journal of Technology and Design Education, 27,* 63-88.

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1), 3-11.

Bybee, R. W. (2010). Advancing STEM education: a 2020 vision. *Technology & Engineering Teacher, 70*(1), 30–35.

Eriksson, T., Jaskari, M., & Kinnunen, P. (2020). Co-teaching is great! – but only if there is time: teacher perspectives on online co-teaching. *Nordic Journal of Business, 69*(3), 47-69.

Garibay, J. C. (2015). STEM students' social agency and views on working for social change: are STEM disciplines developing socially and civically responsible students? *Journal of Research in Science Teaching, 52*(5), 610–632.

Harter, A. & Jacobi, L. (2018). "Experimenting with our education" or enhancing it? Co-teaching from the perspective of students. *Inquiry in Education, 10*(2), 1-16.

Heath, S. E., & White, E. R. (2013). Walking the Line: Lessons in Online Interdisciplinary Instruction. *Currents in Teaching & Learning, 6*(1), 18–29.

Hudley, C.A., & Mallinson, C. (2017). "It's worth our time": a model of culturally and linguistically supportive professional development for K-12 STEM educators. *Cultural Studies of Science Education, 12*(3), 637–660. https://doi.org/10.1007/s11422-016-9743-7

Moore, R. L. (2016). Interacting at a distance: creating engagement in online learning environments. In K.B. Lydia, B. Joseph, N. Esther, & A. Cynthia (Eds.), *Handbook of Research on Strategic Management of Interaction, Presence, and Participation in Online Courses* (pp. 401-425). IGI Global.

Morelock, J.R., Lester, M.M., Klopfer, M.D., Jardon, A.M., Mullins, R.D., Nicholas, E.L., & Alfaydi, A.S. (2017). Power, perceptions, and relationships: a model of co-teaching in higher education. *College Teaching, 65*(4), 182–191. https://doi.org/10.1080/87567555.2017.1336610

Nowikowski, S.H. (2017). Successful with STEM? A qualitative case study of pre-service teacher perceptions. *The Qualitative Report, 22*(9), 2312-2333.

Pharo, E.J., Davison, A., Warr, K., Nursey-Bray, M., Beswick, K., Wapstra, E., & Jones, C. (2012). Can teacher collaboration overcome barriers to interdisciplinary learning in a disciplinary university?

A case study using climate change. *Teaching in Higher Education, 17*(5), 497-507. https://doi.org/10.1080/13562517.2012.658560

Radloff, J. & Guzey, S. (2016). Investigating preservice STEM teacher conceptions of STEM education. *Journal of Science Education Technology, 25*, 759-774.

Tobin, K. (2006). Learning to teach through coteaching and cogenerative dialogue. *Teaching Education*, *17*(2), 133-142.

Vasquez, J.A. (2014). STEM: Beyond the acronym. *Educational Leadership, 72*(4), 10-15.

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APPENDIX A

PARTIAL READING LIST FOR CO-TAUGHT STEM COURSES (readings that address equity or social justice have an asterisk):

*Asghar, A., Sladeczek, I.E., Mercier, J., & Beaudoin, E. (2017). Learning in science, technology, engineering, and mathematics: Supporting students with learning disabilities. *Canadian Psychology, 58*(3), 238-249.

*Basham, J. D., & Marino, M. T. (2013). Understanding STEM education and supporting students through universal design for learning. *Teaching exceptional children, 45*(4), 8-15.

*Basham, J. D., Israel, M., & Maynard, K. (2010). An ecological model of STEM education: Operationalizing STEM for all. *Journal of Special Education Technology, 25*(3), 9-19.

*Bowers, C. (2016). *A Critical Examination of STEM: Issues and Challenges*. Routledge.

Bybee, R.W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher, 70*(1), 30-35.

*Cunningham, C.M. & Higgins, M. (2015). Engineering for everyone. *Educational Leadership, 72*(4), 42-47.

*Dailey, D. (2017). Using engineering design challenges to engage elementary students with gifts and talents across multiple content areas. *Gifted Child Today, 40*(3), 137-143.

*Dalvi, T., Wendell, K.B., & Johnson, J. (2016). Community-based engineering STEM experiences from a second grade urban classroom. *Young Children, 71*(5).

Dankenbring, C., & Capobianco, B.M., & Eichinger, D. (2014). How to develop an engineering design task: Create your own design activity in seven steps. *Science and Children, 52*(5), 70-75.

English, L. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education, 15*, 5-24.

*Garibay, J.C. (2015). STEM students' social agency and views on working for social change: Are STEM disciplines developing socially and civically responsible students? *Journal of Research in Science Teaching, 52*(5), 610-632.

Hemming, J. (2018). Drawbridge by design: Civil engineering for middle school. *Technology and Engineering Teacher, 77*(7), 40-44.

Hollers, B. (2017). Documenting the engineering design process. *Technology and Engineering Teacher, 77*(2), 35-39.

*Hudley, C.A., & Mallinson, C. (2017). "It's worth our time": a model of culturally and linguistically supportive professional development for K-12 STEM educators. *Cultural Studies of Science Education, 12*(3), 637–660. https://doi.org/10.1007/s11422-016-9743-7

*Israel, M., Wherfel, Q.M., Pearson, J., Shehab, S., & Tapia, T. (2015). Empowering k-12 students with disabilities to learn computational thinking and computer programming. *Teaching Exceptional Children, 48*(1), 45-53.

Jones, V.R. (2017). Bridging integrative STEM communities. *Children's Technology and Engineering, 22*(2), 24-26.

*LaForce, M., Noble, E., King., H., Century, J., Blackwell, C., Holt, S., Ibrahim, A., & Loo, S. (2016). The eight essential elements of inclusive STEM high schools. *International Journal of STEM Education, 3*(1), 1-11.

Leonard, J., Russell, N.M., Hobbs, R.M., & Buchanan, H. (2013). Using GIS to teach place-based mathematics in rural classrooms. *Rural Educator, 34*(3), 10-17.

*Long, L.L. & Mejia, J.A. (2016). Conversations about diversity: Institutional barriers for underrepresented engineering students. *Journal of Engineering Education, 105*(2), 211-218

Meyer, D.K., Turner, J.C., & Spencer, C.A. (1997). Challenge in a mathematics classroom: Students' motivation and strategies in project-based learning. *The Elementary School Journal, 97*(5), 501-521.

Monson, D. & Besser, D. (2015). Smashing milk cartons: Third-grade students solve a real-world problem using the engineering design process, collaborative group work, and integrated STEM education. *Science and Children, 52*(9), 38-43.

O'Brien, T.C., Wallach, C., & Mash-Duncan, C. (2011). Problem-based learning in mathematics. *The Mathematics Enthusiast, 8*(1), 147-159.

Peterson, B. (2012). Numbers count: Mathematics across the curriculum. In A.A. Wager & D.W. Stinson (Eds.), *Teaching mathematics for social justice: Conversations with educators* (pp. 147-160). NCTM.

*Skloot, R. (2010). *The immortal life of Henrietta Lacks.* New York: Crown Publishers.

Tippins, D. & Britton, S.A. (2014). Ecojustice pedagogy. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 1-6). Springer, Netherlands.

Welling, J. & Wright, G.A. (2018). Teaching engineering design through paper rockets. *Technology and Engineering Teacher, 77*(8), 18-21.

*Zouda, M. (2016). Deconstructing STEM: A reading through the postmodern condition. *Journal for Activist Science and Technology Education, 7*(1), 73-83.

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APPENDIX B

ASSIGNMENT SAMPLE FROM *SCIENCE FOR ECOJUSTICE* (Learning Array 3: Natural event or Man-Made disaster Website):

Construct a web page for your current event from Learning Array 2. Background research has already been collected, and you have an informational video that can be included for reference. Some of the following may have been included in your narrated presentation, however, you should delve more deeply into the social and environmental aspects of your current event. Think more broadly to include additional content areas, as this lesson will serve as the basis for the unit plan you create for this course. Please use the following questions and prompts to guide your research and web page development.

Consider using the current event that you choose to develop the Engineering Design Process Lesson Plan for the companion course, ***Math for Social Justice***.

1. Identification of “event”. Who, what, when, and where? Please include a brief narrative as to why it is relevant to your community or a community.
2. What are the societal implications of this issue? Consider culture, economy, etc.
3. How could technology have been used to prevent or lessen the impact of this issue?
4. What technological advances are discussed in relation to this current event? (what happened after or as a result of?)
5. How is science represented? Why is this an accurate depiction of science and/or technology?
6. Choose one aspect of technology that is in some way related to the event and explain: How was the technology developed? What was its original purpose – why was it developed?
7. What are the benefits for society as a result of this new technology or the service it provides?
8. How has society been negatively impacted as a result of this technology or the service it provides?
9. What concepts could be used to educate the public regarding this technology? How would you help the common person understand the applications of this technology?
10. How has engineering helped to better protect us from or warn us about these types of events?
11. What mathematical principles can be connected to this event and how would you make it meaningful for your students?

APPENDIX C

ASSIGNMENT SAMPLE FROM *MATH FOR SOCIAL JUSTICE* (Learning Array 4: Engineering Design Process Lesson Plan):

For this assignment, you will create a lesson plan that **starts with a mathematics standard and incorporates at least two standards from two other STEM content areas**. The lesson plan template is located on the last page in the Unit Plan document.

This lesson plan should incorporate an Engineering Design Process, although it is up to you to decide which version of the EDP (5-step, 7-step, etc.) makes the most sense for your students. Keep in mind you have a goal beyond incorporating the EDP to also address topics you believe your students will care about for reasons of personal or community interest. A connection should be made to positively impact lives - their own or their family members' lives, or their community, or society as a whole.

In Science for Ecojustice during Learning Array 3, you are developing a web page that addresses a natural event or man-made disaster. Consider extending that project by connecting the engineering design process that you choose as the focus of your lesson plan to the natural event or man-made disaster you investigated in your web page.

Remember that you will prepare a 5-lesson Unit Plan that will serve as the Key Assessment for this course. This EDP lesson plan can be one of your lesson plans to include in the Unit Plan. You may even find this initial lesson plan covers only part of the EDP cycle for the activity you choose and you may ultimately be able to develop two or three lesson plans for the Unit Plan from the full EDP cycle based on the activity you choose.

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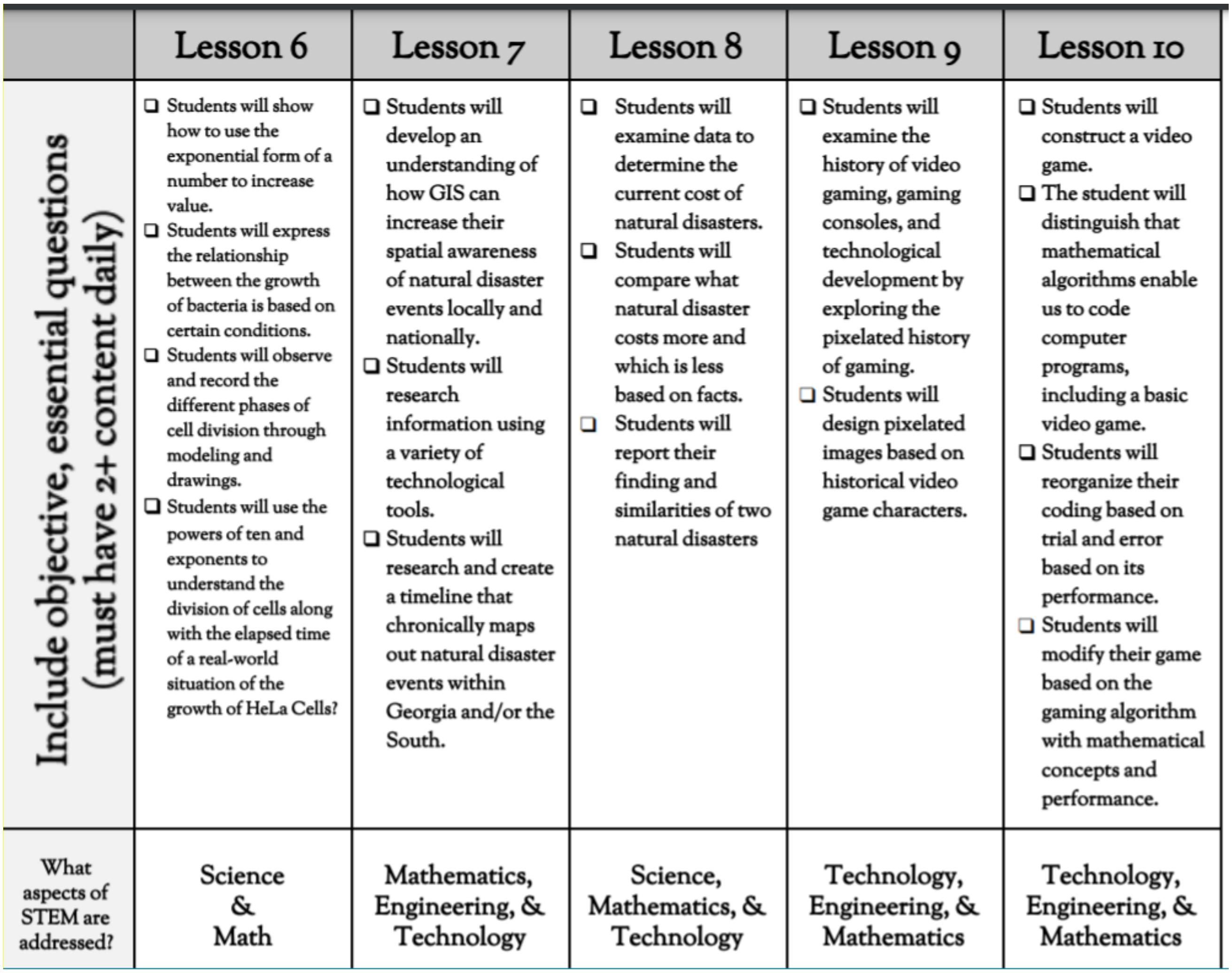
APPENDIX D

ADDITIONAL EXAMPLE FOR 5TH GRADE UNIT PLAN FOR INTEGRATED CONTENT



	Lesson 6	Lesson 7	Lesson 8	Lesson 9	Lesson 10
Include objective, essential questions (must have 2+ content daily)	☐ Students will show how to use the exponential form of a number to increase value. ☐ Students will express the relationship between the growth of bacteria is based on certain conditions. ☐ Students will observe and record the different phases of cell division through modeling and drawings. ☐ Students will use the powers of ten and exponents to understand the division of cells along with the elapsed time of a real-world situation of the growth of HeLa Cells?	☐ Students will develop an understanding of how GIS can increase their spatial awareness of natural disaster events locally and nationally. ☐ Students will research information using a variety of technological tools. ☐ Students will research and create a timeline that chronically maps out natural disaster events within Georgia and/or the South.	☐ Students will examine data to determine the current cost of natural disasters. ☐ Students will compare what natural disaster costs more and which is less based on facts. ☐ Students will report their finding and similarities of two natural disasters	☐ Students will examine the history of video gaming, gaming consoles, and technological development by exploring the pixelated history of gaming. ☐ Students will design pixelated images based on historical video game characters.	☐ Students will construct a video game. ☐ The student will distinguish that mathematical algorithms enable us to code computer programs, including a basic video game. ☐ Students will reorganize their coding based on trial and error based on its performance. ☐ Students will modify their game based on the gaming algorithm with mathematical concepts and performance.
What aspects of STEM are addressed?	Science & Math	Mathematics, Engineering, & Technology	Science, Mathematics, & Technology	Technology, Engineering, & Mathematics	Technology, Engineering, & Mathematics

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Underrepresentation of Minoritized Groups in STEM Education: A Metasynthesis Review

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ABSTRACT

This metasynthesis review analyzes the possible influences impacting the underrepresentation of People of Color (POC) in science, technology, engineering, and mathematics (STEM) education. Underrepresented minoritized (URM) groups are defined in this article as Black and Latinx populations due to their low representation in STEM education professions (National Science Foundation, 2019). This review explores the possible influences at the high school and undergraduate levels in STEM and education. Previous research has explored the racism impacting the underrepresentation of POC in both STEM and education, but little research has examined the intersectionality of STEM education. The purpose of this metasynthesis review is to analyze the existing research on SOC's experiences in STEM and education in order to better understand the underrepresentation of minoritized groups in STEM education.

Keywords: STEM education, Students of Color, Teachers of Color, underrepresented minoritized groups, STEM, education

As the student population becomes more racially diverse, science, technology, engineering, and mathematics (STEM) teachers continue to be predominately White (National Science Foundation, 2019). This metasynthesis review analyzes the possible influences impacting the underrepresentation of People of Color (POC) in STEM education. In this study, underrepresented minoritized (URM) groups include Black and Latinx populations due to their disproportionate numbers in the STEM teaching profession. This article reviews the racial barriers at the high school and undergraduate levels in STEM education. The purpose of this study is to identify in the literature the possible influences on URM groups in STEM education and analyze these influences to better understand the marginalization taking place in STEM education.

According to the National Science Foundation (2019), science and engineering pre-service teachers consist of the following racial demographics: 77% White, 9% Black, 8% Latinx, 4% Asian, and 2% other. This representation is not equivalent to the racial makeup of the student population, which in 2017 consisted of 48% White, 15% Black, 27% Latinx, and 10% other (National Center for Education Statistics, 2020). Asian and Indigenous groups were not included in this analysis due to their lower student population, though analysis of these groups is an

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important area of study. Although racial diversity in the teaching profession is increasing, it is at a much slower rate than the growth of diversity in the population of students (Ingersoll et al., 2019). Racial representation is important for creating an equitable education for Students of Color (SOC). When a SOC aligns with the race of their teacher, this is defined as race congruence. Race congruence can have a positive impact on a SOC's academic achievement (Fox, 2016; Grissom & Redding, 2016; Jacoby-Senghor et al., 2016) and overall educational experience (Burciaga & Kohli, 2018; Cheng, 2019). Previous research has explored the racism impacting the underrepresentation of POC in both STEM and education, but little research has examined the intersectionality of STEM education. The purpose of this metasynthesis review is to use a Critical Race Theory (CRT) lens to analyze the existing research on SOC's experiences in STEM and education in order to better understand the underrepresentation of minoritized groups in STEM education.

First, a summary of the selection procedure for the articles in this review is described. Then, the results are presented in two interrelated subsections on (a) possible influences in STEM and (b) possible influences in education. Finally, the article concludes with a discussion on practice/policy implications and research recommendations.

Critical Race Theory

The CRT framework has been used in education research to critically examine the impact of race on the inequities in education (Ladson-Billings, 1998; Solórzano et al., 2000). The goal of this theoretical framework is to expose the racism taking place, then find solutions to address the problem (Brown, 2014; Ladson-Billings, 1998; Sleeter, 2017). This research utilizes CRT to analyze the underrepresentation of minorized groups in STEM education. The goal of this research is to analyze the underrepresentation of SOC in the STEM education pipeline. This metasynthesis review analyzes the findings of previous research to examine which possible influences are impacting SOC's pursuit of STEM education. Possible influences are defined as experiences in K-12 or post-secondary education that could influence a SOC's pursuit of STEM education. The articles were reviewed with a CRT lens to determine common themes.

Method

Literature Search Strategy

Metasynthesis is a systematic approach to reviewing literature. The process involves combining and synthesizing characteristics from qualitative and quantitative studies. The purpose of a metasynthesis analysis is to generate a holistic interpretation of a phenomenon while still preserving the uniqueness of each individual study (Mays et al., 2005). The goal of this article is to use metasynthesis to systematically review recent literature on the experience of URM groups in STEM education. Previous research has primarily focused on the underrepresentation of POC in either STEM or education. This article examines the intersection of STEM and education to provide a better understanding of how institutional racism influences the disproportionate nature of racial representation in STEM teaching. The research questions that framed this research were: What are the possible influences impacting the underrepresentation of minoritized groups in STEM and education? How do these influences impact the STEM education pipeline?

Selection Procedures

Two comprehensive searches were conducted using EBSCO, in order to answer the research question. The two searches included possible influences in STEM and education. The comprehensive search of possible influences in STEM was conducted using the following search terms: "STEM" AND "racial minorities" OR "Black" OR "African American" OR "Latinx" OR "Latino" OR "Hispanic" OR "Students of Color". The search criteria included recent peer reviewed journal articles published from 2015 to 2021. The number of available articles was 117,551. After eliminating those related to an agricultural or the medical meaning of the word STEM (e.g. plant stems, stem cell research), there were 1,080 available articles focused on pursuing STEM. The second comprehensive search of possible influences impacting entering the education field was conducted using the following search terms: "preservice teachers" AND "racial minorities" OR "Black" or "Latinx" or "Students of Color" or "People of Color" or "Teachers of Color". The search criteria included recent peer reviewed journals published from 2015 to 2021. The number of available articles was 1,083.

The retrieved articles included a variety of qualitative, quantitative, and mixed methods studies. The author began screening titles and abstracts of the initial list of articles for studies that fulfill the inclusion criteria. The inclusion criteria included: (a) being empirical studies that were peer-reviewed and published in scholarly journals, (b) having been recently published, between 2015 and 2021, (c) participants included Black and/or Latinx high school or undergraduate students, and (d) focused on the possible influences in STEM, education, or STEM education. References were also checked on each coded study to locate additional articles. A total of 58 articles were reviewed, including 35 related to SOC pursuing STEM, 21 articles related to the pursuit of a degree in education, and 2 articles related to becoming a STEM educator.

Once the articles were collected, the coding process involved categorizing articles. There were three tabs created in the document including STEM, education, and STEM education. Early in the analysis process, the researcher discovered the lack of articles focused on STEM education, moving the focus of this metasynthesis review to possible influences in STEM and education. The researcher analyzed each article individually and categorized the articles into emerging themes, for example microaggressions or hostile academic environment. Themes were added throughout the process if an article did not fit a current theme in the document. It was possible for articles to fall into more than one theme if the research found two different possible influences. A constant comparative method was used as the articles were revisited as additional themes continued to emerge during the analysis process (Kolb, 2012). In the coding process, the researcher also included the type of study (qualitative, quantitative, or mixed methods), the demographics of participants, and the education level of the participants. In this review, the author synthesizes the findings of recent research and provides direction for future research on URM groups in STEM education.

Results

Possible Influences in STEM

In the metasynthesis analyses, 35 articles were found that related to possible influences impacting URM groups in STEM. The majority of these articles focused on SOC's undergraduate STEM experiences. Though some studies focused on intersecting identities, such as Black women, many articles analyzed the overall experience SOC. When reviewing the articles, five main

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possible influences emerged that challenge SOC's success in STEM: (a) K-12 experiences and STEM exposure, (b) hostile academic environment, (c) stereotype threat, (d) educator relationships, and (e) peer support. These possible influences do not represent the complete list of factors, but are the themes represented within educational research studies. These categories emphasize the problematic areas impacting the underrepresentation of minoritized groups in STEM. The recent research focuses on either the challenges or successes in a SOC's pursuit of STEM. Table 1 contains the possible influences in a SOC's educational journey in STEM and how many articles contained data related to these influences. Some articles were included in multiple STEM influences.

Table 1
Possible Influences in STEM Articles

Possible Influences for SOC in STEM	**Number of Articles**
K-12 Experiences & STEM Exposure	7
Hostile Academic Environment	11
Stereotype Threat	10
Educator Relationships	9
Peer Support	7

K-12 Experiences & STEM Exposure

Although majority of the articles (29 of 35) in this review focused on retaining SOC at the undergraduate level, K-12 experiences can include possible influences that impact STEM recruitment. For example, racism and microaggressions from K-12 STEM teachers can discourage SOC's interest in pursuing STEM (King & Pringle, 2018; Shephard, 2020). Teachers can bring their racial biases into the classroom leading to discrimination of SOC. In Shephard's (2020) study, science teachers evaluated their SOC less favorably than their White students. Although there are many studies that analyze the negative impact of racism and microaggressions (Gershenson et al., 2016; Marrun et al., 2019; Suarez-Orozco et al., 2015), there are not many that focus specifically on the STEM classroom. These negative experiences can cause students to lose interest and motivation in STEM classes and ultimately deter them from wanting to pursue STEM (King & Pringle, 2018; Shephard, 2020). Along with negative experiences with teachers, students may also lack significant STEM exposure during their K-12 education.

Many SOC majoring in STEM struggle to keep up with their coursework due to unequal access to academic preparation (Stipanovic & Woo, 2017). Although this challenge is not exclusively for SOC, many URM students attend high schools in low-income school districts that have fewer resources than primarily White populated school districts (Stipanovic & Woo, 2017). This can include limited high-level courses and schools may have to restrict enrollment for Advanced Placement classes (Stipanovic & Woo, 2017). URM students from low-income school districts can be put at an immediate disadvantage when they enter college due to the lack of exposure to high level math and science courses. The more Advanced Placement classes an URM student has taken, the higher the likelihood of persisting in a STEM major (Gipson, 2016). This emphasizes the impact that K-12 has on the inequalities in the STEM pipeline. STEM enrichment programs are one strategy to provide SOC with engaging and meaningful STEM learning experiences (Alvarado & Muniz, 2018; King & Pringle, 2018). Exposure to STEM early in education can increase students enrollment in STEM AP classes and ultimately impact majoring in STEM (Alvarado & Muniz, 2018). These studies suggest, starting in early education settings, that there are many racial injustices in the current education system. The equity issues continue from the K-12 setting to the undergraduate level when a SOC decides to major in a STEM subject.

Hostile Academic Environment

SOC have described the college STEM education setting as a hostile racialized environment (Jones, 2019; Leath & Chavous, 2018; Ortiz et al., 2019; Winkle-Wagner & McCoy, 2018). Racism and racial microaggressions are not single incidents but are embedded in college campuses (McGee, 2016). SOC experience microaggressions from their STEM professors, advisors, and peers (Lee et al., 2020). These racially charged incidents involve deficit thinking, dismissive comments, racist jokes, and racial slurs (Lee et al., 2020). The discrimination not only creates an unhealthy learning environment, but is negatively associated with math/science self-efficacy (Hall et al., 2017) and retention in STEM (Lee et al., 2020; Park et al., 2019). The hostile STEM environment leaves students feeling lonely and devalued (Green et al., 2018; Lee et al., 2020). The unwelcoming academic environment can cause students to question if they belong in STEM (Lee et al., 2020).

The exclusionary idea of who belongs in STEM starts as early as the introductory mathematics courses (Leyva et al., 2020). It is essential for STEM retention that SOC have positive experiences in their entry level classes (Stokes et al., 2015). Another strategy to increase the number of SOC in STEM departments is to create a more inclusive curriculum. The more inclusive the STEM curriculum, the greater the diversity of the student composition (Garibay & Vincent, 2018). For example, Garibay and Vincent (2018) analyzed the impact of an inclusive curriculum on the enrollment of SOC in environmental science. Inclusive curriculum included curriculum that focused on environmental justice and community engagement. They found a statistically significant connection between inclusive curriculum and racially diverse student enrollment. Curricular components need to be critically analyzed because they imply what and who is valued in their education (Garibay & Vincent, 2018). In order to create a diverse and welcoming educational experience, the racism ingrained in the STEM environment needs to be deeply examined to support SOC in their pursuit of STEM.

Stereotype Threat

The negative STEM environment can involve stereotyping and racial stigmatization from classmates and professors (Leath & Chavous, 2018; Leyva et al., 2020; McGee, 2016). Due to the current lack of adequate representation of POC in STEM fields, many SOC experience stereotype threat relating to their ability to be successful in STEM (Ben-Zeev et al., 2017; McGee, 2018). Stereotype threat is defined as “being at risk of confirming, as self-characteristic, a negative stereotype about one’s group” (Steele & Aronson, 1995, p. 797). Steele and Aronson (1995) researched the impact of stereotype vulnerability on standardized assessments. The researchers found that Black participants were more vulnerable to negative stereotypes leading to self-doubt

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and lower test scores. Although this experiment focused specifically on standardized assessment scores, the current underrepresentation of POC in STEM fields can likely instill the same self-doubt. Currently, 69% of STEM jobs are filled by White individuals, while only 9% are Black and 7% Latinx (Funk & Parker, 2018). The implications of Steele and Aronson's (1995) work in the STEM setting is that students may doubt their success in STEM classes because of the unconscious perception of STEM being a primarily White dominated field.

The desire to challenge stereotypes and prove themselves capable can put a lot of pressure on students, negatively impacting their mental and physical health (McGee, 2018). Students can feel emotionally exhausted from fighting stereotype threat. This is called racial battle fatigue (McGee, 2016, 2018). Many SOC drop their STEM major due to the anxiety and pressure associated with stereotype threat (McGee, 2018). Similarly, students can experience imposter syndrome, which is the belief that they do not belong in STEM. This can cause students to doubt their own ability and constantly question themselves (Collins, et al., 2020). Stereotype threat and imposter syndrome can drastically impact the likelihood of success in STEM subjects.

Educator Relationships

Educator support and relationship-building is an important component to SOC's success in STEM (Green et al., 2018). In the beginning of undergraduate study, it can be challenging to build connections with professors due to the large-enrollment in entry level classes (Rainey et al., 2019). For SOC who are able to interact with faculty, many describe a strained or non-existent relationships with their professors (Lancaster & Xu, 2017). Other students experienced negative interactions where their professors invalidate their academic ability (Burrell et al., 2015; Fries-Britt & White-Lewis, 2020), view them through a deficit lens (Green et al., 2018), and try to weed them out of STEM (McCoy et al., 2017). Although SOC describe the importance of faculty support, many students either struggle with building relationships or have negative interactions that discourage these connections. Existing research has also analyzed the point of view of professors. McCoy et al. (2015) found that professors use colorblind terminology to describe their SOC and tend to highlight their SOC's lack of commitment and preparation. Race neutral language reinforces racial biases and can illuminate why it is challenging for STEM professors to build connections with SOC.

SOC, particularly Black male students, desire meaningful and sincere relationships with their professors (Fries-Britt & White-Lewis, 2020). Positive faculty relationships can involve professors encouraging and mentoring SOC (Gasman et al., 2017; Green et al., 2018; Lancaster & Xu, 2017). Mentorships can include an informal relationship (Lancaster & Xu, 2017) or a structured research partnership (Gasman et al., 2017). Making connections with professors allows students to engage with someone in the field about their STEM barriers and interests. SOC feel assurance in their decision to major in STEM when they have positive interactions with their STEM professors (Nguyen et al., 2021; Rainey et al., 2019). If students do not feel supported by their faculty, they may seek out peer support groups to help them navigate their STEM experience.

Peer Support

SOC may look for support from their peers to overcome hostile STEM environments. However, students can have trouble building connections with their White classmates when there are not many other SOC in their major (Green et al., 2018; Jones, 2019). This feeling of isolation and lack of community leaves SOC less satisfied with their academics than White students (Leath & Chavous, 2018). Students who do not have access to support groups can feel unsupported in their STEM journey.

Peer support groups can include student generated groups, organization on campus, or a summer bridge program (Ortiz et al., 2019; White et al., 2018). Particularly for Black students, the most beneficial support groups are Black student organizations related to a student's STEM major (Lancaster & Xu, 2017). Peer support groups provide advice, study groups, and shared experiences (Burell et al., 2015). This communal climate can help lift students up and increase confidence in their own abilities (Nguyen et al., 2021). There is a positive association between a student being surrounded by a diverse group of friends and their math/science self-efficacy (Hall et al., 2017). STEM degree programs that have a higher average of enrolled SOC were significantly more likely to have an increase in enrollment of SOC in future years (Garibay & Vincent, 2018). Diversity at the university, and within a major, matters to how SOC experience inclusion (Winkle-Wagner &McCoy, 2018). The isolation that SOC can feel in a White dominated STEM environment and the benefits of peer support groups are important resources needed in undergraduate STEM programs (Lancaster & Xu, 2017).

This metasynthesis review analyzes the current barriers in STEM education that are impacting SOC's pursuit of a STEM profession. Some articles focus on the racialized barriers existing in education, while others emphasize the needs and wants of SOC. The racism in the K-12 setting can be a detriment for students' interest in STEM, but there is a lack of research in this area. It is hard to know specifically when the possible influences in K-12 occurs, or whether it is a collective set of events that deters a student from STEM. SOC also have additional challenges once they reach the undergraduate level. There are both internal and external struggles for SOC in their STEM journey. Internally students struggle with stereotype threat, imposter syndrome, and a sense of belonging. Externally students struggle with structural racism in STEM that they see in the academic environment, with their professors, and peers. The STEM synthesis describes the possible influences and racialized barriers across multiple areas of education that impact the underrepresentation of SOC in STEM. STEM education cannot be deemed successful and equitable "if that education is not effective for those students who have been historically marginalized and excluded from the community of scientists, mathematicians, and engineers" (Basile & Murray, 2015, p. 261).

Possible Influences in Teaching

According to the National Center for Education Statistics (2018), in the 2015-2016 school year, 80% of educators consisted of White teachers, while only 9% identified as Latinx and 7% Black. This racial breakdown is not representative of the diverse student population in the public school system (National Center for Education Statistics, 2020). The underrepresentation of Teachers of Color (TOC) is one component of the structural racism experienced by SOC throughout their educational journey. This metasynthesis review found 21 articles on the possible influences of URM groups in education, primarily focusing on the experiences of preservice TOC (PTOC). When reviewing the articles on possible influences in education, three themes emerged as racial barriers in a SOC's pursuit of education: (a) K-12 experiences, (b) lack of diversity in teaching, and (c) racism in teacher preparation programs. These categories emphasize the areas in education impacting the underrepresentation of minoritized groups in teaching. Table 2 contains the possible

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influences in education and how many articles contained data related to these influences. Some articles were included in multiple STEM influences.

Table 2
Possible Influences in Education Articles

Possible Influence for SOC in Education	**Number of Articles**
K-12 Experiences	6
Lack of Diversity in Teaching	4
Teacher Preparation Programs	13

K-12 Experiences

Negative K-12 experiences can either discourage SOC from pursuing teaching (Goings & Bianco, 2016; Marrun et al., 2019) or drive SOC to be the teacher they never had themselves (Brown, 2018; Plachowski, 2019). Leech et al. (2019) found that high school SOC are significantly less interested in teaching than their White classmates. They also rated their learning experience lower than White participants. Adverse learning conditions can involve microaggressions and other forms of racism from teachers and classmates (Goings & Bianco, 2016; Marrun et al., 2019). These possible influences in K-12 schooling can deter SOC from wanting to be in a work environment where they have experienced trauma and oppression.

Conversely, other SOC used their negative experiences as a motivator to become a teacher and be the representation that was lacking in their education. SOC described feeling dismissed by their K-12 teachers (Brown, 2018), experiencing microaggressions, and deficit expectations (Bryson, 2017; Goings & Bianco, 2016). These possible influences can shape a SOC's teaching philosophy and pedagogy by focusing their teaching on changing the system (Bryson, 2017). These SOC are committed to being teachers who recognize and address issues with race and become an advocate for their future students (Brown, 2018). The social justice pedagogical focus not only allows SOC to have a race congruent teacher, but have someone who supports and advocates for them in the classroom.

While the majority of the research focuses on negative experiences in K-12, positive experiences can also have a large impact on a SOC's interest in pursuing teaching (Goings & Bianco, 2016; Plachowski, 2019). Though the SOC in Plachowski's (2019) study still had twice as many negative experiences as positive ones, their positive experiences and personal resilience pushed them to become educators. SOC described the importance of having a teacher who truly cares about them and has high expectations. These meaningful teacher-student interactions not only impact a SOC's experience in education, but can also impact the representation of marginalized groups in teaching. The research on K-12 experiences brings to light the resilience SOC must possess in order to become educators and possibly re-enter the classroom environment where they experienced trauma (Plachowski, 2019). These are racial obstacles that White students, White preservice teachers, and White teachers do not have to overcome in order to enter the profession.

Lack of Diversity in Teaching

Another reason for SOC's disinterest in teaching is the lack of racial representation in schools. Marrun et al. (2019) interviewed college SOC to learn why they are not interested in pursuing teaching. The participants said they never considered teaching because they did not have a role model who looked like them in a teaching position at their school. Students used the phrase "Whiteness in education" to describe the lack of diversity in the teaching profession and the struggle to build connections with their White teachers (Marrun et al., 2019). If SOC do not have a teacher that looks like them, it can be hard to see teaching as a future profession (Gist et al., 2018; Marrun & Clark, 2020). SOC also described the fear of challenging work conditions in K-12 schools because of the low representation of other TOC (Bergey et al., 2019). The underrepresentation of TOC could make education an unwelcoming work environment.

Increasing the number of TOC provides SOC with a role model in the education system. Having a role model in a teaching position allows students to see an individual with a similar background and culture who have succeeded in education. Many preservice Teachers of Color (PTOC) feel pushed to teach in order to build connections with their future SOC (Caldas, 2018; Marrun & Clark, 2020). Their goal is to disrupt racial stereotypes and to be an ally for students (Gist et al., 2018). Having positive role models and racial representation in teaching can have an instrumental impact on SOC's success in school and their future aspirations.

Racism in Teacher Preparation Programs

Teacher preparation programs are intended to support preservice teachers in their journey to become an educator. Unfortunately, many SOC have negative experiences in their teacher preparation programs and field experience that can deter them from pursuing teaching. Since the majority of teachers are White, it is not surprising that the demographic of preservice teachers is also primarily White. Due to the lack of racial representation in teacher preparation programs, SOC can feel isolated and disconnected from their peers (Amos, 2016; Cheruvu et al., 2015; Gist, 2017). This is particularly important when thinking about a teacher preparation program as a teacher's first peer network system. Other negative experiences with teacher preparation programs include SOC feeling silenced and devalued, a hostile academic environment, and a lack of faculty support (Bell & Busey, 2021; Black & Cook, 2018; Cheruvu et al., 2015). The lack of support from their peers, faculty, and environment can make it challenging academically.

It is important for teacher preparation programs to realize that SOC have unique needs but also strengths that should be utilized (Amos, 2016; Caldas, 2018; House-Niamke & Sato, 2019; Kondo & Bracho, 2019; Morales, 2018). When PTOC experience exclusion from curriculum, they may perceive that their background is undervalued compared to their White classmates. Curriculum in teacher preparation programs needs to promote inclusion so that all students feel represented. SOC described positive experiences of representation in programs that cultivate social justice and incorporate diverse perspectives (Brown, 2018; Gist, 2017; Pham, 2018). Inclusion and valuing the experiences of SOC is important to help students not only feel part of the curriculum but part of teacher education.

PTOC can also have negative field experiences that involve racism and a hostile teaching environment (Bell & Busey, 2021; Rodriguez-Mojica et al., 2020). Students may experience microaggressions during student teaching with their cooperating teacher. Students described incidents related to racially insensitive comments about their hair and their language (Bell &

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Busey, 2021). Others felt invisible, stereotyped and uncomfortable with the teacher who was supposed to be their mentor (Rodriguez-Mojica et al., 2020). This negative environment can make it difficult for students to immerse themselves in what could be their future profession. Additionally, PTOC described being unable to include social justice principles in their teaching due to the opinions of their cooperating teacher (Rodriguez-Mojica et al., 2020). Students are unable to get the full teaching experience due to being silenced by the current teaching community. These negative field experiences can deter a student from graduating with a teaching degree and becoming a teacher.

The procedure to get a teaching license can be a demanding process and may deter future educators (Bergey et al., 2019). Many states require preservice teachers to pass a standardized assessment such as the Praxis or Educative Teacher Performance Assessment (edTPA) in order to receive their teaching license. These standardized requirements disproportionately affect SOC (Ingersoll et al., 2019; Petchauer et al., 2018; Williams et al., 2019). Candidates who are student teaching in urban and rural schools, on average, score significantly lower on edTPA than candidates in other schools (Williams et al., 2019). Scorers' implicit biases have also been discovered when analyzing edTPA passing rates for diverse teacher candidates. Researchers have found that Black candidates have statistically lower pass rates than White candidates (Petchauer et al., 2018; Williams et al., 2019). These biases can occur during the review of the videoed lesson when the scorers are able to see and hear the teacher. Although the scorers were trained to not discriminate during their analysis, bias remains a problem.

The adoption of standardized tests such as edTPA has been seen as the adoption of a "color-blind policy" that ignores all historical inequities and attempts to minimize racism by creating a standardized model (Tuck & Gorlewski, 2016). These teaching license requirements further the gap of inequities in schooling because they ignore the institutional racism in education and include racial biases. Instead of creating equity through standardization, many teaching license assessments further the inequalities in education and maintain racial hierarchies.

There are a variety of possible influences throughout schooling that can deter a SOC from pursuing education. These experiences occur throughout the education pipeline including K-12 education, teacher preparation programs, field experience, and the standardized licensure process. These barriers display the structural racism throughout the education system that impacts the underrepresentation of minoritized groups in teaching.

Discussion

When the researcher conducted this metasynthesis analysis of recent STEM and education articles, two articles emerged that fit the inclusion criteria focusing on STEM education (Mensah & Jackson, 2018; Morettini, 2017). In Morettini's (2017) research, she analyzed the impact of a SOC's race on their choice to pursue STEM education. Along with their decision to teach in a school that has a high percentage of SOC. Due to their own racialized experiences in education, the participants in this study wanted to become teachers to be an advocate and a role model for SOC. Although this research focused on those pursuing STEM education, the emphasis was on the desire to become a teacher more than the specifics of teaching STEM.

Mensah and Jackson (2018) analyzed the experience of PTOC in a science methods course. In the course, students learned about traditional science as White property and how to give ownership to their SOC in the science classroom. This inclusive curriculum used a multicultural interdisciplinary approach to teach science. Students were able to apply their experiences to the learning process and their future classroom. The goal of the class was to help PTOC learn how to best support and engage their SOC in the science classroom. The methods course also allowed PTOC to see themselves as belonging in the field and affirmed their desire to become science teachers. This study encourages teacher preparation programs to create a welcoming environment that allows PTOC to feel included in their program. However, due to the lack of research on the intersectionality of STEM and education, more research needs to be conducted about ways to recruit SOC in K-12 education and retain PTOC in undergraduate.

The current teaching population consists of primarily White educators who are responsible for educating a diverse group of students. Diversifying STEM education is important because of the many benefits for SOC being represented in the STEM teaching population (Gershenson et al., 2016; Jacoby-Senghor et al., 2016). Primarily, research has focused on the racialized barriers to enter either STEM or education, this research brings those barriers into view through one analysis that illuminates the intersectionality of the challenges to pursuing STEM education.

Limitations

The goal of this research was to analyze recent research to see possible influences in STEM education. This research generalizes the experiences of SOC and does not consider the intersectionality of the individuals. As research continues, it is important to focus on the intersectionality of identities. One form of intersectionality that requires additional research is the experience of Women of Color, since women and POC are underrepresented in STEM (National Science Foundation, 2019). It is important to understand that not all POC have the same experiences and racialized barriers when moving forward in the best ways to support SOC pursuing STEM education. The goal of this analysis was to be a starting point for future research.

Overview of Findings

The previous articles review the possible influences impacting the underrepresentation of minoritized groups in STEM professions, teaching fields, and more specifically STEM teaching fields. Possible influences can occur in K-12 schooling that impact a SOC’s pursuit of STEM including racism, microaggressions, and a lack of adequate exposure to STEM. For those majoring in STEM, the racialized experiences continue at the college level including a non-inclusive and hostile academic environment. Students also experience challenges with stereotype threat, building relationships with faculty, and finding a peer support group. These added obstacles lead to a racially disproportionate number of SOC graduating in STEM and entering a STEM profession. In order to improve the racial representation in STEM professions, the structural racism in STEM education needs to be addressed.

There are also racial barriers for SOC interested in teaching. Teaching can be seen as an unattractive profession for SOC because of the racism they experienced in K-12 settings and the lack of diversity in the field. Conversely, these negative experiences and the lack of diversity in teaching can be a motivator for PTOC to enter the classroom. Those who enter teacher preparation programs face additional obstacles during their undergraduate education. The low retention of PTOCs may be influenced by poor experiences in teacher preparation programs and unfair teaching license requirements. Previous research has studied the racial injustices at the K-12 and undergraduate level that make it challenging for SOC to become teachers. In order to diversify the

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teaching profession, there needs to be more support systems in place for SOC who are interested in becoming teachers.

The possible influences that impact a SOC's pursuit of STEM or education occur during K-12 and undergraduate school. The common theme in this study is the racism in the education system impacting the underrepresentation of minoritized groups in both STEM and education. It is critical to have racial representation in the teaching profession, particularly in the STEM teaching population. Diversity among STEM teachers serves as "a powerful role in creating a future in STEM fields where People of Color feel less alienated" (Basile & Murray, 2015, p. 264). Increasing the number of TOC can impact students' STEM experience and potentially lead to more URM groups in STEM, education, and STEM education.

Directions for Future Research

Future research needs to continue to study the institutional racism taking place in the K-12 and undergraduate settings. Current research has found a disproportionate number of POC entering STEM and education fields due to possible influences of racism in education. When analyzing the explanations for the lack of POC in these fields, the findings are similar. There is a deeper racism within the culture and climate of the school system that needs to be addressed in order to give all students equitable education. SOC have negative racial barriers in K-12 settings that continue through college. This problem needs to be viewed through a critical race lens in order to understand the deeper issues and start investigating how to invoke serious change.

This metasynthesis analysis grouped the experiences of Black and Latinx populations as underrepresented minoritized groups. Future research needs to focus on the experiences of specific groups and the intersectionality of individuals in order to see the differences in experiences in STEM education. Although this research gave a broad scope of the experiences of POC, future research should focus on specific demographics.

Future research should begin analyze the intersection of barriers when SOC pursue STEM education. The majority of recent research has focused on either STEM or education as separate areas of study and it is important to understand the connection between the two. There may be additional challenges that URM groups experience when pursuing STEM education that previous research has not analyzed. The focus should continue to be on the perspective of minoritized groups in STEM education. Previous research has brought to light the institutional racism taking place in K-12 and undergraduate settings, therefore, future research needs to look at programs and implementation structures to help correct the current inequalities in the STEM education pipeline. This metasynthesis review should be analyzed by K-12 schools, teacher preparation programs, and STEM departments to better understand the challenges that SOC experience during their K-12 and undergraduate periods of entering STEM education.

Another area of study includes analyzing the racialized barriers of TOC. Education struggles with the retention of all teachers; however, TOC are leaving education at a faster rate than their White colleagues (Carver-Thomas & Darling-Hammond, 2019). Almost two-thirds of TOC work in high-poverty, high SOC, urban communities (Ingersoll et al., 2019). The turnover rate of teachers working in schools with primarily SOC is 70% greater than schools with majority White students (Carver-Thomas & Darling-Hammond, 2019). These can be challenging environments to teach in due to the lack of resources, poor working conditions, and large class sizes. It is essential that future research continues to find ways to provide support systems for TOC in order to resolve the high turnover rates.

Policy Implications

The policy recommendations that emerge from the literature on SOC in STEM education include recruiting more racially diverse STEM teachers, retaining TOC, and requiring anti-racist pedagogy training for all teachers. Grow your own programs are one option as a pathway to increase diversity in the teaching profession from within communities (Morales, 2018). There are also other policies and programs in place to diversify the teaching population, but the current strategies are not keeping up with the growth in the number of SOC (Ingersoll et al., 2019). Therefore, practices, programs, and policies to recruit and retain STEM TOC needs to be intensified if schools want to make progress towards racially representing the student population.

It is also recommended to prepare all current and future teachers to teach using anti-racist pedagogy in order to begin addressing the institutional racism taking place in schools (Pierce, 2016). White teachers need to be conscious of the racism SOC experience in their educational journey and address the White privilege in the current system. School districts and teacher preparation programs should provide additional and continuous diversity and critical race theory training moving away from the color-blindness ideologies of the past in order to correct the oppression. There are many components to the institutional racism in the STEM education pipeline. It is going to take a team effort involving policymakers, researchers, and educators to create a STEM education system that is equitable for all students. If we only focus on the underrepresentation of POC in STEM education without thinking about the institutional system that causes this low representation, then we are not truly grasping the oppression in the education system.

References

Alvarado, S. E., & Muniz, P. (2018). Racial and ethnic heterogeneity in the effect of MESA on AP STEM coursework and college STEM major aspirations. *Research in Higher Education, 59*(7), 933-957. https://doi.org/10.1007/s11162-018-9493-3

Amos, Y. T. (2016). Voices of teacher candidates of Color on White race evasion: ‘I worried about my safety!”. *International Journal of Qualitative Studies in Education, 29*(8), 1002-1015. https://doi.org/10.1080/09518398.2016.1174900

Basile, V., & Murray, K. (2015). Uncovering the need for diversity among K-12 STEM educators. *Teacher Education and Practice, 28*(2), 255-268.

Bell, P., & Busey, C. L. (2021). The racial grammar of teacher education: Critical race theory counterstories of Black and Latina first-generation preservice teachers. *Teacher Education Quarterly, 48*(1), 33-56.

Ben-Zeev, A., Paluy, Y., Milless, K. L., Goldstein, E. J., Wallace, L., Marquez-Magana, L., Bibbins-Domingo, K., & Estrada, M. (2017). ‘Speaking truth’ protects underrepresented minorities’ intellectual performance and safety in STEM. *Education Sciences 65*(7), 1-12. doi:10.3390/educsci7020065

Bergey, B. W., Ranellucci, J., & Kaplan, A. (2019). The conceptualization of costs and barriers of a teaching career among Latino preservice teachers. *Contemporary Educational Psychology, 59*(1), 1-16. https://doi.org/10.1016/j.cedpsych.2019.101794

https://ir.library.illinoisstate.edu/jste/vol57/iss1/8
DOI: 10.30707/JSTE57.1.1664998343.93078

Black, T. R., & Cook, E. J. B. (2018). Black on Black education 2.0: Critical race perspectives on personally engaged pedagogy for/by Black pre-service teachers, *Teaching Education, 29*(4), 343-356. https://doi.org/10.1080/10476210.2018.1514000

Brown, K. D. (2014). Teaching in color: A critical race theory in education analysis of the literature on preservice teachers of color and teacher education in the US. *Race Ethnicity and Education, 17*(2), 326-345. https://doi.org/10.1080/13613324.2013.832921

Brown, K. D. (2018). Race as a durable and shifting idea: How Black millennial preservice teachers understand race, racism, and teaching. *Peabody Journal of Education, 93*(1), 106-120. https://doi.org/10.1080/0161956X.2017.1403183

Bryson, B. S. (2017). 'They were constantly on the losing side of things': The pedagogical power of an African-American teacher candidate bearing witness in teacher education. *Race Ethnicity and Education, 20*(4), 527-545. http://doi.org/10.1080/13613324.2017.1294566

Burciaga, R., & Kohli, R. (2018). Disrupting whitestream measures of quality teaching: The community cultural wealth of Teachers of Color. *Multicultural Perspectives, 20*(1), 5-12. https://doi.org/10.1080/15210960.2017.1400915

Burrell, J. O., Fleming, L., & Fredericks, A. C. (2015). Domestic and international student matters: The college experiences of Black males majoring in engineering at an HBCU. *The Journal of Negro Education, 84*(1), 40-55. https://doi.org/10.7709/jnegroeducation.84.1.0040

Caldas, B. (2018). "More meaningful to do it than just reading it:" Rehearsing praxis among Mexican-American/Latinx pre-service teachers. *Teaching Education, 29*(4), 370-382. https://doi.org/10.1080/10476210.2018.1510482

Carver-Thomas, D., & Darling-Hammond, L., (2019). The trouble with teacher turnover: How teacher attrition affects students and schools. *Education Policy Analysis Archives 27*(36), 1-28. https://doi.org/10.14507/epaa.27.3699

Cheng, D. A. (2019). Teacher racial composition and exclusions rates among black of African American students. *Education and Urban Society, 51*(6), 822-847. https://doi.org/10.1177/0013124517748724

Cheruvu, R., Souto-Manning, M., Lencl, T., & Chin-Calubaquib, M. (2015). Race, isolation, and exclusion: What early childhood teacher educators need to know about the experiences of pre-service Teachers of Color. *Urban Review, 47*(2), 237-265. https://doi.org/10.1007/s11256-014-0291-8

Collins, K. H., Price, E. F., Hanson, L., & Neaves, D. (2020). Consequences of stereotype threat and imposter syndrome: The personal journey from STEM-practitioner to STEM-educator for four Women of Color. *Taboo, 19*(4), 161-180.

Fox, L. (2016). Seeing potential: The effect of student-teacher demographic congruence on teacher expectations and recommendations. *AERA Open 2*(1), 1-17. https://doi.org/10.1177/2332858415623758

Fries-Britt, S., & White-Lewis, D. (2020). In pursuit of meaningful relationships: How Black males perceive faculty interactions in STEM. *The Urban Review, 52*(3), 521-540. https://doi.org/10.1007/s11256-020-00559-x

Funk, C., & Parker, K. (2018). *Women and men in STEM often at odds over workplace equity.* Pew Research Center. https://www.pewsocialtrends.org/2018/01/09/diversity-in-the-stem-workforce-varies-widely-across-jobs/

Garibay, J. C., & Vincent, S. (2018). Racially inclusive climates within degree programs and increasing Students of Color enrollment: An examination of environmental/sustainability programs. *Journal of Diversity in Higher Education, 11*(2), 201-220. https://doi.org/10.1037/dhe0000030

Gasman, M., Nguyen, T., Conrad, C., Lundberg, T., Commodore, F., & Worthington, R. L. (2017). Black male success in STEM: A case study of Morehouse College. *Journal of Diversity in Higher Education, 10*(2), 181-200. https://doi.org/10.1037/dhe0000013

Gershenson, S., Holt, S. B., & Papageorge, N. W. (2016). Who believes in me? The effect of student-teacher demographic match on teacher expectations. *Economics of Education Review, 52*(1), 209-224. https://doi.org/10.1016/j.econedurev.2016.03.002

Gipson, J. (2016). Predicting academic success for Students of Color within STEM majors *Journal for Multicultural Education, 10*(2), 124-134. https://doi.org/10.1108/JME-12-2015-0044

Gist, C. D. (2017). Voices of aspiring Teachers of Color: Unraveling the double bind in teacher education. Urban Education, 52(8), 927-956. https://doi.org/10.1177/0042085915623339

Gist, C. D., White, T., & Bianco, M. (2018). Pushed to teach: Pedagogies and policies for a black women educator pipeline. *Education and Urban Society, 50*(1), 56-86. https://doi.org/10.1177/0013124517727584

Goings, R. B., & Bianco, M. (2016). It's hard to be what you don't see: An exploration of Black male high school students' perspectives on becoming teachers. *Urban Review, 48*(1), 628-646. https://doi.org/10.1007/s11256-016-0371-z

Green, A. M., Brand, B. R., & Glasson, G. E. (2018). Applying actor-network theory to identify factors contributing to nonpersistence of African American students in STEM majors. *Science Education, 103*(2), 241-263. https://doi.org/10.1002/sce.21487

Grissom, J. A., & Redding, C. (2016). Discretion and disproportionality: Explaining the underrepresentation of high-achieving Students of Color in gifted programs. *AERA Open, 2*(1), 1-25. https://doi.org/10.1177/2332858415622175

Hall, A. R., Nishina, A., & Lewis, J. A. (2017). Discrimination, friendship diversity, and STEM-related outcomes for incoming ethnic minority college students. *Journal of Vocational Behavior, 103*(1), 76-87. https://doi.org/10.1016/j.jvb.2017.08.010

House-Niamke, S., & Sato, T. (2019). Resistance to systemic oppression by Students of Color in a diversity course for preservice teachers. Educational Studies, 55(2), 160-170. https://doi.org/10.1080/00131946.2018.1501567

Ingersoll, R., May, H., & Collins, G. (2019). Recruitment, employment, retention and the minority teacher shortage. *Education Policy Analysis Archives, 27*(37), 1-38. https://doi.org/10.14507/epaa.27.3714

Jacoby-Senghor, D. S., Sinclair, S., & Shelton, J. N. (2016). A lesson in bias: The relationship between implicit racial bias and performance in pedagogical contexts. *Journal of Experimental Social Psychology, 63*(1), 50-55. https://doi.org/10.1016/j.jesp.2015.10.010

Jones, T. C. (2019). Creating a world for me: Students of Color navigating STEM identity. *The Journal of Negro Education, 88*(3), 359-378. https://doi.org/10.7709/jnegroeducation.88.3.0358

King, N. S., & Pringle, R. M. (2018). Black girls speak STEM: Counterstories of informal and formal learning experiences. *Journal of Research in Science Teaching, 56*(5), 539-569. https://doi.org/10.1002/tea.21513

Kolb, S. M. (2012). Grounded theory and the constant comparative method: Valid research strategies for educators. *Journal of Emerging Trends in Educational Research and Policy Studies, 3*(1), 83-86.

Kondo, C. S., & Bracho, C. A. (2019). Friendly resistance: Narratives from a preservice Teacher of Color navigating diversity courses. *Educational Studies, 55*(2), 139-159. https://doi.org/10.1080/00131946.2018.1500913

Ladson-Billings, G. (1998). Just what is critical race theory and what's it doing in a nice field like education? *International Journal of Qualitative Studies in Education, 11*(1), 7-24. https://doi.org/10.1080/095183998236863

Lancaster, C., & Xu, Y. J. (2017). Challenges and supports for African American STEM student persistence: A case study at a racially diverse four-year institution. *The Journal of Negro Education, 86*(2), 176-189. https://doi.org/10.7709/jnegroeducation.86.2.0176

Leath, S., & Chavous, T. (2018). Black women's experiences of campus racial climate and stigma at predominantly White institutions: Insights from a comparative and within-group approach for STEM and non-STEM majors. *The Journal of Negro Education, 87*(2), 125-139. https://doi.org/10.7709/jnegroeducation.87.2.0125

Lee, M. J., Collins, J. D., Harwood, S. A., Mendenhall, R., & Huntt, M. B. (2020). "If you aren't White, Asian or Indian, you aren't an engineer": Racial microaggressions in STEM education. *International Journal of STEM Education, 7*(1), 1-16. https://doi.org/10.1186/s40594-020-00241-4

Leech, N. L., Haug, C. A., & Bianco, M. (2019). Understanding urban high school Students of Color motivation to teach: Validating the FIT-choice scale. *Urban Education, 54*(7), 957-983. https://doi.org/10.1177%2F0042085915623338

Leyva, L. A., Quea, R., Weber, K., Batter, D., Lopez, D. (2020). Detailing racialized and gendered mechanisms of undergraduate precalculus and calculus classroom instruction. *International Journal of Research in Undergraduate Mathematics Education, 20*(1), 1-31. https://doi.org/10.1080/07370008.2020.1849218

Marrun, N. A., & Clark, C. (2020). The rise of the GYO-TOCs as pop-ups: Lessons in racial resistance from the abriendo caminos/opening pathways for Students of Color into the teaching profession: Giving back to community through teaching project. *Taboo, 19*(4), 65-93.

Marrun, N. A., Plachowski, T. J., & Clark, C. (2019). A critical race theory analysis of the 'demographic diversity' gap in schools: College students of color speak their truth. *Race Ethnicity and Education, 22*(6), 836-857. https://doi.org/10.1080/13613324.2019.1579181

Mays, N., Pope, C., & Popay, J. (2005). Systematically reviewing qualitative and quantitative evidence to inform management and policy-making in the health field. *Journal of Health Services Research & Policy, 10*(1), 6-20. http://doi.org/10.1258/1355819054308576

McCoy, D. L., Winkle-Wagner, R., & Luedke, C. L. (2015). Colorblind mentoring? Exploring White faculty mentoring of students of color. *Journal of Diversity in Higher Education, 8*(4), 225-242. http://dx.doi.org/10.1037/a0038676

McCoy, D. L., Luedke, C. L., & Winkle-Wagner, R. (2017). Encouraged or weeded out: Perspectives of Students of Color in the STEM disciplines on faculty interactions. *Journal of College Student Development, 58*(5), 657-673. https://doi.org/10.1353/csd.2017.0052

McGee, E. O. (2016). Devalued Black and Latino racial identities: A by-product of STEM college culture? *American Educational Research Journal, 53*(6), 1626-1662. https://doi.org/10.3102/0002831216676572

McGee, E. (2018). "Black genius, Asian Fail": The detriment of stereotype life and stereotype threat in high-achieving Asian and Black STEM students. *AERA Open, 4*(4), 1-16. https://doi.org/10.1177/2332858418816658

Mensah, F. M., & Jackson, I. (2018). Whiteness as property in science education. *Teacher College Records, 120*(1), 1-38.

Morales, A. R. (2018). Within and beyond a grow-your-own-teacher program: Documenting the contextualized preparation and professional development experiences of critically conscious Latina teachers. *Teaching Education, 29*(4), 357-369. https://doi.org/10.1080/10476210.2018.1510483

Morettini, B. (2017). Challenging their conceptions of intellectualism: Exploring the relationship between race and the motivation to teach for STEM educators. *The Journal of Negro Education, 86*(2), 163-165. https://doi.org/10.7709/jnegroeducation.86.2.0163

National Center for Education Statistics. (2018). *Characteristics of Public School Teachers*. https://nces.ed.gov/programs/coe/indicator_clr.asp

National Center for Education Statistics. (2020). *Concentration of Public School Students Eligible for Free or Reduced-Price Lunch.* https://nces.ed.gov/programs/coe/indicator_clb.asp

National Science Foundation: Women minorities, and persons with disabilities in science and engineering (2019). *Special Report NSF 9-5 Employed scientists and engineers, by occupation, highest degree level, and sex: 2017*. https://ncses.nsf.gov/pubs/nsf19304/data

Nguyen, T. H., Gasman, M., Lockett, A. W., & Pena, V. (2021). Supporting Black women's pursuits in STEM. *Journal of Research in Science Teaching, 58*(6), 879-905. https://doi.org/10.1002/tea.21682

Ortiz, N. A., Morton, T. R., Miles, M. L., Roby, R. S. (2019). What about us? Exploring the challenges and sources of support influencing Black students' STEM identity development in postsecondary education. *The Journal of Negro Education, 88*(3), 311-326. https://doi.org/10.7709/jnegroeducation.88.3.0311

Park, J. J., Kim, Y. K., Salazar, C., & Hayes, S. (2019). Student-faculty interaction and discrimination from faculty in STEM: The link with retention. *Research in Higher Education, 61*(3), 330-356. https://doi.org/10.1007/s11162-019-09564-w

Petchauer, E., Bowe, A. G., & Wilson, J. (2018). Winter is coming: Forecasting the impact of edTPA on Black teachers and Teachers of Color. *Urban Review: Issues and Ideas in Public Education 50*(2), 323-343. https://doi.org/10.1007/s11256-018-0453-1

Pham, J. H. (2018). New programmatic possibilities: (Re)Positioning preservice Teachers of Color as experts in their own learning. *Teacher Education Quarterly, 45*(4), 51-71.

Pierce, A. J. (2016). Interest convergence: An alternative to White privilege models of anti-racist pedagogy and practice. *Teaching Philosophy, 39*(4), 507-530. https://doi.org/10.5840/teachphil201612260

Plachowski, T. J. (2019). Reflections of preservice Teachers of Color: Implications for the teacher demographic diversity gap. *Education Sciences, 144*(9), 1-19. https://doi.org/10.3390/educsci9020144

Rainey, K., Dancy, M., Mickelson, R., Stearns, E., & Moller, S. (2019). A descriptive study on race and gender differences in how instructional style and perceived professor care influence decisions to major in STEM. *International Journal of STEM Education, 6*(6), 1-13. https://doi.org/10.1186/s40594-019-0159-2

Rodriguez-Mojica, C., Rodela, K. C., & Ott, C. (2020). "I didn't wanna believe it was a race issue": Student teaching experiences of preservice Teachers of Color. *The Urban Review, 52*(1), 435-457. https://doi.org/10.1007/s11256-019-00546-x

Shephard, M. A. (2020). Effects of race/ethnicity, gender, and intonation on secondary science teachers' evaluation of spoken responses. *Urban Education, 55*(5), 730-752. https://doi.org/10.1177/0042085916660346

Sleeter, C. E. (2017). Critical race theory and whiteness of teacher education. *Urban Education, 52*(2), 155-169. https://doi.org/10.1177/0042085916668957

DOI: 10.30707/JSTE57.1.1664998343.93078

Solórzano, D. Ceja, M., & Yosso, T. (2000). Critical race theory, racial microaggression, and campus racial climate: The experiences of Black college students. *The Journal of Negro Education, 69*(1), 60-73. https://doi.org/ 0.2307/2696265

Steele, C. M., & Aronson, J. (1995). Stereotype threat and the intellectual test performance of African Americans. *Journal of Personality and Social Psychology, 69*(5), 797-811. https://doi.org/10.1037//0022-3514.69.5.797

Stipanovic, N., & Woo, H. (2017). Understanding African American students' experiences in STEM education: An ecological systems approach. *The Career Development Quarterly, 65*(3), 192-206. https://doi.org/10.1002/cdq.12092

Stokes, P. J., Levine, R., & Flessa, K. W. (2015). Choosing the geoscience major: Important factors, race/ethnicity, and gender. *Journal of Geoscience Education, 62*(3), 250-263. https://doi.org/10.5408/14-038.1

Suarez-Orozco, C., Casanova, S., Martin, M., Katsiaficas, D., Cuellar, V., Smith, N. A., & Dias, S. I. (2015). Toxic rain in class: Classroom interpersonal microaggressions. *Educational Researcher 44*(3), 151-160. https://doi.org/10.3102/0013189X15580314

Tuck, E., & Gorlewski, J. (2016). Racist Ordering, Settler Colonialism, and edTPA. *Educational Policy,30*(1), 197-217. https://doi.org/10.1177/0895904815616483

White, V. M., Alexander, J. H., Prince, D., & Verdell, A. (2018). The impact of student engagement, institutional environment, college preparation, and financial support on the persistence of underrepresented minority students in engineering at a predominately White institution: A perspective from students. *Journal of Higher Education Theory and Practice, 18*(2), 24-38. https://doi.org/10.33423/jhetp.v18i2.544

Williams, J. A., Hart, L. C., & Algozzine, B. (2019). Perception vs. reality: EdTPA perceptions and performance for teacher candidates of Color and White candidates. *Teaching and Teacher Education, 83*, 120-133. https://doi.org/10.1016/j.tate.2019.04.006

Winkle-Wagner, R., & McCoy, D. (2018). Feeling like an "alien" or "family"? Comparing students and faculty experiences of diversity in STEM disciplines at a PWI and an HBCU. *Race Ethnicity and Education, 21*(5), 593-606. https://doi.org/10.1080/13613324.2016.1248835

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Teaching Elementary Mathematics with Educational Robotics

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ABSTRACT

Current education reforms call for engaging students in learning science, technology, engineering, and mathematics (STEM) in an integrative way. This critical case study of one fourth grade teacher investigated the use of educational robots (ER) not only for teaching coding, but as an instructional support in teaching mathematical concepts. To support teachers in teaching coding in an integrative and logical manner, our team developed the Collective Argumentation Learning and Coding (CALC) approach. The CALC approach consists of three elements: choice of task, coding content, and teacher support for argumentation. After a cohort of elementary teachers completed a professional development course, we followed them into their classrooms to support and document implementation of the CALC approach. Data for this case consisted of video recordings of two lessons, a Pre-interview, and Post-interview after each lesson. Research questions included: How does an elementary teacher use the CALC approach (integrative STEM approach) to teach mathematics concepts with ER? What are the teacher's perspectives towards teaching mathematics with ER using an integrative STEM approach? Results from this critical case provide evidence that teachers can successfully integrate ER into the mathematics curriculum without losing coherence of mathematics topics and while remaining sensitive to students' needs.

Keywords: STEM Integration; Argumentation; Educational Robotics; Teacher Perspectives; Engineering Education; Coding

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The calls to integrate STEM (i.e., science, technology, engineering, and mathematics) education at the elementary level have become a national priority (National Science and Technology Council, 2013). Research has shown that elementary students are capable of learning mathematics and science concepts in technology and engineering contexts, and elementary classrooms provide a powerful environment for STEM implementation and learning (Baker & Galanti, 2017; English, 2017; Estapa & Tank, 2017). The Standards for Technological and Engineering Literacy (ITEEA, 2020) support the integrated nature of STEM and advance not only authentic connections across the individual STEM areas, but also learning of each individual STEM discipline.

Some engineering and technology educators have argued that elementary STEM education provides rich opportunities for Technology and Engineering Education to thrive (Daugherty et al., 2014). The study reported here grew from a collaboration among university faculty from Engineering, Technology and Engineering Education, Mathematics Education, and Science Education. The Educational Robotics (ER) activities were provided through a Technology and Engineering Education course for elementary teachers and the argumentation and mathematics instruction was guided by a faculty member in Mathematics Education.

STEM integration requires the inclusion of two or more STEM disciplines in a manner that supports students in making connections across disciplines while at the same time ensuring that students develop conceptual knowledge within each of the disciplines (Bybee, 2010). ER has been considered an effective tool not only for teaching coding itself but for developing interest in STEM-related activities and practices (Gomoll et al., 2016). Argumentation has been recognized as an essential goal in STEM fields of education due to its support for a student's ability to rely on evidence for verification and the impact on student learning when they are actively involved in collective argumentation.

Problem Statement

Some mathematics educators and researchers (e.g., Baker & Galanti, 2017; English, 2016; Shaughnessy, 2013) have expressed concern about the role of mathematics in integrated STEM instruction; they argue mathematics is reduced to supporting calculation and representation, which are less likely to produce positive learning outcomes or authentically engage students in mathematics. In other words, from a mathematics education perspective, STEM integration "must involve significant mathematics for students" (Shaughnessy, 2013, p. 234) and should play a key role in promoting conceptual understanding of mathematics.

There is limited empirical research about ER’s full potential as an instructional support in teaching mathematics content (Zhong & Xia, 2020). Although integrating ER and computer coding into mathematics instruction has been positively linked to students’ understanding of mathematics concepts (Fernandes et al., 2009), mathematical dispositions (Padayachee et al., 2015), and skills development, such as computational thinking (Leonard et al., 2016), use of ER alone may not enhance mathematical learning. We propose that the choice of task, the context of learning, and support from teachers play vital roles in integrating and reinforcing the interconnections between students’ mathematics learning and the use of ER (Conner et al., 2020).

In this study, we view argumentation as a bridge across disciplines in the teaching and learning of STEM (we consider computer coding to be a component of STEM). We examine the role of argumentation in teaching integrative mathematics lessons and explore the use of ER in teaching and learning mathematics concepts.

Literature Review

Argumentation

There are many benefits of incorporating argumentation in classroom discourse (Andriessen, 2006; Goos, 2004; Whitenack & Yackel, 2002). For instance, argumentation practices offer the means to focus students on the need for quality evidence, which helps to develop their deep level understanding of content (Nussbaum, 2008). Argumentation as a construct is complex and multifaceted; it may be interpreted in various ways based on different aspects of argumentation theory (van Eemeren et al., 1996). This study follows a dialectic perspective (Habermas, 1984; Toulmin, 1958/2003) toward argumentation, in which the goal of argumentation is reaching a mutually accepted conclusion about the truth of a claim. Krummheuer (1995) referred to argumentation that takes place in a social setting as *collective argumentation*. In this study, we adopted Conner et al.'s (2014) definition of collective argumentation as "any instance where students and teachers make a mathematical claim and provide evidence to support it" (p. 414).

In mathematics and science education literature, Toulmin's (1958/2003) model has been widely used to identify argument components and analyze argumentation practices (Chin & Osborne, 2010; Conner et al., 2014; Erduran et al., 2004; Jiménez-Aleixandre et al., 2000; Krummheuer, 1995, 2007; Osborne et al., 2004; Zhuang & Conner, 2018). An argument includes three core components: a *claim* (or hypothesis) that is based on *data* (or evidence) accompanied by a *warrant* (or reasoning) that relates the data to the claim (Krummheuer, 1995; Toulmin, 1958/2003). Following Conner (2008), our adaptation of Toulmin's diagrams (see Figure 1) includes the use of color and line style to record the contributor(s) of a component for a given argument and uses 'Teacher Support' to denote teachers' contributions and actions that prompt or respond to parts of arguments. Sometimes, parts of an argument may not be explicitly stated by the teacher or students but can be inferred from the context of the argument in the given classroom community; these implicit parts are labelled with a surrounding cloud.

Educational Robotics in Mathematics Teaching

A report (Seehorn et al., 2011) published by The Association for Computing Machinery (ACM) and the Computer Science Teachers Association (CSTA) outlined learning standards for K-12 computer science education and arranged these standards into levels for elementary, middle, and high school grades. This report recommends the integration of the foundational concepts of computer science (e.g., algorithmic thinking) into concepts that are currently taught in the elementary grade science, mathematics, and social studies curricula and explicitly stipulates that computer science concepts should be embedded in the middle school curriculum. Numerous studies (e.g., Grover & Pea, 2013; Lye & Koh, 2014) offered different strategies that would meet the ACM-CSTA recommendations for incorporating computer programming and other STEM studies into K-12 school activities. ER are often used to teach children how to program while they apply what they have learned in mathematics and science (Barker et al., 2014; Kazakoff et al., 2013; Liu et al., 2010). A review of the literature (e.g., Benitti, 2012; Karim et al., 2015; Mubin et al., 2013) provides evidence that teachers are hesitant to use ER to learn new concepts unless these concepts can be linked to a learning standard. Zhong and Xia (2020) investigated how ER has been incorporated into mathematics education and found in the few published studies, ER most often are linked with the learning of geometric and algebraic concepts.

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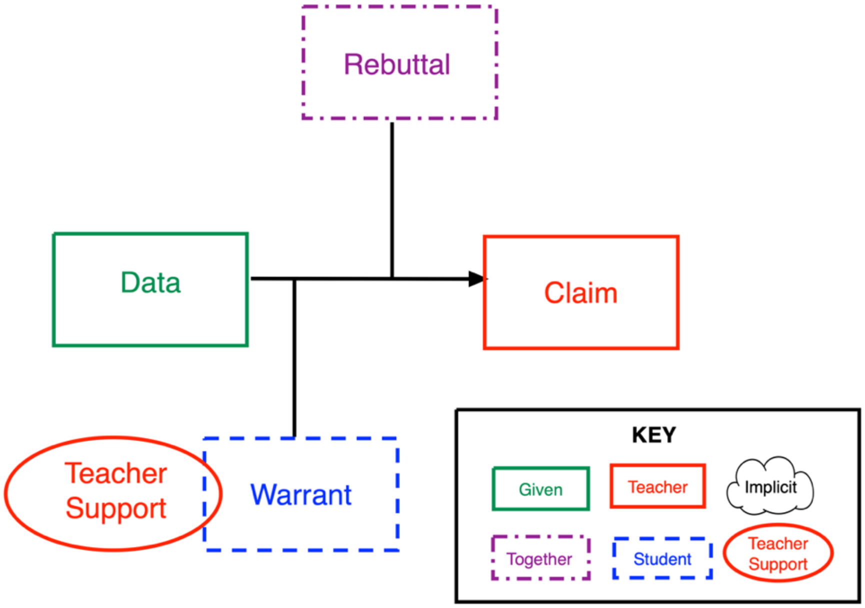

Figure 1. Components of an Expanded Toulmin's Diagram (adapted from Conner, 2008).

Teacher Perceptions of STEM Integration

Many teachers value integrating mathematics with other disciplines, but they also perceive barriers to the implementation of STEM integration (Conner et al., 2020; El-Deghaidy et al., 2017; English, 2016; Margot & Kettler, 2019). These barriers included lack of strategies to provide students opportunities to learn mathematics in integrated STEM contexts and support for teachers to incorporate engineering and technology into mathematics instruction. A literature search of studies that investigated teachers' perceptions of integrated STEM revealed mixed results. A limited number of studies focused specifically on mathematics teachers' perceptions. In their review of literature, Margot and Kettler (2019) found several factors that could impede or facilitate positive perceptions of integrated STEM: (a) years of teaching experience, (b) teacher age, (c) prior experience with STEM application and (d) school context (e.g., administrative flexibility for curricula structure, content support). The teacher's subject and the teacher's experience are other factors that predict teacher perception of integrated STEM (Al Salami et al., 2017; Shidiq & Faikhamta, 2020; Thibaut et al., 2018a, b, 2019). Teachers' perceptions of STEM integration in science and technology classrooms are more positive than their perceptions of STEM integration in mathematics classrooms; however, the relationship becomes more positive with professional development (Al Salami et al., 2017; Nadelson et al., 2013). The literature provides evidence that mathematics teachers regard STEM integration as an approach that allows students to apply mathematics in real-world situations, but recognize that STEM integration must address content standards (Thibaut et al., 2018a; Wang et al., 2011; Weber et al., 2013).

Findings from the limited research on elementary school teachers' perceptions of STEM and integrated STEM are mixed. Teachers commonly express positive views toward STEM but also express opinions that challenge the implementation of STEM integration (Lamberg & Trynadlowski, 2015; Park et al., 2016; Toma & Greca, 2018). Participants who attended an early childhood conference expressed a perspective that STEM, including STEAM, is a separate content area for students to learn and is not integrated content learning (Jamil et al., 2018). Park et al. (2017) reported that 2/3 of interviewed elementary teachers regarded STEM education as important. Although this literature is limited, studies show that professional development programs can positively influence elementary school teachers' perspectives (e.g., Jamil et al., 2018; Laksmiwatti et al., 2020; Nadelson et al., 2013; Park et al., 2017).

Conceptual Framework

The conceptual framework for this study was the Collective Argumentation Learning and Coding (CALC) approach and model (Conner et al., 2020; see Figure 2). The CALC approach is based on a dynamic, learner-centered integrative approach to STEM (Sanders, 2012; Sanders & Wells, 2010; Wells, 2013). Integrative STEM, as implemented in CALC, encourages synchronous versus asynchronous instruction of coding, mathematics, science, and argumentation, and the use of ER presents contextualized problem-solving experiences that give purpose and meaning to mathematics and science. Traditional approaches to learning content in elementary schools have often been siloed, and time periods have been defined in lesson plans for addressing disciplines separately. The CALC approach asserts that if argumentation is a collective practice in each STEM discipline individually, then argumentation can be a unifying construct for teachers in achieving integrative STEM. The CALC approach consists of three elements: choice of task, coding content, and teacher support for argumentation.

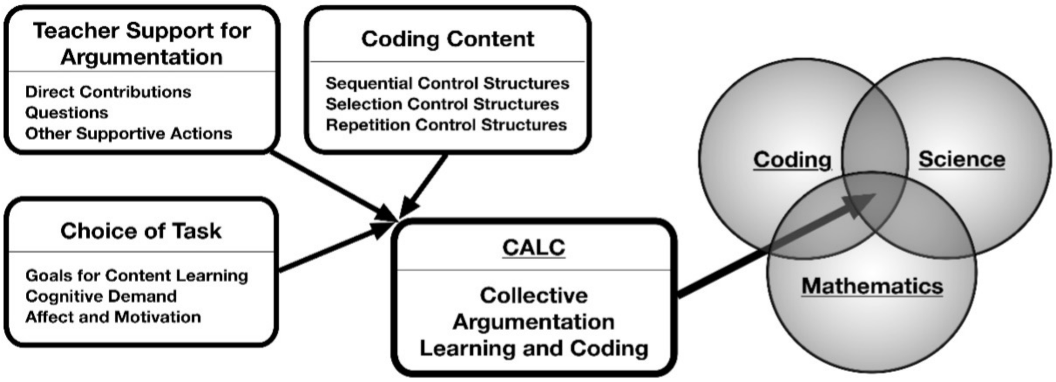

Figure 2. The CALC Framework (reprinted, with permission, from Conner et al., 2020).

Choice of Task

The element of *choice of task* in the CALC framework provides three criteria to assist teachers in selecting robotics task for integrative STEM learning. First, teachers are to shape task goals that consider conceptual understanding of mathematics, science, engineering, or technology as well as the skills students need to develop the code logically. For instance, teachers can address students' understandings of angles and angle measure while students develop pseudocode for programming an ER to travel the perimeter of a scale model of the Pentagon building in Arlington, VA. Second, teachers are to ensure integrative STEM tasks are complex enough so that students will need to reason about and discuss viable solutions to the tasks (see, e.g., Smith & Stein, 1998). Finally, teachers are to see that the task would be motivating and lead to positive affective outcomes for students.

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Coding Content

The element of *coding content* focused on teachers' knowledge of algorithms, variables, use of control structures, and modularity in coding. Of significance for the current study, the CALC approach emphasizes three basic control structures that are developmentally appropriate for elementary students (K-12 Computer Science Framework, 2016): sequential, selection, and repetition. A sequential control structure executes a coding sequence line-by-line – similar to following a recipe or list of commands in order. The selection and repetition control structures are for more complex tasks. A selection control structure is suitable for tasks involving a decision before proceeding on to the next step. For instance, some cars are programmed to turn on the headlights if the lighting is not optimal for visibility. A repetition control structure executes repetitive tasks; it sometimes can make sequential control structures more efficient in terms of the number of lines of coding. For instance, instead of having five lines of codes for an ER to blink a light five times in succession, a programmer can "loop" or repeat that one line of code five times. These fundamental control structures are combined with the choice of task so that teaching and learning of STEM content is supported.

Teacher Support for Argumentation

Based on Conner et al.'s (2014) framework for teacher support of collective argumentation, the element of *teacher support for argumentatio*n outlines three kinds of support teachers can provide when engaging their students in argumentation: directly contributing argument components, asking a question that prompts a student to contribute, or engaging in some other supportive action that responds to a student's contribution to the argument (see Table 1). A teacher may make a direct contribution to an argument by providing a claim (e.g., The use of repetition will make the code more efficient). Teachers may ask questions that *request an idea* (e.g., So if I have eight-tenths and I doubled it, how many wholes would it fill?) or *request elaboration* (e.g., And why did you double the eight-tenths?), prompting students to contribute a claim or warrant. Teachers' other supportive actions (e.g., *repeating* a student's claim or warrant verbally or by writing it on the board) also support argumentation.

Research Questions

The following research questions guided this study: How does an elementary teacher use the CALC approach (integrative STEM approach) to teach mathematics concepts with ER? What are the teacher's perspectives towards teaching mathematics with ER using an integrative STEM approach?

A focus on teaching and learning of mathematics was chosen as a focus because it is one of the more challenging applications for ER and the CALC approach. Technology and Engineering Educators frequently find that ER has obvious connections to science content (think simple machines) or technology (electrical control systems), but effectively implementing ER to enhance learning in mathematics has implicit hurdles.

Table 1
Teacher Support for Collective Argumentation Framework (reprinted, with permission, from Conner et al., 2014)

Direct Contributions		Questions		Other Supportive Actions	
Claims	Statements whose validity is being established	*Requesting a factual answer*	Asks students to provide a mathematical fact	*Directing*	Actions that serve to direct the students' attention and/or the argument
Data	Statements provided as support for claims	*Requesting a method*	Asks students to demonstrate or describe how they did or would do something	*Promoting*	Actions that serve to promote mathematical exploration
Warrants	Statements that connect data with claims	*Requesting an idea*	Asks students to compare, coordinate, or generate mathematical ideas	*Evaluating*	Actions that center on the correctness of the mathematics
Rebuttals	Statements describing circumstances under which the warrants would not be valid	*Requesting elaboration*	Asks students to elaborate on some idea, statement, or diagram	*Informing*	Actions that provide information for the argument
Qualifiers	Statements describing the certainty with which a claim is made	*Requesting evaluation*	Asks students to evaluate a mathematical idea	*Repeating*	Actions that repeat what has been or is being stated
Backings	Usually unstated, dealing with the field in which the argument occurs				

Methods

This study is a qualitative, critical case study (Yin, 2018) of one teacher's implementation of the CALC approach. A critical case is useful to confirm, challenge, or extend a well-defined theory or approach, which in this study is the CALC approach. Therefore, we chose a critical case study design in order to examine how a teacher might implement the CALC approach in an integrative way to develop students' mathematical understandings with ER. The case was bounded by two lessons in Fall 2018 that were taught by a teacher (Sarah, pseudonym) who participated in a professional development (PD) course on the CALC approach in Spring 2018. We purposefully selected Sarah as the focus teacher because she expressed an interest in implementing the CALC approach with mathematics content and ER after participating in the PD course: "I would really like to see more of this argumentation in math...and then, how to use robots in math and how to make those connections." (Pre-Interview, 2:35). The bounded case of Sarah's two lessons provided the opportunity to confirm whether the CALC approach would engage students in STEM integration lessons that "involve[d] significant mathematics for students" (Shaughnessy, 2013, p.

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234). In addition, we extend our understanding by considering Sarah's perspective towards teaching mathematics with ER in an integrative manner, about which our literature review revealed mixed results (e.g., Lamberg & Trynadlowski, 2015; Park et al., 2016; Toma & Greca, 2018).

Context and Participant

The aims of the PD course were to (a) enhance teacher knowledge of collective argumentation and its application within the context of mathematics, science, and technology learning, (b) increase teachers' ability to code robots, (c) develop teachers' capacity to use collective argumentation in coding activities consistent with grade-appropriate learning content, and (d) to develop CALC-based mathematics, science, and technology lessons that could be enacted in elementary school classrooms. The course was taught in a hybrid format, with four face-to-face meetings spaced out over the course of a semester and additional instruction and assignments delivered in an online format. The PD course included 30 hours of instruction: 12 hours of instruction in face-to-face meetings and 18 hours of instruction online. After the PD course, we followed Sarah into the next school year to support and document her implementation of the CALC approach.

Sarah had more than 20 years of elementary teaching experience, most of which she described as looping with a group of students for their kindergarten and 1st grade years. Her undergraduate education background was in music performance and elementary education. She also earned a master's degree in education that emphasized integrating the arts into the general curriculum. At her school, Sarah served as a resource specialist for students who were identified as gifted; she had served for the previous three years in that role in which she described her primary work as STEM-focused. Starting in Fall 2018, Sarah began a "push-in" model, in which she co-taught gifted students with their peers with the general classroom teacher. Sarah self-selected a 4th grade class to be observed by the research team. She stated, "The class that I chose for the project is a 4th grade [class] and the time that I push into their class is math...I deliberately chose a class that had a math – it would easily work into creating some more lessons involving math, because I see that's a weakness [for me]." The mathematics class was an "advanced content" class, which means that the students were identified as either gifted or high achieving. The teachers at Sarah's school implemented the Eureka Math curriculum (Great Minds, 2015).

Data Sources

The data sources for this study included video recordings of Sarah's implementation of two fourth-grade lessons, an interview before the first lesson (Pre-Interview), and an interview after each lesson (Post1 and Post2). To video record the lessons, two cameras were placed in the classroom. One camera captured a whole-class perspective and tracked Sarah. The other camera captured the interaction of a small focus group of students. Three microphones were placed in the classroom. One microphone was worn by Sarah, one microphone was placed in the front of the classroom to capture whole-class audio, and the other microphone was placed on a table with the focus group of students. In total, there were approximately 260 minutes of video recording across the lessons.

In the interviews, Sarah reflected on the CALC approach (e.g., What would you say are the challenges in implementing the CALC approach?), her planning for the lessons (e.g., How did you plan the lesson?), and short videos clips of her teaching (e.g., How did you support the argumentation?). The interviews ranged between 30 to 45 minutes in duration.

Data Analysis Procedures

To answer our first research question, we identified episodes of argumentation in each lesson and then selected episodes in which mathematics or coding was the primary focus of the argument. Using an adapted Toulmin (1958/2003) model (as detailed in Conner, 2008), we diagrammed the selected episodes and identified teachers' supportive actions for the arguments (Conner et al., 2014). Then, we developed a spreadsheet with a row for each argumentation diagram that described Sarah's choice of tasks and detailed mathematics and coding concepts that had been addressed within the arguments or tasks and how she supported the arguments. Using the constant comparative method (Glaser & Strauss, 1967), we searched for similarities and differences in how Sarah used the CALC approach to teach mathematics concepts with ER in the episodes of argumentation. We analyzed the potential of Sarah's task for integrative STEM instruction focused on mathematics using the CALC framework.

In order to answer the second research question, the research team met to complete a microanalysis of Sarah's interviews (Corbin & Strauss, 2015). We initially examined Sarah's interviews to understand dimensions of Sarah's experiences: implementing the CALC approach, creating lessons with ER for teaching mathematics, and interpreting students' understanding. In order to understand her perspectives more fully, we individually coded Sarah's utterances in her interviews, compared and combined our codes, looked for confirming and disconfirming evidence, and wrote memos describing themes that emerged from our iterative coding.

Results

The results of this study are presented in a narrative manner. We begin by presenting our analysis of Sarah and her orientations toward teaching, argumentation and the CALC approach, and teaching mathematics with ER. Next, we present the analysis of Sarah's first integrative lesson with ERs. We then present Sarah's task design and our task analysis for the second lesson, which sought to integrate mathematics and coding content. Finally, we conclude with our analysis of Sarah's second integrative lesson using the CALC approach.

It might be noted that the results from the first lesson provide a context for the main results in the second lesson. The lesson one data provides evidence of Sarah's thinking; the lesson two data provides evidence of learning in mathematics that took place.

Sarah's Orientation Towards Teaching

Sarah articulated views of teaching that, taken as a whole, contributed to a picture of her orientation towards student-centered instruction. Two key aspects included her emphasis on students' thinking and her role in facilitating their thinking. For example, Sarah stated, "I'm big on them thinking first, and I don't like to give them the ideas and the answers" (Pre-Interview, 13:24). A way to initiate students' thinking included asking a question: "If I know where I want to head, I would probably present more of a question to start off with, if it's a problem" (Pre-Interview, 13:24). Sarah described argumentation as the way she had always liked to teach but for which she previously didn't have a label (Post2, 16:38). She preferred for students to think and learn through argumentation rather than front-loading information (Post1, 28:01). Throughout our

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conversations with her, Sarah expressed her belief that argumentation can be used in teaching any subject area (Post1, 20:25) and that argumentation is valuable for all students (Post2, 8:29).

Another aspect of her orientation towards teaching included her vision of a classroom culture in which students were not afraid to get a wrong answer: “So, with a lot of these kids, we do develop a culture of taking risks and you know being okay to get it wrong.” Post1, 22:34). She wanted students to learn from their setbacks by analyzing “what went wrong and what went right” and then decide how this analysis would allow them to “make a better choice” about how to proceed (Post1, 11:24). She related this vision of classroom culture to argumentation: “if they use argumentation and they think that through, where they make that claim and it may be wrong, but then they analyze, I think that analysis piece is critical” (Post1, 20:01). Sarah described the students’ use of feedback from ERs to identify a problem by asking, “Why didn’t this work?” (Post1, 3:52). Sarah also valued argumentation for the possibility of students hearing others’ opinions and challenging their thinking.

Sarah articulated strong views of teaching with interdisciplinary integrations. Sarah summarized this view as, “Integration is really to me, where it is [at], and that’s kind of the way that I’ve always done everything” (Pre-Interview, 28:35). Sarah’s descriptions of her planning were one manifestation of her orientation towards integration. She described including multiple content standards across disciplines in her lessons (Pre-Interview, 4:44). Sarah did not segment lessons across disciplinary lines.

Sarah’s Perceived Value of Using CALC Approach

In her pre-interview, Sarah revealed that she valued using the CALC approach in coding and ER activities and emphasized that students should use evidence to support their claims. Prior to teaching her first integrative lesson, she voiced her intention to use argumentation. Sarah wanted her students to “make some claims as to what type of code sequence would be the best for that, and why; where they could support their argument.” (Pre-Interview, 23:10). Sarah specifically noted the utility of CALC approach:

> What would be done if you weren't using the CALC approach is... I think it would be… more teacher centered, in the sense of, there's not inquiry where they find out. And I think kids, too, will be less engaged, because they don't take ownership of it. (Pre-Interview, 24:23).

Sarah expressed these perspectives about the CALC approach and argumentation across all three interviews.

Sarah’s Orientation Towards Using ER to Teach Integrative Math Lessons

Sarah held a positive view towards planning for integrative STEM lessons. Her view of STEM integration included her love of “something that allows kids to connect multiple content standards together at once” (Pre-Interview, 4:44). “It’s okay if using the robots doesn’t teach new content but that it takes the content that they’ve learned and then applies it in different ways” (Pre-Interview, 9:55). Sarah thought that it made a lot of sense to teach coding and math in similar ways, “There’s so many ways to do [math]. And it’s the same way with coding is that, there’s a lot of ways to get there, but which way is the most efficient?” (Pre-Interview, 16:10). Sarah’s view of integrative STEM appeared well established, perhaps due to her already strong orientation towards integration.

Sarah consistently expressed a desire for rigorous mathematics instruction focused on conceptual understanding, and she hoped ER would provide opportunities for her students to be challenged. When Sarah talked about integrating ER, she focused on making sure that mathematics was "up to the caliber and level that those kids need" (Pre-Interview, 5:18). We interpreted Sarah's concern for the "caliber" and "rigor" of the mathematics as engaging the students in conceptually rich mathematics that deepened their understanding and challenged them to conceive or apply mathematics in new ways. Sarah said she was "really trying to figure out how we can…really use robotics to raise that level of rigor of understanding of mathematics" (Post1, 4:42). Similarly, she concluded after the second class that engaging students in learning mathematics with ER increased engagement and "was even more challenging" for students (Post2, 5:50). When Sarah talked about her instructional goals, she inevitably talked about engaging in cross-disciplinary investigation and developing conceptual understanding.

Sarah's Lesson 1: Using ER and CALC to Disconfirm Students' Mathematical Understanding

An Illustrative Collective Argumentation Episode from Lesson 1

This Lesson 1 Episode is illustrative of Sarah's first integrative lesson using the CALC approach. In the lesson, students were asked to program the ER to go 6 inches and observe how many seconds it took the ER to go that distance. The goal of this task was for students to then use proportional reasoning to decide how long the ER should travel for distances of 12 and 24 inches, without having to resort to trial and error. Lesson 1 Episode was chosen because it reflects the nature of using ER to disconfirm students' mathematical understanding. Moreover, this episode reveals through engaging her students in argumentation, Sarah became aware that some students had not previously worked with decimal numbers, which is a fourth-grade Common Core State Standard (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). This awareness provided Sarah with the opportunity to address mathematical content with ER in the next lesson.

In the lesson, Sarah intentionally engaged her students in argumentation; she expected students would use evidence-based reasoning to plan coding sequences for moving the ER. In the following transcript, the students had been working on coding an ER to travel 6 inches in a straight line. This Lesson 1 Episode is an excerpt from a whole class discussion in which Sarah asked a group to share their work with the class (see Figure 3 for a visual depiction).

1. S(tudent)1: Oh, no, we did two [second delay] at first and then that went 12 inches. (*Data/Claim 2*) And then we did one [second delay] and that went like 7 inches. (*Data/Claim 3*) And then we tried 0.5 [second delay] and that went halfway. (*Data/Claim 4*) And then we tried 0.10 [spoken as zero point ten], and that was only like this much [holds up fingers to show tiny amount] because that's one-tenth. (*Data/Claim 5*)
2. Sarah: So, tell me your order. You tried 2, then 1, then 0.5...(*Support 1*)
3. S1: And then 0.10 [spoken as point one zero] (*Data/Claim 5*)
4. Sarah: And so, when you were at 0.10, what did that get you, what results did that get you? (*Support 2*)
5. S1: It only got us like that much [gestures again]. (*Data/Claim 5*)
6. Sarah: So, you went from 0.5, which was 0.5 too far? (*Support 3*)
7. S1: No, it was too short. (*Warrant 1*)
8. Sarah: So, why did you go from 0.5, if it was too short, to 0.1? (*Support 4*)

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9. S1: Because we didn't know that 0.1 would be that. We thought it would be more that 0.5 because it was ten. (*Warrant 1*)
10. Classroom teacher: We haven't learned fraction comparisons yet so, they were just seeing 10 bigger than 5.
11. Sarah: So, then what did you do to adjust, once you realized 0.1 is actually shorter than 0.5, what did you do? (*Support 5*)
12. S1: Then we [did] 0.9 (*Claim 6*) because that is nine one-tenths. (*Warrant 2*)
13. Sarah: Nine-tenths. (*Support 6*)
14. S1: Yeah nine-tenths. And then that would get us more farther than the 0.10. And we tried that and it was like that close [gestures an even tinier amount]. (*Warrant 2*)

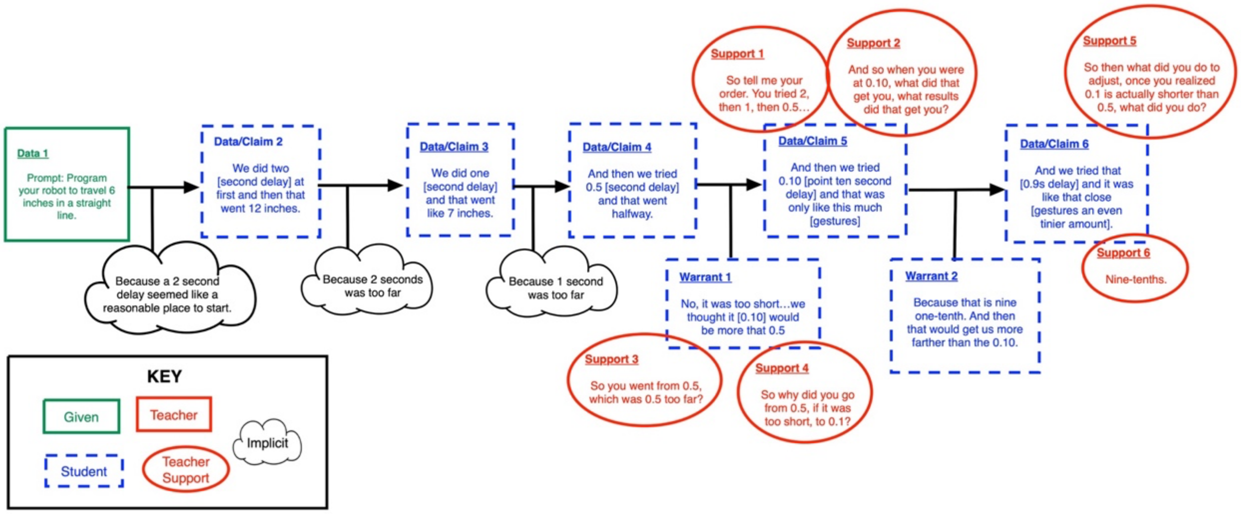

Figure 3. Lesson 1 Episode: An Illustrative Episode of Argumentation from Sarah's Lesson 1.

Sarah supported argumentation in this episode by asking questions that *requested elaboration* and *requested a method*. She ensured others in the class heard and understood students' answers by *repeating* some answers. After the group shared their work (line 1), instead of giving direct feedback, Sarah posed a question, "So, why did you go from 0.5, if it was too short to 0.1" (Line 8, Support 4) to request elaboration to uncover the reasoning for S1's claim (Data/Claim 5). The student explained, "Because we didn't know that 0.1 would be that [short of a distance]. We thought it would more than 0.5 because it was ten." (Line 9). The classroom teacher further explained to Sarah that "We haven't learned fraction comparisons yet so, they [students] were just seeing 10 bigger than 5" (Line 10). Sarah then realized that the students were still developing their understandings of decimal place value.

In summary, the use of ER in this episode provided opportunity for students to begin making sense of decimal place value. For some students, the observation that ER traveled "smaller distance" in "bigger numbers" disconfirmed their assertion that 0.10 would be more than 0.5. For Sarah, the student's arguments allowed her to assess her students as not yet knowing an important mathematical concept needed for developing their coding sequences. With this new awareness, Sarah planned for continued learning with decimal place value in the next integrative mathematics lesson.

Sarah's Reflection on Lesson 1

After watching a video clip of the Lesson 1 Episode, Sarah explained that this episode demonstrated some gaps in students' decimal place value understanding that hindered students' completion of the task. She stated, "They went ahead and figured, adjusted based on just that alone, but they don't understand it mathematically, you know" (Post1, 17:47). We interpreted this statement as Sarah attributing students' difficulties with adjusting a coding sequence to their limited knowledge of mathematical ideas. While the students appeared to be using trial and error to successfully complete the task in the Lesson 1 Episode, Sarah believed students were systematic in their trials and there was potential for evidence-based reasoning. She also asserted that the mathematical content with which they struggled was "content that they have not encountered yet in their typical pacing of their math" (Post1, 1:52). This observation impacted her design and implementation of the second lesson we observed.

Sarah reflected that having students analyze their work from the perspective of argumentation was critical. She stated, "if they use argumentation and they think that through, where they make that claim and it may be wrong, but then they analyze, I think that analysis piece is critical" (Post1, 20:01). We interpreted this comment and others like it as indications that she perceived the CALC approach, and particularly argumentation, as shifting students away from a trial-and-error approach to coding ER and helping develop students' reasoning skills. Nevertheless, Sarah did find some value in the use of trial and error, but only when used systematically. The following statement from Sarah supports this interpretation: "Give it a shot, but then again, see what happens, think about what happened and then try to narrow your focus on so that you're not just shooting in the dark all the time." (Post1, 21:59).

Sarah's Lesson 2: Using ER and CALC to Support Students' Conceptual Understanding of Decimals

Sarah's Design of Lesson 2

Sarah was determined to recognize and build upon students' mathematical reasoning in designing future integrative mathematics activities. After reflecting on what her students said and did, related to the relationship between 0.5 and 0.10, she said, "I want [students] to have some actual practice and conceptually understand why that [0.10] actually is a smaller amount than point five" (Post1, 2:38) and "I need to develop some lessons that kind of address that…I want to make sure we have that understanding before they move forward" (Post1, 3:52).

In Sarah's second integrative mathematics lesson, her goals were for students to be able to: (a) identify equivalent mathematical representations for certain tenth areas of decimal squares (e.g., six-tenths of the area of a square in either Figure 4a or Figure 4b) and (b) develop a coding sequence for an ER to travel around those areas using repetition structures (i.e., loops). In addition to her focus on conceptual understanding of mathematical ideas, Sarah considered mathematical representations, ER platforms, and intentional scaffolding in her lesson planning.

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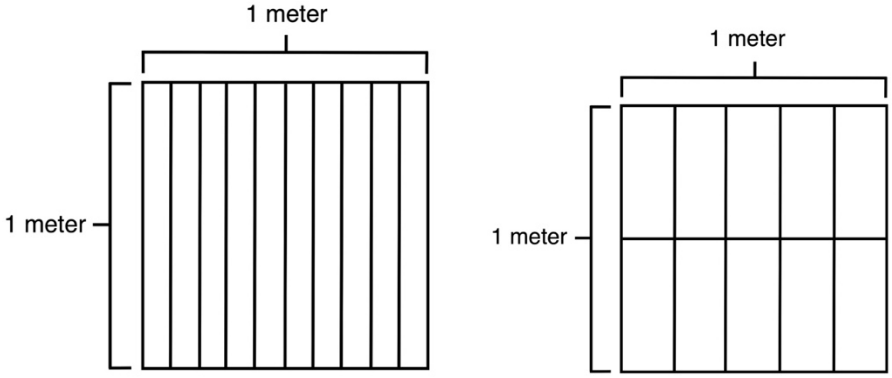

Figure 4. Decimal Square Models.

The Task Designed by Sarah for Each Group

Sarah constructed decimal squares of two different configurations on the floor of her classroom using tape (see Figure 4). Each square measured 1 meter on a side. Students, in groups, were given one of the taped squares and asked to program their robots to travel around a fractional part of the area of the square. Groups were given a decimal quantity (either 0.6 or 0.8, depending on the group) and a task page containing instructions and a sentence frame (see Figure 5). Each task page also included one of the two decimal square models illustrated in Figure 4. During the work session, Sarah interacted with groups and asked them to recount their experiences. She also pushed them to make their code more efficient. One of these interactions is captured in included Lesson 2 Episode.

Your team must maneuver around a fraction of a square meter.
Use the space below to record your coding successes and failures to help determine your 'next steps'.

<u>Claims</u> (Based on results, what do you expect to be a reasonable 'next step'?) "If ____ resulted in ____, then ____ should result in ____."	**Data and reasoning**

Figure 5. Recreation of Task Page Sarah Created to Scaffold her Students' Arguments and Coding.

Task Analysis Using the CALC Framework

We examined Sarah's task using the CALC Framework to understand its potential for supporting students' integrative STEM learning in the context of mathematics and coding. Because Sarah's goals aligned with those of the CALC project, it is not surprising that Sarah's task aligned with the CALC framework. For this task analysis, we considered Sarah's written task, her instructions to students, her account of planning the lesson, and her reflection on the lesson. Our analysis includes aspects of all three components of the CALC Framework, with the choice of task element being most salient.

The intentional scaffolding on the task page, as illustrated in Figure 5, provides evidence of attention to supporting her students' construction of arguments, including the vocabulary she chose to use of claims, data, and reasoning (*Teacher Support for Argumentation* component). Her design of the task, including intentional choice of which ER platform to use, demonstrates attention to *Coding Content.* In particular, she chose to use a platform with which her students were familiar in order to facilitate attention to the mathematics content and in hopes of her students engaging in more complex coding, including attention to loops, a repetition control structure. When asked about her goals, she said, "I was hoping that they would eventually then go into this whole idea of looping" (Post2, 4:34). We next discuss elements of the *Choice of Task* component in her task design.

Goals for Content Learning. As demonstrated above, Sarah designed her task explicitly to enhance students' conceptual understanding of decimal place value. Her goals for students included connecting different representations of fractional area. Connections are an important part of conceptual understanding as defined by Hiebert and Carpenter (1992); moving flexibly among representations is necessary for understanding fractions, including decimal fractions (e.g., Deliyianni et al., 2016; Lamon, 2001). The task provided students with opportunities to identify mathematical structures and discuss how to make their coding sequences more efficient by connecting the mathematical structures with repetition control structures. For instance, they could identify how long it took for the ER to travel 1/10 of the length of the square and use that time and a loop to code it to travel any multiple of 1/10 of the length of the square. They also could leverage equivalent representations of fractional areas to create more efficient codes. For instance, students could first find two or more representations in a square model that have the same fractional value. Then, given these equivalent fractional representations, students can select the representation that has fewer turns. This potential is illustrated in our account of the Lesson 2 Episode in the next section.

Cognitive Demand. The cognitive demand of a task should be appropriate for the students for whom it is designed. We consider cognitive demand to include the extent to which a task engages students in thinking, reasoning, and problem solving (Smith & Stein, 1998). Sarah gave explicit attention to cognitive demand by her intention that the task be appropriately challenging for her students. She wanted to "make it something that would be really challenging for those kids" (Pre, 20:22). Sarah's task had a high level of cognitive demand because it required them to make use of their developing understandings of decimal place value in programming ER to accomplish a task. They did not have access to a rote procedure for such activity. Additionally, they had to choose and coordinate different representations of fractional areas to make decisions about efficient programming and then explain and justify their choices to their group members and on their task pages. These aspects of multiple representations, connections, explanations, using knowledge, and complex thinking align with Smith and Stein's (1998) description of high cognitive demand tasks.

Affect and Motivation. Many students find coding ER to be inherently motivating (Chin et al., 2014). Sarah intentionally leveraged this motivation in her design of the task.

> I think the engagement level —You know, if you just give some kid a problem, like on paper, and then they have to figure out what that would be, to me, they would probably do it, again, because a lot of kids would do it. But their determination to solve that problem wouldn't be as great, because to me, they're not as engaged. But then also, there's not a lot

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> of challenge in that, whereas what they were doing here, to me, was even more challenging. (Post2, 5:50)

Sarah provided an appropriate level of challenge along with instructional scaffolds (the task page), and the ER provided immediate feedback regarding students' progress with the task.

An Illustrative Collective Argumentation Episode from Lesson 2

The following argumentation episode from Sarah's second lesson (Lesson 2 Episode) was chosen because it reflected how two lesson goals mutually informed each other. In the Lesson 2 Episode, Sarah provided a group of students with an additional task to code the ER in a more efficient manner. To support the goal of coding efficiency, Sarah engaged the group in argumentation related to programming the ER to travel around the same fractional part of the square with a path that involved fewer turns. By doing this, Sarah supported students to work with equivalent mathematical representations of fractions, which was one of her goals.

1. S(tudent)2: But we are trying to make it like - from here and then turning right and then go one. If I [am] measuring it, we got 6. (*Claim 1;* see Figure 6a for student's gestured path)
2. Sarah: Right, well. How? Yeah.
3. S2: What we need to do is we can go like this or we can just go
4. Sarah: What's another one you can do 6 [tenths] a little more efficiently? What is a way that you could do it that would involve fewer turns? Because if I do it this way, I've got to go here, I got to turn, I got to go up there, I got to turn, got to go there, turn, here, turn, here, turn, here, right? That's an awful lot of turns. (*Rebuttal/Data 2*)
5. S1: Really?
6. Sarah: Yeah, you got to go all the way around it. (*Rebuttal/Data 2*)
7. S1: And then back?
8. Sarah: Yes! (*Rebuttal/Data 2*)
9. S1: Okay, then we have to...
10. Sarah: So, what would be a better way to do it, that you could still do six, but with fewer turns? Look and see. Look at this. (*Support 1*)
11. S1: I think that we could go 1, 2, 3, 4, 5... (*Claim 2*)
12. Sarah: What do you think we could do? (*Support 2*)
13. S1: And then go another one that's invisible...(*Claim 2,* see Figure 6b for student's gestured path)
14. Sarah: There's no invisible (laughs) (*Rebuttal 1*)
15. S1: I know, I know.
16. Sarah: S2 had an "ah ha". What do you think S2? (*Support 3*)
17. S2: We could go these three right here, then turn that way, and turn that way, and then go back. (*Data/Claim 3;* see Figure 6c for student's gestured path)
18. S1: I agree.
19. Sarah: Do you see how then that would only be here, turn, here, turn, here, turn, here? (*Support 4*)
20. S1: Yeah. (*Warrant 1*)
21. Sarah: Is it still six tenths? (*Support 5*)
22. S1: Yes! (*Warrant/Claim 4*)
23. S1: Because three and three is six. (*Warrant 2*)
24. Sarah: That was good guys. That was a good thing to try to figure out. (*Support 6*)
25. S1: So two, four, six. (*Warrant 3*)

At the beginning of Lesson 2 Episode, S2 made a claim about how to program the ER to travel around six-tenths of the area in a unit square (Line 1). As shown in Figure 6a, this travel path of ER involved six turns. Instead of ending the task with S2's claim (which was technically valid), Sarah challenged students to think about "What's another one [way] you can do 6 [tenths] a little more efficiently?" (Line 4). Thus, Sarah led the argumentative discourse to concentrate on how to code the ER in a more concise way that involved fewer turns. At this point, the role of the teacher's intervention was critical to encourage students to explore how to efficiently code ER and investigate equivalent representations for six-tenths.

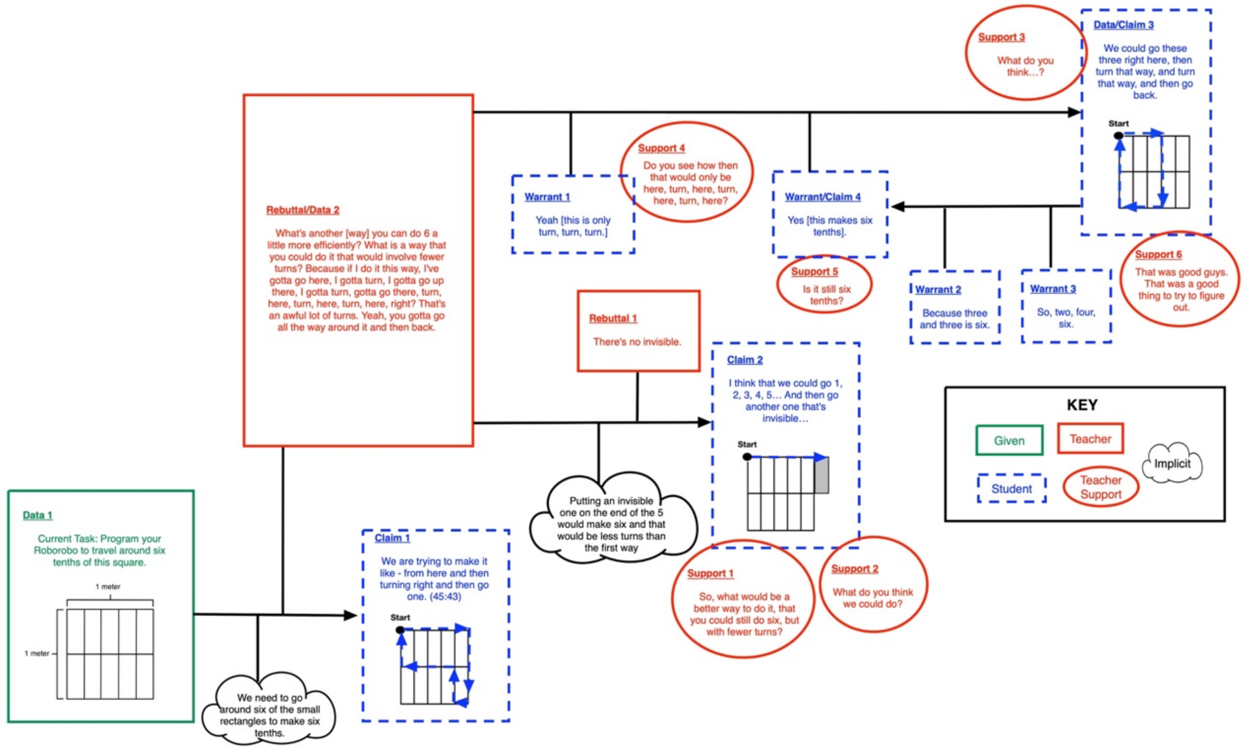

Figure 6. Lesson 2 Episode: An Illustrative Episode of Argumentation from Sarah's Lesson 2.

Another student proposed that the addition of an invisible one-tenth at the end of the five-tenths would make six-tenths (Lines 12 and 14; see Figure 7b) and would have fewer turns than the initial travel path (Figure 7a). Sarah noticed that the student's answer neglected the unit of specifically outlined square that the students were given, although it had fewer turns. Sarah contributed a rebuttal, "There's no invisible" (Line 15) in response to the student's proposal. Sarah's rebuttal not only provided students with opportunities to leverage the concept of unit and equivalent representations but also ensured that the argumentation continually progressed in a productive direction towards her goal for the lesson. The students ultimately arrived at an alternative correct travel path with explanations of how they could program the ER to travel six-tenths of the area of a unit square with only four turns involved (Lines 18 to 25; see Figure 7c). Through this process, the students determined multiple ways they could code ER to travel around six-tenths of the area in the square.

In summary, the discussion of coding efficiency in this episode required students to think conceptually about the equivalent mathematical representations of a particular fractional area. Students were expected to identify the area of six-tenth in a decimal square in multiple ways. On

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the other hand, the equivalent mathematical structures provided opportunities for students to explore a more efficient path in programming an ER with fewer turns.

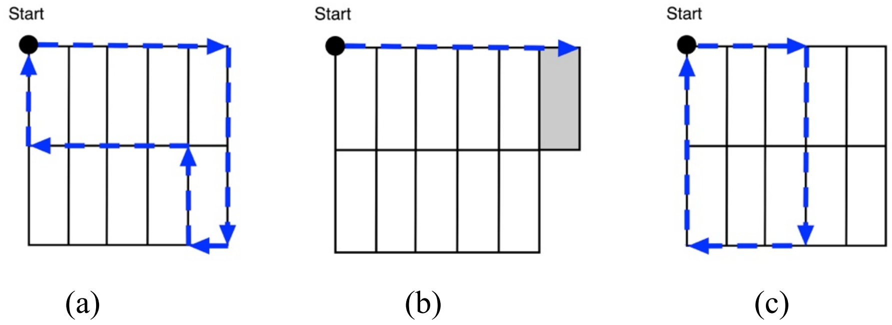

Figure 7. Student Solutions to the Task in the Second Lesson.

Discussion

While the potential benefits of incorporating ER as an educational tool are widely accepted, previous studies have mainly focused on the use of ER in teaching concepts that relate to the robotics field (e.g., programming, construction, mechatronics) and not to the teaching of mathematics (Mitnik et al., 2009; Zhong & Xia, 2020). In addition, some researchers have argued the passive role of mathematics in integrated STEM instruction (English, 2017; Shaughnessy, 2013). This study responds to calls to explore more ways for integrating ER and mathematics education (e.g., Benitti 2012; Zhong & Xia, 2020). Sarah's case provides empirical evidence to support the potential of ER in teaching mathematics concepts of decimals and fractions. The study also illustrates how mathematics could play a major role in improving integrative STEM instruction that facilitates students' in-depth conceptual understanding of mathematics as well as concepts from other STEM disciplines (i.e., coding concepts). In this section, we discuss the results of our analysis of Sarah's use of the CALC approach and her perspectives towards teaching mathematics with ER.

Use of the CALC Approach to Teach Mathematics Concepts with ER

Our results showed that Sarah's lessons aligned with the CALC approach in the following ways: (a) choice of task, (b) coding content, and (c) teacher support for argumentation. Next, we discuss each of these components.

Sarah's Choice of Task

We interpret Sarah's lessons as satisfying all three criteria of task selection as described in the CALC approach. In the first lesson, Sarah's task (and her support for argumentation) allowed her to identify a gap in students' mathematical understanding. In order to ensure students grasped the mathematics concepts of decimal place value, which they had not yet learned, Sarah shaped the task in the second lesson to address students' mathematical understandings of decimals and fractions before moving forward with coding (criterion 1). Sarah provided additional tasks so that students could determine how to code ER more efficiently by asking the students to provide reason and discuss various paths to programming ER travel around a particular fractional area (criterion 2). In this way, the tasks that Sarah designed scaffolded the students to build knowledge in both mathematics concepts and coding structures. Furthermore, Sarah viewed the task as directly motivating for students, in particular the use of ER to engage students in coding activities (criterion 3).

Coding Content

The coding content in Sarah's lessons included sequential and repetition control coding structures. Sarah expected the students to use proportional reasoning rather than only trial-and-error to justify their block-based coding sequences. For instance, students were learning to construct a line-by-line coding sequence for programming an ER to travel 6 inches based on their previous trials. In the second lesson, Sarah intentionally extended students' exploration of coding to include repetition structures (i.e., loops) to find an alternative path of travel around the decimal square. The coding content element in Sarah's lessons focused on providing students with knowledge of and insights into control structures, which worked in combination with her strategic choices of tasks.

Sarah's Support for Argumentation

Based on Conner et al.'s (2014) framework for teacher support of collective argumentation, Sarah engaged students in participating argumentation through multiple ways. Sarah posed questions to request elaboration to elicit students' ideas and uncover their processes of reasoning (e.g., "So why did you go from 0.5, if it was too short, to 0.1?"). Sometimes, Sarah directly contributed argument components (e.g., rebuttal/data shown in Figure 6) to ensure that argumentative practices remained productive. In other instances, Sarah engaged in other supportive actions (e.g., repeating students' statements). Sarah's support for argumentation was essential for the purpose of guiding students to construct, explain, or clarify their arguments, and, in the first lesson, assisted in identifying needed conceptual understanding.

Sarah's Perspectives Towards Teaching Mathematics with ER

Sarah's perspectives towards teaching mathematics with ER using the CALC approach were consistent across time and settings. We argue that this consistency was largely due to Sarah's orientations toward teaching in general. Her orientations toward teaching were the basis for her perspectives towards teaching integrative mathematics with ER. These orientations included her value of student-centered instruction, desire for a classroom culture in which students were not afraid to be wrong, and preference for integrating content areas.

Sarah valued instruction that was student-centered, which aligns with the stance of integrative STEM (Sanders, 2012; Sanders & Wells, 2010) in the CALC approach. Sarah found the CALC approach to be consistent with her orientation towards student-centered instruction because this approach allowed students to own their claims. Sarah expressed the belief that individuals can construct their knowledge by engaging in argumentation.

Sarah believed, particularly for the advanced content students, that it was important for students to know that they could be wrong. Sarah observed that having students analyze their work from the perspective of argumentation was critical. With the CALC approach, challenges to students' problematic claims did not lead to unproductive discourse but led to civil discussions about ideas and concepts that supported the classroom community. This aligns with goals for argumentation across disciplines (Andriessen, 2006).

Sarah also valued integration in her instruction. Her previous graduate studies focused on how to integrate the arts across the general curriculum. She described this integrated approach to teaching as working well for her and that she generally regarded her teaching as integrative. For instance, she described how her lesson plans often connected multiple content standards across disciplines. The CALC approach aligned with Sarah's orientation towards integrating content across disciplines in order to meet learning goals for the students. For Sarah, using the CALC approach did not take away from developing rigorous mathematics with students. Rather, Sarah found that she could integrate mathematics with ER in ways that challenged students, while also engaging them in meaningful learning of mathematics.

Limitations

In suggesting that elementary teachers can integrate ER to teach formal mathematical and coding concepts, we also recognize the limitations of this critical case study. We examined two lessons focused on one mathematical concept from one teacher, including a pre-interview and post-lesson interview for each lesson. Although we cannot claim that the findings will generalize to other mathematical concepts or are reflective of elementary teachers' capacities to teach mathematics with the CALC approach, we believe the findings are generative for preparing teachers to teach STEM in an integrative manner.

Conclusion

This critical case study afforded the opportunity to strategically investigate if the conceptual model of the CALC approach could support teachers using integrative STEM. Sarah was an ideal candidate to build our critical case because her initial perspectives aligned with the goals of CALC and integrative STEM, in general. She was well-poised to implement the CALC approach into her practice because she had participated in previous long-term PDs with some of the university faculty. Sarah's participation led to partnerships that built mutual trust and her goal for integration. This critical case reveals what is possible in teaching integrative STEM lessons using argumentation. We recognize future studies with other teachers that participated in the PD course may contribute to building more encompassing theory for CALC. Nevertheless, this critical case of Sarah's lessons provides some cogency to the CALC approach.

Sarah's critical case shows that ER combined with the CALC approach can be used to teach mathematics concepts in ways that are consistent with an integrative STEM perspective. We believe that Sarah's use of the CALC approach enabled her to identify students' understanding of decimals and to plan for future mathematics instruction with ER. Sarah's case also provides evidence that teachers can integrate ER into the mathematics curriculum without losing coherence of mathematics topics and while remaining sensitive to students' needs. Opportunities to reflect on her teaching with the CALC approach provided Sarah with expanded perspectives on integrating mathematics with ER. Sarah's case provides evidence of a teacher using ER and coding to effectively teach mathematical concepts. This evidence influenced Sarah's perspectives towards teaching mathematics with ER and also provided the researchers with insights into the potential for integrative STEM to be used in mathematics instruction. Future research is needed to examine what mathematics concepts are able to be taught using integrative STEM and at what grade levels it is appropriate. Additionally, research is needed to understand how to support teachers who are new to argumentation in professional learning about integrative STEM teaching.

For Technology and Engineering educators, this study provides a model for reaching out to colleagues in the discipline of mathematics. The perspective that the role of mathematics in integrated STEM instruction is often supporting calculation and representation, which are less likely to produce positive mathematical learning outcomes (Baker & Galanti, 2017; English, 2016; Shaughnessy, 2013). We believe such perspective discourages involvement and collaboration of mathematics in integrative STEM ventures. Demonstrating the potential for true learning of mathematics concepts was a significant milestone for this study.

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References

Al Salami, M. K., Makela, C. J., & de Miranda, M. A. (2017). Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. *International Journal of Technology and Design Education*, *27*(1), 63–88. https://doi.org/10.1007/s10798-015-9341-0

Andriessen, J. (2006). Arguing to learn. In R. K. Sawyer (Ed.), *The Cambridge handbook of: The learning sciences* (p. 443–459). Cambridge University Press.

Baker, C. K., & Galanti, T. M. (2017). Integrating STEM in elementary classrooms using model-eliciting activities: Responsive professional development for mathematics coaches and teachers. *International Journal of STEM Education*, *4*(1), 10. https://doi.org/10.1186/s40594-017-0066-3

Barker, B. S., Nugent, G., & Grandgenett, N. F. (2014). Examining fidelity of program implementation in a STEM-oriented out-of-school setting. *International Journal of Technology and Design Education*, *24*(1), 39–52. https://doi.org/10.1007/s10798-013-9245-9

Benitti, F.B.V. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers and Education, 58*, 978-998.

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30–35.

Chin, C., & Osborne, J. (2010). Supporting argumentation through students' questions: Case studies in science classrooms. *Journal of the Learning Sciences*, *19*(2), 230–284. https://doi.org/10.1080/10508400903530036

Chin, K.-Y., Hong, Z.-W., & Chen, Y.-L. (2014). Impact of using an educational robot-based learning system on students' motivation in elementary education. *IEEE Transactions on Learning Technologies*, *7*(4), 333–345. https://doi.org/10.1109/TLT.2014.2346756

Conner, A. (2008). Expanded Toulmin diagrams: A tool for investigating complex activity in classrooms. In O. Figueras, J. L. Cortina, S. Alatorre, T. Rojano, & A. Sepulveda (Eds.), *Proceedings of the Joint Meeting of the International Group for the Psychology of Mathematics Education 32 and the North American Chapter of the International Group for the Psychology of Mathematics Education XXX* (Vol 2, pp. 361-368). Morelia, Mexico: Cinvestav-UMSNH.

Conner, A., Crawford, B. A., Foutz, T., Hill, R. B., Jackson, D. F., Kim, C. M., & Thompson, S. A. (2020). Argumentation in primary grades STEM Instruction: Examining teachers' beliefs and practices in the USA. In J. Anderson & Y. Li (Eds.), *Integrated approaches to STEM education: An international perspective*. (1st ed.). Springer.

https://ir.library.illinoisstate.edu/jste/vol57/iss1/8
DOI: 10.30707/JSTE57.1.1664998343.93078

Conner, A., Singletary, L. M., Smith, R. C., Wagner, P. A., & Francisco, R. T. (2014). Teacher support for collective argumentation: A framework for examining how teachers support students' engagement in mathematical activities. *Educational Studies in Mathematics, 86*(3), 401–429. https://doi.org/10.1007/s10649-014-9532-8

Corbin, J. M., & Strauss, A. L. (2015). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (Fourth edition). SAGE.

Daugherty, M. K., Carter, V., & Swagerty, L. (2014). Elementary STEM education: The future for technology and engineering education? *Journal of STEM Teacher Education*, *49*(1), 45-55. https://doi.org/10.30707/JSTE49.1Daugherty

Deliyianni, E., Gagatsis, A., Elia, I., & Panaoura, A. (2016). Representational flexibility and problem-solving ability in fraction and decimal number addition: A structural model. *International Journal of Science and Mathematics Education*, *14*(2), 397–417. https://doi.org/10.1007/s10763-015-9625-6

El-Deghaidy, H., Mansour, N., Alzaghibi, M., & Alhammad, K. (2017). Context of stem integration in schools: Views from in-service science teachers. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(6). 2459-2484. https://doi.org/10.12973/eurasia.2017.01235a

English, L. D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education*, *15*(S1), 5–24. https://doi.org/10.1007/s10763-017-9802-x

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, *3*(1), 3. https://doi.org/10.1186/s40594-016-0036-1

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education*, *88*(6), 915–933. https://doi.org/10.1002/sce.20012

Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: A professional development approach centered on an engineering design challenge. *International Journal of STEM Education*, *4*(1), 1-16. https://doi.org/10.1186/s40594-017-0058-3

Fernandes, E., Fermé, E., & Oliveira, R. (2009). The robot race: Understanding proportionality as a function with robots in mathematics class. In V. Durand-Guerrier, S. Soury Lavergne, & F. Arzarello (Eds.), *Proceedings of the sixth congress of European research in mathematics education* (pp.1211–1220). Institut National de Recherche Pedagogique.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine.

Gomoll, A., Hmelo-Silver, C. E., Šabanović, S., & Francisco, M. (2016). Dragons, ladybugs, and softballs: Girls' STEM engagement with human-centered robotics. *Journal of Science Education and Technology*, *25*(6), 899–914. https://doi.org/10.1007/s10956-016-9647-z

Goos, M. (2004). Learning mathematics in a classroom community of inquiry. *Journal for Research in Mathematics Education*, *35*(4), 258–291. https://doi.org/10.2307/30034810

Great Minds. (2015). *Eureka Math.* Authors. https://greatminds.org/math/eurekamath

Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. *Educational researcher*, *42*(1), 38-43.

Habermas, J. (1984). *The Theory of Communicative Action: Vol. 1. Reason and the Rationalization of Society*, (T. McCarthy trans.). Beacon Press. (Original work published 1981).

Hiebert, J., & Carpenter, T. P. (1992). Learning and teaching with understanding. In D. Grouws (Ed.). *Handbook of research on mathematics teaching and learning: A project of the National Council of Teachers of Mathematics.* (pp. 65–97). Macmillan Publishing Co, Inc.

International Technology and Engineering Educators Association (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education*. http://www.iteea.org/STEL.aspx.

Jamil, F. M., Linder, S. M., & Stegelin, D. A. (2018). Early childhood teacher beliefs about STEAM education after a professional development conference. *Early Childhood Education Journal*, *46*(4), 409–417. https://doi.org/10.1007/s10643-017-0875-5

Jiménez-Aleixandre, M. P., Rodríguez, A. B., & Duschl, R. A. (2000). “Doing the lesson” or “doing science”: Argument in high school genetics. *Science Education*, *84*(6), 757–792. https://doi.org/10.1002/1098-237X(200011)84:6<757::AID-SCE5>3.0.CO;2-F

M. E. Karim, S. Lemaignan and F. Mondada. (2015). A review: Can robots reshape K-12 STEM education?. *2015 IEEE International Workshop on Advanced Robotics and its Social Impacts (ARSO)*, (pp. 1-8). IEEE. https://doi.org/10.1109/ARSO.2015.7428217

Kazakoff, E. R., Sullivan, A. & Bers, M.U. (2013). The effect of a classroom based intensive robotic and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal, 4 1*(4), 245-255. https://doi.org/10.1007/s10643-012-0554-5

Krummheuer, G. (1995). The ethnography of argumentation. In P. Cobb & H. Bauersfeld (Eds.), *The emergence of mathematical meaning: Interaction in classroom cultures* (pp. 229–269). Erlbaum.

Krummheuer, G. (2007). Argumentation and participation in the primary mathematics classroom: Two episodes and related theoretical abductions. *Journal of Mathematical Behavior*, *26*(1), 60–82.

K–12 Computer Science Framework. (2016). *A Vision for K–12 Computer Science.* Retrieved from https://k12cs.org/a-vision-for-k-12-computer-science/

Laksmiwati, P. A., Padmi, R. S., & Salmah, U. (2020, July). Elementary school teachers’ perceptions of STEM: What do teachers perceive? *Journal of Physics.*, *1581*(1), 1-9. https://doi.org/10.1088/1742-6596/1581/1/012039

Lamberg, T., & Trzynadlowski, N. (2015). How STEM academy teachers conceptualize and implement stem education. *Journal of Research in STEM Education*, *1*(1), 45–58. https://doi.org/10.51355/jstem.2015.8

Lamon, S. J. (2001). Presenting and representing: From fractions to rational numbers. In A. Cuoco & F. R.Curcio (Eds.), *The roles of representation in school mathematics* (pp. 146-165). The National Council of Teachers of Mathematics.

Leonard, J., Buss, A., Gamboa, R., Mitchell, M., Fashola, O. S., Hubert, T., & Almughyirah, S. (2016). Using robotics and game design to enhance children’s self-efficacy, STEM attitudes, and computational thinking skills. *Journal of Science Education and Technology*, *25*(6), 860–876.

Liu, E., Feng, Z., Lin, C.H. & Chang, C.S. (2010). Student satisfaction and self-efficacy in a cooperative robotics course. *Social Behavior and Personality, 38*(8), 1135-1146.

Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12*?. Computers in Human Behavior*, *41*, 51-61. https://doi.org/10.1016/j.chb.2014.09.012

Margot, K. C., & Kettler, T. (2019). Teachers’ perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education*, *6*(1), 2. https://doi.org/10.1186/s40594-018-0151-2

Mitnik, R., Nussbaum, M., & Recabarren, M. (2009). Developing Cognition with Collaborative Robotic Activities. *Educational Technology & Society*, *12* (4), 317–330.

Mubin, O., Stevens, C. J., Shahid, S., Mahmud, A. A., & Dong, J.-J. (2013). A review of the applicability of robots in education. *Technology for Education and Learning*, *13*(1). https://doi.org/10.2316/Journal.209.2013.1.209-0015

Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based stem professional development for elementary teachers. *The Journal of Educational Research*, *106*(2), 157–168. https://doi.org/10.1080/00220671.2012.667014

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common core state standards.* Authors.

National Science and Technology Council (2013). *A report from the committee on STEM education*. National Science and Technology Council.

Nussbaum, E. M. (2008). Collaborative discourse, argumentation, and learning: Preface and literature review. *Contemporary Educational Psychology*, *33*(3), 345–359. https://doi.org/10.1016/j.cedpsych.2008.06.001

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994–1020. https://doi.org/10.1002/tea.20035

Padayachee, K., Gouws, P. M., & Lemmer, M. (2015). Evaluating the effectiveness of LEGO robots in engaged scholarship. *Proceedings of the Annual Global Online Conference on Information and Computer Technology (GOCICT)* (pp. 16–20). IEEE.

Park, H., Byun, S., Sim, J., Han, H., & Baek, Y. S. (2016). Teachers' perceptions and practices of STEAM education in South Korea. *Eurasia Journal of Mathematics, Science, & Technology Education, 12*(7), 1739–1753. https://doi.org/10.12973/Eurasia.2016.1531a.

Park, M. H., Dimitrov, D. M., Patterson, L. G., & Park, D. Y. (2017). Early childhood teachers' beliefs about readiness for teaching science, technology, engineering, and mathematics. *Journal of Early Childhood Research*, *15*(3), 275-291.

Sanders, M. E. (2012). Integrative STEM education as best practice. In H. Middleton (Ed.), *Explorations of best practice in technology, design, and engineering education*, (Vol. 2, 102-117). Griffith University. https://vtechworks.lib.vt.edu/handle/10919/51563

Sanders, M.E. & Wells, J.G. (2010) Virginia Tech, Integrative STEM Education Graduate Program http://web.archive.org/web/20100924150636/http://www.soe.vt.edu/istemed

Seehorn, D., Carey, S., Fuschetto, B., Lee, I., Moix, D., O'Grady-Cunniff, D., Owens, B. B., Stephenson, C., & Verno, A. (2011). *CSTA K--12 Computer Science Standards: Revised 2011* [Technical Report]. Association for Computing Machinery.

Shaughnessy, J. M. (2013). Mathematics in a STEM context. *Mathematics Teaching in the Middle School*, *18*(6), 324.

Shidiq, G. A., & Faikhamta, C. (2020). Exploring the relationship of teachers' attitudes, perceptions, and knowledge towards integrated STEM. *İlköğretim Online*, 2514–2531. https://doi.org/10.17051/ilkonline.2020.764619

Smith, M. S. & Stein, M. K. (1998). Selecting and creating mathematical tasks: From research to practice. *Mathematics Teaching in the Middle School 3*(5), 344–350.

Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2018a). How school context and personal factors relate to teachers' attitudes toward teaching integrated STEM. *International Journal of Technology and Design Education*, *28*(3), 631-651.

Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2018b). The influence of teachers' attitudes and school context on instructional practices in integrated STEM education. *Teaching and Teacher Education*, *71*, 190-205. https://doi.org/10.1016/j.tate.2017.12.014

Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2019). Teachers' attitudes toward teaching integrated STEM: The impact of personal background characteristics and school context. *International Journal of Science and Mathematics Education*, *17*(5), 987-1007.

Toma, R. B., & Greca, I. M. (2018). The effect of integrative STEM instruction on elementary students' attitudes toward science. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(4), 1383–1395. https://doi.org/10.29333/ejmste/83676

Toulmin, S.E. (2003). *The uses of argument: Updated edition*. Cambridge University Press. (First published in 1958).

van Eemeren, F. H., Grootendorst, R., Henkemans, F. S., Blair, J. A., Johnson, R. H., Krabbe, E. C. W., Plantin, C., Walton, D. N., Willard, C. A., et al. (1996). *Fundamentals of argumentation theory: A handbook of historical backgrounds and contemporary developments.* Lawrence Erlbaum Associates, Inc.

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, *1*(2), 1-13.

Weber, E., Fox, S., Levings, S. B., & Bouwma-Gearhart, J. (2013). Teachers' conceptualizations of integrated STEM. *Academic Exchange Quarterly*, *17*(3), 47-53.

Wells, J.G. (2013). Integrative STEM education at Virginia Tech: Graduate preparation for tomorrow's leaders. *Technology and Engineering Teacher*, *72*(5), 28–34.

Whitenack, J., & Yackel, E. (2002). Making mathematical arguments in the primary grades. *Teaching Children Mathematics*, *8*(9), 524–527. https://doi.org/10.5951/TCM.8.9.0524

Yin, R. K. (2018). *Case study research and applications: design and methods* (6th ed.). Sage.

Zhong, B., & Xia, L. (2020). A systematic review on exploring the potential of educational robotics in mathematics education. *International Journal of Science and Mathematics Education*, *18*(1), 79–101. https://doi.org/10.1007/s10763-018-09939-y

Zhuang, Y. & Conner, A. (2018). Analysis of teachers' questioning in supporting mathematical argumentation by integrating Habermas' rationality and Toulmin's model. In T. Hodges, G. Roy, & A. Tyminski (Eds.), *Proceedings of the 40th Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 1323-1330). Greenville, SC: University of South Carolina & Clemson University.

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Exploring the Experiences and Perceptions of 21st Century Leadership Academy Participants

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ABSTRACT

The *21st Century Leadership Academy* grew out of an effort by the Council of Technology Teacher Education's (CTTE) Leadership Development Committee to prepare future leaders for the field of Technology & Engineering Education (TEE). Efforts by Drs. Roger Hill (University of Georgia) and Bill Havice (Clemson University) led to the creation, and subsequent implementation, of this leadership academy with support from CTTE (later renamed the Council on Technology & Engineering Teacher Education [CTETE]) and the International Technology & Engineering Education Association (ITEEA). Initially, participation in the leadership academy was focused on early-career university faculty but recruitment was later expanded to include individuals with related professional experience (e.g., graduate students, tenured faculty members, etc.) and, as of January 2021, more than 80 individuals have participated in the academy. This study reports an investigation into the experiences and perceptions of the academy alums with an additional focus on their professional involvement, how participation may have influenced these activities, and suggestions they had for future cohorts. In addition, our investigation provides suggestions for future similar leadership training efforts that could be applied in a variety of fields. Our efforts, as researchers, aim to present the shared experience as navigated by the cohort participants. Although individual takeaways vary, overall themes such as networking and collaboration underscore the experience of participants in each cohort year. While participants consider themselves active in the field of Technology & Engineering Education, few of them are serving in leadership roles within CTETE or ITEEA.

Keywords: Technology and Engineering Education, STEM Education, Professional Development

Technology & Engineering Education (TEE) has a long and somewhat-complicated history (Herschbach, 2009). Rising out of manual arts and then industrial arts, technology education gave way to TEE in the early 2000s (Reed & LaPorte, 2015). Today TEE actively contends for a place in Science, Technology, Engineering, and Mathematics (STEM) education and positions itself as an important part of general education aimed at ensuring a technological and engineering literate society (Daugherty, Carter, & Sumner, 2021). The recent release of *Standards for Technological and Engineering Literacy* (ITEEA, 2021a) represents the latest in these efforts to integrate TEE within the larger STEM community.

Inherent to and undergirding these efforts is the professional development of TEE professionals, critical to the overall success of TEE as a profession and career pathway for young professionals entering the workforce. These professional development efforts include work with TEE teachers, researchers, administrators, and teacher-educators. Despite shrinking numbers in TEE over the past few decades (Moye, 2017), recent successes (e.g., the recently released STEL) suggest a continued role for TEE in STEM and general education. However, for TEE to remain a strong and vibrant profession, leaders who can embrace the ever-changing educational landscape and tackle the unknown are clearly needed but must be encouraged.

This need for leadership development within the TEE community was formally recognized by the CTTE leadership development community in the early 2000s. Recognizing the need to develop leaders, Drs. Bill Havice and Roger Hill submitted a funding proposal for the 21st Century Leadership Academy (21stCLA). This initiative has since involved more than 80 TEE professionals, with participants ranging from classroom teachers to university administrators. While the activities of the participants have evolved over the years, the core goal of preparing future leaders for the field has remained.

Statement of the Problem

Although the 21stCLA has been in place for 15 years, a systematic investigation of the alignment between the stated goals of the academy and participant outcomes has not been conducted. Out of consideration for the efforts of Drs. Havice and Hill, and all those involved over the years with the 21stCLA, an understanding of the impact this initiative has had is needed. Further, the sizable financial investment into this initiative by both the CTTE, and later the CTETE, and the International Technology and Engineering Educators Association (ITEEA) points toward the need for an increased understanding of the impact of the 21stCLA and the perceptions of participants.

Research Aim

To investigate how the 21stCLA has impacted the participants, as well as exploring the extent to which the stated aim has been achieved, we surveyed 21stCLA participants from the 15 years (2006-2021) of the program's existence. Further, we interviewed the founding directors (Drs. Havice and Hill) to explore the history of this initiative and better understand the efforts, changes, and aims of the 21stCLA over the years. These approaches align with our stated research aim to explore the experience(s) and perception(s) of 21stCLA alumni. We believe the findings gleaned through this effort may serve useful in shaping the 21stCLA moving forward and as a check into the impact of the initiative thus far. Further, findings from this effort may be useful for similar leadership initiatives across a wide range of fields and professions.

ITEEA & CTTE/CTETE

To understand the 21stCLA, it is important to understand the professional organization, and associated groups, which support, strengthen, fund, and carry out the 21stCLA. The International

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Technology & Engineering Education Association (ITEEA) and the Council on Technology and Engineering Teacher Education (CTETE) – a council within ITEEA – are the two main organizations supporting the 21stCLA. ITEEA is a professional organization with a long and valued history in the fields associated with TEE and has the following stated mission (ITEEA, 2021b) to:

> *advance technological and engineering capabilities for all people and to nurture and promote the professionalism of those engaged in these pursuits. ITEEA seeks to meet the professional needs and interests of members as well as to improve public understanding of technology, innovation, design, and engineering education and its contributions.*

To this end, ITEEA has played a pivotal role in supporting TEE curriculum in public schools while also helping prepare the next generation of TEE professionals and serving to align the efforts of many people engaged in TEE around a common set of goals and principles. This is evident not only in the produced educational standards, but also in the variety of committees, professional projects, research, and published articles produced by, and/or shared through, ITEEA.

Professional organizations, such as ITEEA, have traditionally been seen as a source for professional growth and other opportunities. Initiatives such as teacher professional development, educational standards, the organization of conferences or forums, and even political campaigns all stem from professional organization efforts (Phillips & Leahy, 2012, Ritz & Martin, 2013). Hanson (1983) argued for such benefits that professional organizations offer – with a specific note to that of "community." A professional community can facilitate open discourse among participants, the exchange knowledge, direct contact with leaders in the field, and an overall strength in number (potential political power) (Hanson, 1983). ITEEA's professional efforts, opportunities (e.g., committee, task forces, etc.) have spanned a variety of initiatives and recent projects have included, but are not limited to, the following (ITEEA, 2021b; Reeve, 1999):

- Foundation for Technology Education (FTE)
- Council on Technology and Engineering Teacher Education (CTETE)
- Council for Supervision and Leadership (CSL)
- Elementary STEM Council (ESC)
- Technology and Engineering Education Collegiate Association (TEECA)
- International Conference on Technology Education (ICTE)
- Pupils Attitudes Toward Technology (PATT)
- STEM Center for Teaching and Learning (STEM CTL)

Further, ITEEA has also collaborated with other professional organizations to embrace the prevalence of the field associated with TEE and to best support its organizational members. Those organizations include, but are not limited to:

- American Association for the Advancement of Science (AAAS)
- Association for Career and Technical Education (ACTE)
- Association for Educational Communications and Technology (AECT)
- American Society for Engineering Education (ASEE)
- Association of Supervision and Curriculum Development (ASCD)
- Association of Technology, Management, and Applied Engineering
- (ATMAE)
- National Science Teachers Association (NSTA)
- Society of Manufacturing Engineers (SME)

As a group within ITEEA, the Council on Technology and Engineering Teacher Education (CTETE) is one of the many councils associated with the ITEEA. Formed in 1950, today's Council on Technology and Engineering Teacher Education (CTETE) was initially called The American Council on Industrial Arts Teacher Education (ACIATE) and later (1986) renamed the Council for Technology Teacher Education (CTTE). Then, in 2012, the organization was once again renamed Council on Technology & Engineering Teacher Education (CTETE). Regardless of name changes, the overall mission of the organization has been to aid in teacher preparation and teacher preparation programs for TEE. CTETE's goals include supporting excellence in technology and engineering teacher education and stimulating research in areas of interest to the profession (CTETE, 2021a). The CTETE has been pivotal in providing focused research opportunities and publications for teacher educators (e.g., yearbooks) and has been a primary editing/review body for the Journal of Technology Education - the premiere peer-reviewed publication for the TEE profession (CTETE, 2021c).

The CTETE structure consists of committees that address concerns/interests of the membership and the community and, as one of these committees, the CTETE's Leadership Development Committee specifically sought to engage young professionals by providing resources to (1) assist professional in succeeding in Technology and Engineering Education, (2) revitalize active and professional research and scholarship, and (3) build a future for the profession (CTETE, 2021b). The 21stCLA specifically represents a funded proposal stemming from the CTETE Leadership Development members to build community and professional development amongst early-career TEE faculty. The program was developed to "facilitate a sense of community and provide activities and resources to support scholarly and professional development opportunities for groups of early career technology education faculty" (Havice & Hill, 2012, para. 1).

The 21st Century Leadership Academy

The 21stCLA began at a strategic planning meeting by leaders of the CTTE at the 2006 ITEEA conference. Drs. Havice and Hill, leaders of the Leadership Development Subcommittee, developed a proposal for a professional development program for young professionals centered on future service and leadership in the profession. The 21stCLA began in 2007 with the following vision which has evolved over the years to reflect technological advances and program evolution (ITEEA, 2021c):

> *This program is providing an opportunity for rising technology and engineering educators from across the country to develop as professional leaders, develop community, and have experiences related to the promotion of technology and engineering education and technological literacy in our schools. Furthermore, the best of practices are being shared throughout different regions of the country via the media technology established in the course of this year long program.*

Havice and Hill determined to hold the academy yearly with a group of young professionals engaging in a series of activities, training, and experiences aimed at providing valuable leadership experience and instruction. Each month, a professional within the ITEEA membership would present on a current topic for approximately one hour followed by thirty minutes of discussion. Further, Havice and Hill decided upon a cohort of six members to ensure a setting conducive to discussion, mentoring, and individual accountability. This decision has continued throughout, and the yearly cohort size remains at six to date. Following the initial cohort, which represented a "trial phase" for different activities, lessons, and discussions, additional refinements were made (D. Lecorchick, personal communication, December 2, 2020).

One of the most significant additions to the program was a group trip to Washington D.C.; this was added to the agenda for cohort members in addition to the presentations, discussions, and other instruction. This trip, commonly referred to as "the D.C. Experience," was added to provide cohort members an opportunity to spend time meeting with several prominent leaders of the field (TEE) and other closely associated fields. Over the years "the D.C. experience" meetings have varied and have included visits to ITEEA, American Society for Engineering Education (ASEE), National Science Foundation (NSF), and National Academy of Engineering (NAE). Inherent in these D.C. trips was the charge to expand participants' understanding of leadership within the technology and engineering education profession, facilitate contacts and collaboration, and engender leadership traits and qualities in cohort members.

At the onset, the initial aim of the 21stCLA (ITEEA, 2021c) was to reach, guide, and grow leaders who were early faculty members at colleges/universities or doctoral students preparing for those roles. This emphasis was seen in the cohort members from the initial years of the program which largely consisted of faculty in TEE programs at 4-year universities. However, this focus was broadened in 2010 when ITEEA directed funding from the Foundation for Technology Education Gerrish funds to support 21stCLA activities. These funds provided additional, and needed, support and also resulted in the program being expanded to include an option for participation by any TEE faculty, K-12 practitioners, and/or administrator (ITEEA, 2021c).

Another development occurred in 2013 when an ITEEA member asked for a regular session at the annual ITEEA conference where 21stCLA alumni could meet and discuss their current research agendas and fellowship with one another. This session was first held in 2014 and has occurred each year since. Further additions to the 21stCLA program have included the expansion of cohort member participation with mid-to-late career professionals and the organization of a yearly research project to be completed by cohort members. These research projects, which are not required but have been strongly recommended, typically begin with the initial cohort meeting (at the ITEEA annual conference) and culminate in a presentation at the following ITEEA conference (D. Lecorchick, personal communication, December 2, 2020). Another adjustment came in 2020 when Havice retired from being a co-director of the academy; his successor is Dr. Douglas Lecorchick, who joined Hill in leading the 21stCLA.

Methods

In line with our stated research objective, this project used multiple approaches to collect data and explore the 21stCLA. The two primary methods used were surveys and interviews. Interviews were conducted with the founding professors of the 21stCLA (Havice and Hill) to better understand the intent of their actions and modifications of the 21stCLA including the input from the CTETE Leadership Development Committee and the CTETE Executive Committee throughout the years. These interviews followed a semi-structured approach (Berg, 2004) where questions were asked about the leadership program including the why, when, how, personal impressions, and so forth. The interview began with an overarching and general question of "Could you speak to how this academy began?" and probing questions followed. In each instance, the interviewer was able to ask follow-up questions to ensure understanding and elicit additional responses for different topics. The results from these interviews are included in the description of the program recounted previously, as well as the discussion section of this piece.

The second step in our inquiry involved the design, development, and deployment of a survey for alumni. The survey was created by the four primary researchers of this project. To create the survey, survey questions were proposed by each of the four contributing researchers (three of which are 21stCLA alumni), and then individually evaluated and assessed by each researcher. When a consensus among the four researchers was reached on the most appropriate questions to ask, those questions were included in a final survey. The researchers used face validity as the primary survey construct where research consensus is typical of this type of research and survey design. Although a construct and content validity methodology may have proved helpful, because the research aim was broad and wasn't aimed at measuring one specific construct, both construct and content validity were not emphasized in this research design (Sireci, 1998). The survey was digitized and created in Qualtrics© to facilitate administration purposes. Although no formal pilot of the survey was administered, each of the researchers took the survey to verify survey function, flow, and accuracy (i.e., if the survey questions addressed the research aim). The researchers then met and discussed any needed changes and came to a consensus prior to finalizing the survey. Once the survey was finalized, the survey was sent through email to each 21stCLA alumni based on their contact that was listed with 21stCLA. However, if alumni had changed email or positions where we did not have contact, they did not receive the survey link. Accordingly, if no response was received, the researchers used Linkedin© and various searches (e.g., personal contacts, Google©) to verify if positions had changed and to try to identify current contact information. In total the researchers were able to identify contact information for 73 of the 86 total participants.

After making these attempts at identifying contact for each participant, all surveys were sent out via email to the 73 participants with confirmed contact information. Each participant was provided a unique link to access the survey and given one week to respond. Following the first week, all non-responding alumni were emailed and/or called, and then provided an additional week to respond to the survey. Following this second round, additional contact (email or phone call) was made to each non-responding participant and one additional week was provided to respond. These efforts resulted in 62 survey respondents out of 73 alumni contacted (85% response rate) (out of 86 total alumni). Although we recognize the data may be biased (e.g., based on people who responded, three of which are authors on this paper) or incomplete (13 of the 86 total participants were not contacted due to outdated contact information), we were unable to otherwise control for this and the associated findings should be taken in light of this limitation.

Following the receipt of all survey responses, all data was collected and aggregated. Data conditioning was performed to remove incomplete entries and facilitate analysis. All data was analyzed to identify emergent themes (Given, 2008) using suggestions by Saldana (2016) for thematic coding. In each instance the responses were reviewed by the researchers, themes identified, and then responses were checked against the identified themes.

Findings

The purpose of the 21stCLA is to build leaders within the field of Technology and Engineering Education. The survey was designed to explore the experiences of participants and explore whether 21stCLA participants have become leaders within the field (TEE) on a national level, i.e., serving in positions or on committees associated to the sponsoring organizations of the field, namely ITEEA and CTETE. The general findings suggest that most participants feel they are active in the field (i.e., attend conferences related to the field), however, their lack of leadership on committees

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associated to the sponsoring organizations led us to wonder "what does it mean to be a leader in the field", and if 21stCLA is helping people to be leaders in the field. The data below highlights our efforts to investigate people's experiences with 21stCLA to understand what may have helped or hindered their investment to becoming a leader in the field. We believe the data provides some insight into a potential disconnect, namely people may feel active within the organization, however, they do not serve in leadership roles. Further research needs to investigate what it means to be "active" in the field – and provide a case for what it means to be "active" outside of professional sponsoring organizations. Notwithstanding that limitation, the findings presented and discussed below do provide an interesting lens to consider whether investing money and time to expose and train people will lead them to a more active role within the field.

Demographics and Highlights. The initial questions of our survey were used to obtain basic demographic information from the participants. At the time of this survey, the majority of 21stCLA participants were employed in higher education (35/58) while others were employed in state, district, or local education positions (16/58) and the remaining were working in a variety of other positions or were retired (7/58). This data point establishes as baseline comparison, where most past participants are in education related positions. This is important because initial acceptance into the 21stCLA required that the participants be in education related positions. Because nearly 88% of the participants are still in education fields, we felt that our initial investigation into what the participants are currently doing, and if they are leaders in the field, was worth pursuing.

To start our investigation, we wanted to first understand why the participants wanted to be part of the 21stCLA. The survey question about the application process showed that most participants were nominated (88%, 52/59) for the 21stCLA. Further, nearly all the alumni shared that they believed that participation in the 21st CLA was recommended to them to help them with "networking and professional development opportunities within the field". Upon further investigation we found that most of the nominations were received from university mentors. Although we can't be certain what it means that majority of participants were recommended by their university mentors, in talking with several of these university mentors we learned that they believed the program would help introduce and connect the participants to the field, which could potentially lead them into a more active role in the profession through networking and understanding of the profession. This finding was further investigated when 21st CLA participants were asked "Why did you choose to participate in the 21st CLA?" Alumni answers contained references to multiple topics and ideas. Each reference was counted individually (resulting in more total references than survey responses), and all were then tallied. The final themes for "why" alumni participated included four main ideas: 1) networking (30%, 25/83), professional development (27%, 22/83), a feeling of obligation (e.g., because they were nominated) (25%, 20/83), and/or leadership skill development (16/83, 19%). Comments from participants included ideas such as:

> *I wanted an experience to hear from other leaders in the field whom I did not get a chance to hear from other ways.*

> *Being able to hear from Mark Sanders about the history of I-STEM, and Bill Dugger [sic] about the creation of the STL are just two examples of things that I will forever remember and helped shape my work and leadership as I moved into*

> *academia. I also wanted the opportunity to work with others from various universities.*
>
> *The cohort itself was appealing because it allowed me to work with others who had diverse backgrounds but had similar interests, and continue working with them on projects beyond the 21st CLA. My graduate advisor also highly recommended I apply so that helped too. Dr. Havice and Dr. Hill were great to work with and I learned a lot from their leadership.*

Alumni were also asked to recount the experiences they remembered from participation and to identify the "highlight" of their participation in the 21stCLA. The reason this question was asked was to understand what were the potential items that could have excited and or taught participants about the profession. Responses included the welcome dinner/event, monthly meetings, networking and collaborating on group projects, and various activities included in the "D.C. experience." The most referenced event was "the D.C. experience". One participant remarked:

> *My favorite experience was traveling to Washington, DC for the two-day meeting where I had the opportunity to network with national/international organizations such as the National Academy of Engineering, National Science Foundation, and International Technology and Engineering Educators Association. I also was very pleased with the monthly meetings and being able to publish a paper with some of the other 21st CLA members.*

According to the directors of the 21stCLA and participants, two pillars of the 21stCLA are the monthly online sessions and the trip to Washington D.C. ("the D.C. Experience"). The respondents of this survey indicated that their overall satisfaction with the monthly sessions was predominantly positive with forty-one out of fifty-eight (70.7%, 41/58) of participants rating the monthly session "somewhat effective" or "very effective".

Forty-six of fifty-seven (80.7%, 46/57) participants selected 'yes' to the question "Do you remember having a Washington D.C. experience as part of your 21stCLA participation?". The reason 11 respondents did not respond yes is likely because the DC experience did not occur twice. It was added after the first year, and then in a later year, there was insufficient funding to include it for that one year. Drs. Havice and Hill confirmed this – sharing that "the D.C. experience began during the second cohort class, and then another year it was canceled because there was insufficient funding for the experience". Out of the respondents who did have the opportunity for "the D.C. Experience," all rated the trip between "somewhat effective" to "very effective" with the majority (88.1%, 37/42) giving this experience the highest satisfaction rating of 5 - very effective.

The DC experience is obviously a memorable event, however, despite participants listing those items they remembered and or felt were helpful because they taught them about the profession, none of the participants reported that the DC Experience outside of being interesting and fun, helped them towards a leadership position within the field. Although in talking with the primary organizers of the 21stCLA they did not state that it was a specific goal of the DC experience, they did share they hoped that the DC experience would further endear participants to the field and would thereby encourage more active participation in the field. While this could

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occur, our data is inconclusive if that did or did not happen. Our data simply states that the DC experience was the most memorable part of the 21stCLA because it was (in the words of a participant) "interesting to visit the headquarters of the organizations in the field and meet with the people who work there." Similarly, the other events that participants recalled from the 21stCLA, namely monthly meetings, appear to have taught participants about the field, but not necessarily encourage participation in the field outside of normal membership in the professional organizations. We surmise that if the monthly meetings had more explicitly invited participants to be leaders in the field on a national level, and provided them rationale, and a "how to" guide to get involved, that more participants may have sought that type of active leadership.

Professional Progression. Survey items sixteen through twenty were centered on the professional progression of the academy participants. The majority of those responding to the survey indicated that they were at the professorial level (39.6%, 21/53) at the time of participation (see Figure 1). This was followed by classroom teachers (28.3%, 15/53), other professionals (17%, 9/53), and graduate students (15%, 8/53); with only four individuals indicated on the survey that (at the time of their participation) they were not directly associated with the field of Technology and Engineering Education (7%, 4/57). This was an important question to ask because it helped establish a baseline of where participants were at the time of participation the 21stCLA, compared with where they currently find themselves.

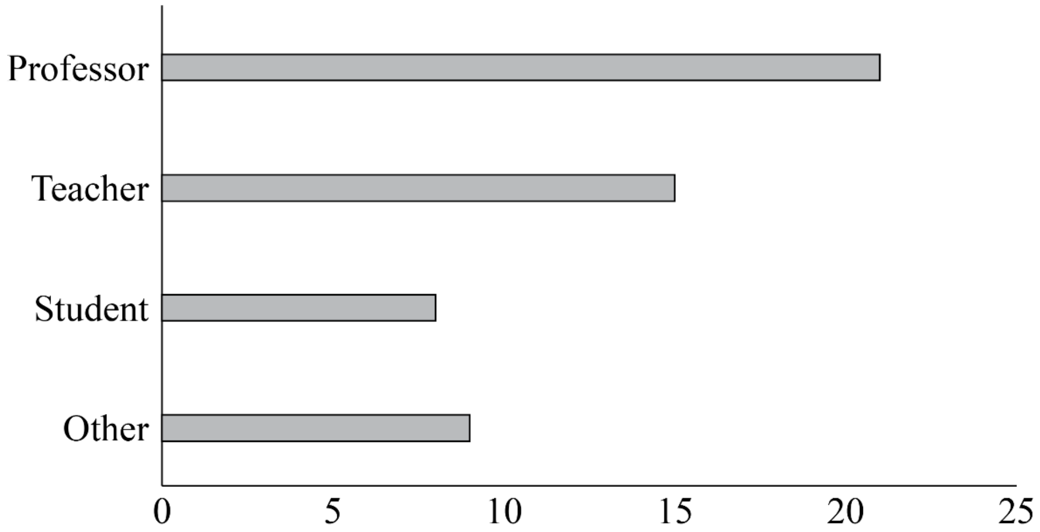

Figure 1. 21stCLA alumni position at the time of participation

Interestingly, following the 21stCLA experience, many of the participants changed positions. Out of the fifty-seven respondents for this question, thirty-five indicated a change in position (61.4%, 35/57) between the time of their participation in the academy and the survey. A closer review of the responses revealed that twenty of the participants who indicated a change in position are now in leadership roles (Directors, Deans, or Coordinators in school districts or universities; 57.1%, 20/35). An additional ten participants (28.6%, 10/35) indicated professional promotions (e.g., from assistant to associate professor), though not specifically into leadership positions. Though this information appears to present positive implications regarding the 21stCLA, more comparative data would need to be collected to establish a causal relationship. The retention rates of similar non-participating professionals would be a potential field of comparison for future research.

The Goals and Mission. Responses from cohort alumni indicated they were aware of the goals and mission of the 21stCLA (ITEEA, 2021c), with forty-seven out of fifty-two (90.3%, 47/52) participants stating those goals were met during their time in the academy. When asked "What benefit(s) do you see from participating in the 21CLA?," the majority of responses (58.9%, 33/56) included networking, and, when asked about current networking strategies, thirty-seven out of fifty-seven (64.9%, 37/57) participants noted that they continue to keep in contact with members of their cohort.

Connection to Technology & Engineering Education. The latter part of the survey investigated professional connections to TEE as a field (e.g.., "What was your commitment to the field prior to and following participation in the 21CLA experience?"). The final questions on the survey explicitly asked whether the participants were "active" in the field; of the 57 respondents, 48 (84%) said they were still "active". Although the definitions of "active" most likely vary among TEE professionals the survey results suggest that "active" is defined as: participation in professional organizations connected to TEE such as ITEEA, CTETE, Technology & Engineering Collegiate Association (TEECA), ASEE, and others that the field is commonly associated with (e.g., Pupils Attitudes Toward Technology, PATT). Those that reported no longer being connected to the field stated their reasons as: received a new position not connected to the field (n = 2), change of career focus (n = 5), and new position is too broad to stay connected (n = 2).

Our survey further investigated the idea of being "active" and "connected" to the field by asking participants about their connection to the field's national sponsoring organization: ITEEA (which is also a sponsoring organization for the 21st CLA). Although the majority said they hold ITEEA membership (83%), only 46% said they serve on or participate on ITEEA committees or affiliate councils such as CTETE, TEECA, etc. This phenomenon needs to be further investigated – why such a low percentage, what level of activity is considered "active" by participants, and where are efforts currently being focused if not in ITEEA activities, events, or efforts? Although we surmise this finding may indicate a lack of knowledge of how to be involved, we are not confident in this guess and instead posit that this may be an area where the 21stCLA could improve. For example, 21stCLA could include a general overview of the ITEEA structure and ways for participants to get and stay involved.

A final phenomenon that was found in the survey data was that most participants stated that their commitment to the field went up after participating in the CLA - regardless of if they found themselves in a position connected to the field or not. A potential reason for this finding is that an enhanced commitment is a result of the community built among the cohort members during the year. It also reinforces the idea that when members of a professional organization interact as a team they identify more closely with the aims and goals of that professional organization (McLean & Akdere, 2015).

Discussion and Conclusion

We set out to explore the experience of 21stCLA alumni with a specific emphasis on how their experience may or may not have aligned with the stated aims of the program. The first and foremost aim of the program is to develop professional leaders. Our analysis of the collected data, although not conclusive, suggests that the program has been successful with many participants

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currently acting in leadership roles and participants responses affirming this perception as well. However, it may be reasonably suggested that "leadership" and "active participation" in the field could mean serving on committee and council responsibilities within ITEEA, CTETE, or in other related fields/organizations. Given the low number of respondents reporting committee/council responsibilities (in or outside of those listed above) (46%, 26/56), some might alternatively argue that the program has not been successful in all regards. Additional research is needed to fully understand this disconnect, i.e., Why are 21stCLA participants continuing to rate themselves as "active" in TEE (84%, 47/56) but not filling leadership and committee assignments?

The second noted aim of the 21stCLA is to "develop community" (ITEEA, 2021c). Our exploratory qualitative analysis of the survey responses suggests that this aim has been met. Many responses to the survey suggested that networking and community were two of the greatest benefits of participation in the 21stCLA. Further, we noted the high response rate to our inquiries for survey participants (72%, (62/86) of all alumni responded to the survey) as a sign of a continuing sense of "community" and connection to the 21stCLA among the alumni.

The third aim of the 21stCLA is to provide "experiences related to technology and engineering education and technological literacy in our schools" (ITEEA, 2021c). Activities related to this aim were clearly listed (e.g., the monthly meetings and other trainings were noted and rated highly in the survey) with the most impactful aspect of the 21stCLA being "the D.C. experience." Alumni repeatedly cited the impact of this experience on their professional growth and, with only a few exceptions, almost all of the 21stCLA participants have experienced this opportunity and noted the benefits. As one participant put it:

> *The DC trip was the biggest highlight, although both ITEEA conferences were important. There is nothing that can beat face to face communication. When talking and learning about leadership and how to build leadership in a community, being in the capital of the US, where the leaders of our nation live, it just makes the entire experience more applicable.*

The last aim noted was to share "best practices". There is some discretion here in terms of assessing how well this aim was met because what constitutes a "best practice" for leadership in TEE is debatable. If "best practices" entails leadership in ITEEA/CTETE committees or councils, it appears that there is room for improvement as a surprisingly low number of academy participants are serving in ITEEA or CTETE (26/57, 46% - as indicated previously). The reason for this low number is not directly identified, but, based upon other data collected, it could be correlated with other conference participation and/or current position requirements focusing on more local events (i.e. state level). Further investigation into these items may help guide future endeavors of the academy as well as identify current trends in the field that may better shape professional and leadership development strategies.

Conversely, if best practices were viewed more broadly to include skills such as publishing, teaching, and mentoring, the overall impact of the 21stCLA may have been greater. Further, its important to note that the impacts of the 21stCLA may extend into other fields and thus not be fully demonstrated on our survey. While a high number of 21stCLA members did move "up" into leadership positions following their participation, many of these were locally focused (e.g., state, district, etc.) rather than nationally and, after reviewing the data, several other professional organizations and conferences were identified by academy participants as areas where they were invested. When questioned, several indicated that their participation in these other organizations varied, but included networking, professional development, and trends in the field (depending on their current position). This presents a few additional items for further discussion and investigation.

When the respondents were asked to provide advice for future cohorts, six common areas of suggested improvements were identified:

1. Having a reunion or ongoing recognition for alumni during the ITEEA conference each year.
2. Selecting a more diverse cohort including elementary school teachers and international participants.
3. Including more face-to-face meetings and activities.
4. Asking alumni to mentor and present to current cohort members.
5. Discuss with the current cohort what topics they would like to hear about during the monthly sessions.
6. Solve a common problem through researching a topic together as a cohort.

These suggestions outline potential action items for the directors of the academy to discuss as the program continues to evolve as well as important considerations for those involved with other leadership development initiatives. In 2020-2021, suggestions 5 and 6 were implemented with the cohort of participants as these cohort members, working under the guidance of the academy's co-directors, collaborated on a research topic involving identifying contemporary trends of online teaching within TEE. Their research will be presented at the ITEEA conference and will also be represented in a refereed journal article submission, a first for most of the participants.

The impact of the 21stCLA has been significant in many ways. We believe that there are many positive takeaways from the 21stCLA and we applaud the efforts of all involved – especially Drs. Havice and Hill. In addition to recognition of these positive impacts, additional areas of future research have been discussed. Perhaps most importantly, why are alumni of the program continuing to rate themselves as "active" in TEE (84%, 47/56) but not filling leadership and committee assignments (26/57, 46%)? Where are the efforts of alumni being spent and how might the 21stCLA be shaped to be more effective? How do non-participating professionals in the field compare to the 21stCLA cohort? The committee will continue to investigate these items as the research and the 21stCLA continue supporting future leadership development in the TEE community.

In summary, after reviewing the data from our research, it appears that the 21stCLA has provided a beneficial experience to many. However, the effectiveness of the 21stCLA in meeting its stated goals to develop leaders, is unclear. Specifically, if the goal of the 21stCLA is to prepare leaders for the field of TEE, what does that mean? Are there expectations that "leaders" will serve and lead committees? Are there other expectations for "leaders" and, if so, how are these defined, by whom, and for what purpose? If the 21stCLA is to become a "win-win" for all involved--both those funding and those participating--it appears that additional work is needed to ensure the maximum return on investment and perhaps clarify the expectations following participation.

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References

Berg, B.L. (2004) *Qualitative Research Methods for the Social Sciences*. 5th Edition, Pearson Education, Boston.

Council on Technology & Engineering Teacher Education (2021a). *About, History*. Retrieved from ctete.org/about/ on February 3rd, 2021.

Council on Technology & Engineering Teacher Education (2021b). *Committees/CTETE Committees.* Retrieved from ctete.org/contact/ on February 3rd, 2021.

Council on Technology & Engineering Teacher Education (2021c). *Publications.* Retrieved from ctete.org/publications/ on February 3rd, 2021.

Daugherty, M., Carter, V., & Sumner, A. (2021). Standards for Technological and Engineering Literacy and STEM Education. *Technology and engineering teacher*, *80*(5).

Given, L. (2008). *The SAGE Encyclopedia of Qualitative Research Methods.* DOI: https://dx.doi.org/10.4135/9781412963909.

Hanson, R. (1983). Gaining and maintaining professionalism, In R.E. Wenig and J. I. Matthews (Eds.) *The dynamics* of *creative leadership for industrial arts education,* 32nd ACIATE yearbook. Bloomington, IL: McKnight Publishing Company.

Havice, W., & Hill, R. (2012). *Foundation for technology and engineering education, international technology and engineering educators association, and council on technology teacher education 21st century leadership academy*. Retrieved from: http://www.iteea.org/Membership/21CenturyLeaders/LeadershipAcademyApplication2014.pdf

Herschbach, D.R. (2009). *Technology education foundations and perspectives*. Homewood, IL: American Technical Publishers.

International Technology and Engineering Educators Association. (2021a). *Standards for technological literacy revision project: Background, rationale and structure*. Reston, VA: Author.

International Technology Education Association. (2021b). https://www.iteea.org/.

International Technology Education Association. (2021c). *21st Century Leadership Academy*. Retrieved on February 10, 2021 from: https://www.iteea.org/Activities/AwardsScholarships/Awards/Twenty-FirstCenturyLeadershipAcademy.aspx

McLean, G. N., & Akdere, M. (2015). Enriching HRD Education Through Professional Organizations. *Advances in Developing Human Resources, 17*(2), 239–261. https://doi.org/10.1177/1523422315572650

Moye, J. J. (2017). The supply and demand of technology and engineering teachers in the United States: Who knows? *Technology and Engineering Teacher, 76*(4), 32-37.

Phillips, B. N., & Leahy, M. J. (2012). Prediction of membership in rehabilitation counseling professional associations. *Rehabilitation Counseling Bulletin*, *55* (4), 207-218.

Reed, P. A., & LaPorte, J. E. (2015). A content analysis of AIAA/ITEA/ITEEA conference special interest sessions: 1978-2014. *Journal of Technology Education*, *26*(3).

Reeve, E. M. (1999). *Professional associations, organizations & other growth opportunities.* In A. F. Gilberti & D. L. Rouch, Advancing professionalism in technology education (pp. 69-96). New York: Glencoe McGraw-Hill.

Ritz, J., & Martin, G. (2013). Perceptions of new doctoral graduates on the future of the profession. *Journal of Technology Studies, 39*(2)

Saldaña, J. (2016). The coding manual for qualitative researchers (3rd ed.). London, England: SAGE.

Sireci, S.G. The Construct of Content Validity. *Social Indicators Research* 45, 83–117 (1998). https://doi.org/10.1023/A:1006985528729

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An Exploration of Communities of Practice in the STEM Teacher Context: What Predicts Ties of Retention?

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ABSTRACT

The STEM teacher workforce in the United States has faced a host of pressing challenges, including teacher shortages, pervasive job dissatisfaction, and high turnover, problems largely attributable to working conditions within schools and districts. These problems have been exacerbated in high-needs districts with fewer resources and more students from low-income communities. Since social network research has shown that workplace relationships are vital for retention, this study investigates the demographic and relational antecedents to what we dub *ties of retention*. We explore how demographic and relational properties affect the likelihood that teachers have "retention-friendly" networks, characterized by connections important for retention. Our analysis of data from a sample of 120 STEM teachers across five geographic regions identifies key demographics (i.e., site, gender, career changer, and prior teaching experience) and relational properties (network size, positive affect, and perceptions of bridging) associated with ties of retention. We discuss the implications of our findings for the STEM teacher workforce and for teacher education programs.

> *"I think another thing as far as retention of teachers goes is department/dynamics/support/cohesiveness. It makes a world of difference to have coworkers that are supportive. And difficult coworkers can make work miserable. New teachers often are hesitant to go to administration for help but are more willing to ask a veteran teacher and not feel judged, so building those relationships among teachers is key." (Jenny Blue, High School Science Teacher).*

There have been historic and persistent shortages of teachers in the US workforce, a problem that has worsened due to the COVID-19 pandemic (Bailey & Schurz, 2020; Hutchison, 2012; Lachlan et al., 2020; Steiner & Woo, 2021; Sutcher et al., 2016). The problem has been exacerbated by high turnover among new teachers and is especially salient among science, technology, engineering, and mathematics (STEM) teachers working in high-needs districts (Ingersoll et al., 2021; Ingersoll & Strong, 2011; Sutcher et al., 2016). This is a national concern since students from low-income communities especially need good role models and quality education for economic empowerment and upward mobility (Berry, 2008; Gershenson et al., 2018; Ofem et al., 2021). Instability in a school's teacher workforce negatively affects student achievement, diminishes teacher effectiveness and quality, and consumes economic resources that could be deployed elsewhere. Filling a vacancy costs $21,000 a year on average, costing an estimated $8 billion a year nationally (Garcia &Weiss 2019); and the opportunity costs of lower student achievement at these critical life stages could be even greater.

This study aims to advance knowledge on the ongoing high turnover problem by exploring the following research question: What workplace conditions affect the likelihood of retention among STEM teachers working in high-needs districts? Since social network research has established that workplace relationships are vital for retention (Ballinger et al., 2016), we investigate the demographic (i.e., attributes of the teachers) and relational antecedents (i.e., attributes of their relationships) to what we dub *ties of retention*. As the opening quote illustrates, promoting retention occurs through the modality of relationship. People are more likely to stay in a workplace characterized by more positive and supportive ties (Coyle, 2018). We explore how teacher demographics and properties of workplace ties affect the likelihood that teachers have "retention friendly" networks, characterized by connections identified as important for retention. We present ties of retention as a useful construct for research on turnover, and investigate its cofactors in data from a sample of 120 middle and high school science and mathematics teachers working in high-needs districts across five geographic regions in the US.

We first describe the distinctive features of social network analysis. Next, we present our methods and analysis, and document patterns we observe in our new STEM teacher dataset in predicting ties of retention. We then discuss the broad implications of our findings for theory and

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practice. We do this while making the case for the dual wielding of human and social capital approaches in tackling the voluntary turnover problem across schools and districts. Furthermore, we contend that this approach is useful for teacher educators equipping this critical workforce with the right knowledge, skills, abilities, and other characteristics (KSAOs) to succeed in their early years of in-service.

Theoretical Framework

The fundamental insight of social network analysis (SNA) is that individual behavior is best understood in the context of social relationships, which can be modeled with a social network perspective (Borgatti & Ofem, 2010). A social network consists of a set of nodes and ties, where the nodes are the social actors (e.g., people, teams, schools), and the ties are the relationships between them (e.g., friendships, information sharing, trust). The structure and composition of social networks have important implications for the social actors within them. They serve as *pipes* through which information, resources, and influence flow; *bonds* facilitating cooperative action; and *prisms* signaling status to network observers (Borgatti & Ofem 2010). The network lens has exploded across the social sciences over the past few decades, and scholars have applied it to understanding human resource outcomes such as organizational attachment and employee turnover (Ballinger et al., 2016).

For educational researchers and teacher preparation programs, this relational perspective is crucial for theory and practice. Relationships constitute the most critical feature of the workplace, so understanding how their patterning affects teachers' perceptions, attitudes, and behaviors is essential for promoting retention. The network lens provides analytical tools and constructs for diagnosing, treating, and innovatively solving problems of retention (Cross et al., 2018).

Explaining Retention

Scholarship around retention has generally followed a traditional mode of explanation in the social sciences that focuses on the characteristics of entities to predict outcomes. In this view, retention is explained in terms of how characteristics of the organization (e.g., selection processes, onboarding practices, work design, promotion and compensation packages, etc.) impact characteristics of the individual (e.g., knowledge, skills and abilities) that make them more likely to stay (Cross et al., 2018). Or, they use other characteristics of the individual (e.g., age, prior experience) to predict voluntary turnover (Ingersoll, 2001). These explanations/antecedents have an atomistic quality in the sense that individual outcomes are considered in isolation and use a *human capital* lens.

In contrast, SNA points to the importance of *social capital*, which refers to the relational advantages available to social actors due to their position within a larger network (Adler & Kwon, 2005). In this mode of explanation, characteristics of the social actor and the social environment (i.e., social network) are used to explain organizational outcomes. Over a decade of research across dozens of organizations has shown that social network measures predict retention better than typical human capital measures (Ballinger et al., 2016; Cross et al., 2018). Yet, research has only begun expanding the suite of social capital measures, beyond simple measure of network size, to explore what factors matter the most for voluntary turnover and retention for new STEM teachers across schools, districts, and/or the overall teaching profession.

In this study, we apply an egocentric approach to investigate the demographic (i.e., site of teacher preparation, prior teaching experience, career changer, age, and gender) and relational (i.e., instrumental and expressive ties) correlates of what we dub *ties of retention*, characterized by connections identified as important for retention. Thus, this study is primarily a *theory of network* study that aims to predict why some teachers report more ties identified as important for their retention than other teachers. The outcome variable we explore is based on the commonsense notion that teachers are more likely to stay in their school/profession if they have people contributing to their *perceived desirability* to remaining in their school/profession. This perceived desirability is especially critical for retaining STEM teachers in high-needs districts that face additional stressors and resource constraints.

In sum, our guiding theory is this: Demographics (i.e., characteristics of the teachers) and network properties (i.e., characteristics of their networks) both contribute to whether teachers' ego networks consist of ties deemed important for retention. Demographic and network properties are both associated with resources that help or hinder the *perceived desirability* of remaining in the school/profession, contributing to job satisfaction and retention. The dual wielding of human and social capital approaches is the best way to study and manage voluntary turnover (Cross et al., 2018). Individual differences *and* networks both matter for predicting ties of retention for new STEM teachers working in high-needs districts.

Methods

Data Collection

The study sample was drawn from a pool of teachers with recent involvement in a teacher preparation program from five higher education institutions awarded a Robert Noyce Teacher Scholarship Program grant by the National Science Foundation. The Noyce programs are designed specifically for preparing teachers to work in high-needs districts, which have more serious problems with recruitment and retention (Kirchhoff & Lawrenz, 2011). The pool of teachers in our sample completed Noyce programs that spanned institutions in the Midwest, Northeast, and Southeast parts of the United States.

We designed an online survey to capture teacher demographics (i.e., personal characteristics and attributes) and network characteristics (i.e., properties of their ego networks). To collect the demographic variables, we included items in the survey that asked about personal characteristics (e.g., age, gender, prior teaching, etc.). To collect the network variables, we used a *name generator*, followed by more detailed questions in the *name interpreter* about the nature of each teacher's professional contacts. On the basis of Coburn et al.'s (2013) finding that interactions based on teaching expertise are a sustainable feature in teacher networks, we asked each teacher this question as part of the name generator: "*Who do you interact with on matters pertaining to teaching content and/or pedagogy?*" Since professional ties occur beyond a given school, we asked this question for the school, district, state, and national levels. We then asked, as part of the name interpreter, more detailed questions about each relationship (e.g. frequency of interaction, importance to retention, etc.). These series of questions form the basis of a teacher's community of practice (CoP), which in network terminology we define as the teacher's professional *ego network*. The ego is the teacher, and the alters constitute their professional network pertaining to teaching content and/or pedagogy.

After crafting the survey, we piloted the instrument with a small group of teachers at a participating institution, which resulted in a few revisions to improve survey design and item clarity. We then distributed surveys via email to approximately 431 teachers who went through these various teacher preparation programs, which generated 166 responses for a completion rate of 38.5%. There were 159 full responses due to missing data in seven survey responses. Of those, 120 respondents identified working in a high needs district, and that is the focus of this analysis.

Dependent Variable

Ties of retention. This is the key variable we aim to explore the correlates of in this study. *We define ties of retention as those ties identified by a focal teacher as important for their retention in the school and/or teaching profession*. We measured ties of retention in two ways. Total strength (TS) of retention is the sum of valued ties of retention (0, 1, 2); where 0 is not important, 1 is somewhat important, and 2 is very important for a teacher's retention. These come from the network survey items that required respondents to rate the importance of each alter on a three-point, Likert-type scale. For example, if someone has three ties and all were rated as somewhat important, TS would equal 3 (1 + 1 +1). Total number (TN) of strong ties of retention is the number of ties identified as very important (1) for retention, 0 otherwise. For example, if someone has three ties and all were identified as somewhat important or not important, TN would equal 0 (0 + 0 + 0), since none of the alters (i.e., contacts) were rated as very important. TN is essentially a dichotomized variable that makes two the threshold of a very important tie. These two operationalizations allow us to get at the same idea in two different ways. The hope is that we will see consistent effects of the demographic and relational variables on these two operationalizations, adding to the robustness of our findings.

Demographics

Based on the work of Ofem et al. (2020), we considered key demographic/attribute variables that could impact perceptions of ties of retention.

Gender. Gender is measured dichotomously, with 0 representing female and 1 representing male. Gender is a social construction that affects a variety of organizational outcomes. Gendered and socialization processes could lead to differences in how teachers perceive their ego networks (i.e., more or less ties of retention).

Age. Age is measured in years as a count variable of the length of life. Age, like gender, is associated with socialization processes that could lead to differences in how teachers perceive their ego network.

Career changer. Career changer refers to whether the respondent had a previous career prior to becoming a teacher. This could affect socialization patterns and ties identified as important for retention.

Prior teaching experience. Prior teaching experience is a count measure of the total number of years teaching prior to the current school year. This, too, could affect socialization patterns and the perception of ties identified as important for retention.

Site. To explore differences across the five sites that provided teacher training, we created four dummy variables to represent the four universities. This allows us to statistically account for differences in teacher preparation, geography, and other unobservable fixed effects.

Relational Properties

Upon our knowledge of the social context (i.e., middle and high school STEM educators), a pilot test, and related literature from this context (e.g., Ofem et al., 2020), we selected measures that captured both instrumental and expressive ties. We calculated ego network size, the frequency of interaction, the expressive relation of positive affect, and perceptions of bridging (i.e., structural holes).

*Network size***.** Network size is a count measure of the total number of alters (i.e., contacts) identified in a teacher's professional ego network (i.e., community of practice). More ties could provide more resources and social support. Conversely, too many ties could be overwhelming and/or costly for new teachers (Cross et al., 2018).

*Frequency of interaction***.** The frequency of interaction with each alter was measured on a 5-point scale, where 1 is "once a year" and 5 is "daily." We then calculated the sum of the total level of interaction between the ego and their set of alters. This measure captures the overall level of interaction within the teacher's ego network. Greater involvement with other teachers measured through interaction could affect how teachers describe their ego network (e.g., more or less ties of retention).

*Positive affect***.** We measured positive affect through the operationalization of *energizing ties*. We measured an energizing relationship on a 5-point scale, where 1 is "mostly de-energizes" and 5 is "mostly energizes." Energizing ties is the sum total of an ego's valued ratings of each alter along this relational dimension. This measure is based on the idea that some relationships energize and some do not (Gerbasi et al., 2015). We theorize that ego networks characterized by more positive affect, measured through energizing ties, should be more likely to consist of "ties of retention." Energizing ties, due to the psychological safety they inspire, should be more likely to co-occur with ties of retention.

Perceptions of bridging. Bridging (or brokerage) is the extent to which a person bridges different people or groups who are not connected to one another. It comes with control and information benefits. We measured this using Mehra et al.'s (2014) visual network scale. This methodological innovation in social network measurement makes it more efficient, and less burdensome on respondents, to collect network data on perceived ego network structure. It consists of stylized depictions of network properties. Figure 1 depicts the scale we used. It reflects the extent to which a teacher perceives themselves in a bridging position, meaning the extent to which they possess structural holes (i.e., a lack of connection between alters).

Analysis

Our analysis begins with a general description of the data. We provide the summary statistics of variables and the correlation matrix, and make notable observations. Next, to address our research question, we use Poisson regression to model our two measures of ties of retention, tie strength (TS) and total number (TN). This model specification is appropriate for variables with a count distribution. The ties of retention fit this criterion since both operationalizations have discrete probability distributions, as opposed to the normal distribution required for normal parametric statistical tests. Poisson regression is appropriate for outcome variables that take the form of events, counts, incidence, and rates. It is a generalized linear model (GLM) that is part of the log-linear family of statistical tests. With the assumption that a Poisson process underlies the events of interest, Poisson regression finds maximum-likelihood estimates of the β parameters (Hamilton, 2012).

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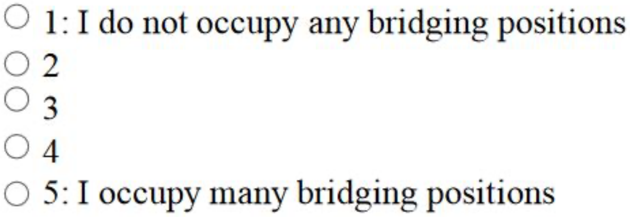
In the diagram below, there are two groups of people. The large circle that connects the two groups can be thought of as a bridge. A bridge connects two groups, or even two people, who are not connected to each other. Without the bridge, the two groups or two people would not interact.
Using the scale below, please rate the extent to which you think you occupy a bridge position in your OVERALL personal network of professional contacts related to teaching content and/or pedagogy.



○ 1: I do not occupy any bridging positions
○ 2
○ 3
○ 4
○ 5: I occupy many bridging positions

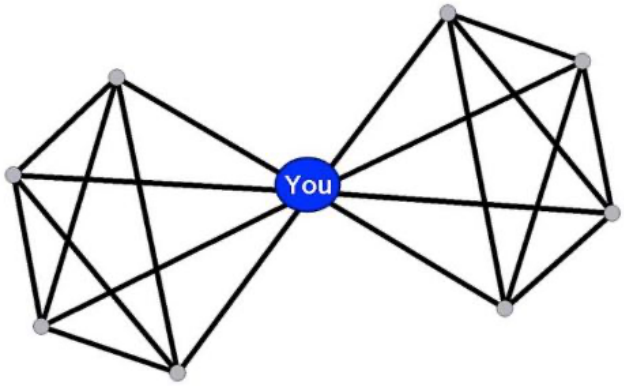


Figure 1. Visual Network Scale

Results

To paint a fuller picture of our data set, Table 1 below shows the mean, standard deviation, minima and maxima, of all the variables in this study. Table 2 is a correlation table for all the variables used in our analysis. A few notable observations: 1) A majority of the study participants are female (i.e., 61%); 2) most of the study participants have limited teaching experience (i.e., mean of 3.56); 3) approximately half of the study participants had a previous career before becoming a teacher (i.e. mean of .46); and 4) the network measures (i.e., retention strength, retention size, network size, frequency of interaction, total energizing, and bridge overall) all show significant variability in their distributions. In addition, the network variables show significant correlations with the two outcome variables, total strength (TS) and total number (TN) of ties of retention. These initial observations empirically support the premise of this article—that *properties of workplace relationships*, above and beyond sheer size, is where a lot of the cultural action is in analyzing workplace dynamics.

Table 1
Summary Statistics

	Mean	SD	Min	Max
Retention strength	9.22	7.53	0	40
Retention size	2.78	3.55	0	19
Kentucky	0.24	0.43	0	1
Minnesota	0.16	0.37	0	1
Wisconsin	0.2	0.41	0	1
Kennesaw	0.21	0.41	0	1
Gender	0.39	0.49	0	1
Age	32.98	8.17	23	63
Career changer	0.46	0.5	0	1
Years teaching	3.56	3.6	0	24
Network size	9.89	6.24	0	38
Total frequency	34.26	20.14	0	124
Total energizing	40.54	26.51	0	155
Bridge overall	2.66	0.98	1	5

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Table 2

Correlations

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Total strength (TS)													
2	Total size (TN)	0.88												
3	Kentucky	-0.14	-0.09											
4	Minnesota	0.15	0.2	-0.25										
5	Wisconsin	-0.1	-0.16	-0.28	-0.22									
6	Kennesaw	0.02	-0.03	-0.29	-0.23	-0.26								
7	Gender	0.05	0.04	-0.06	0.05	0.05	-0.09							
8	Age	-0.12	-0.15	-0.27	-0.23	0.57	0.14	0.07						
9	Career changer	-0.12	-0.18	-0.29	-0.1	0.42	0.23	-0.04	0.56					
10	Prior teaching	0.11	0.06	-0.01	-0.17	0.01	0.25	0.04	0.3	-0.12				
11	Network size	0.46	0.27	-0.16	0	-0.18	0.38	-0.12	-0.01	0.06	0.38			
12	Frequency	0.52	0.33	-0.14	0.01	-0.19	0.24	-0.1	-0.05	0.03	0.28	0.94		
13	Energizing ties	0.53	0.35	-0.18	0	-0.15	0.37	-0.13	0.01	0.08	0.37	0.98	0.93	
14	Bridging	0.2	0.14	-0.14	-0.03	-0.07	0.13	-0.07	-0.01	-0.03	0.25	0.32	0.33	0.34

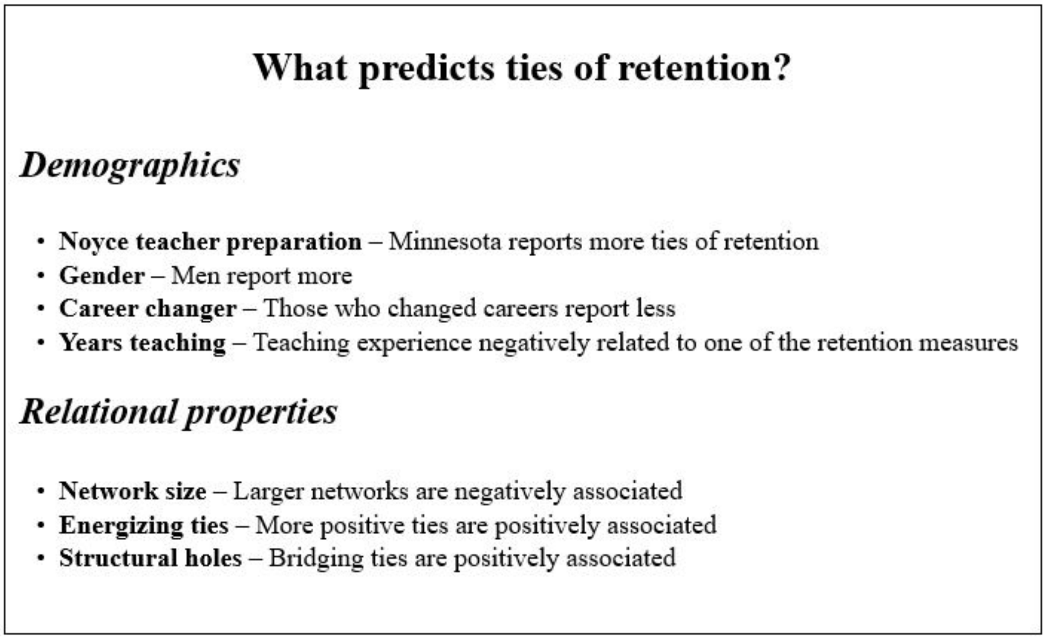
$p < .05$ if $|R| > 0.19$

To better tease out the individual effects of our predictor variables on ties of retention, Table 3 shows the result of two Poisson regression models with the two operationalizations of the dependent variable (i.e., TS and TN). In regard to the demographic variables, we find statistically significant correlations with the Noyce teacher preparation site (β = .27 and .41, with p < .01 and .05, respectively); gender (β = 24 and .26, with p < .001 and .05, respectively); career changer (β = -.21 and -.36, with p < .05 and .05, respectively); prior teaching experience (β = -.04 with p < .001); (β = -.21 and -.36, with p < .05 and .05, respectively). In regard to the network properties, we find statistically significant correlations with network size (β = -.12 and -.24, with p < .001 and .001, respectively); total energizing ties (β = .04 and .07, with p < .001 and .001, respectively); and total bridging ties (β = .09 and .15, with p < .01 and .01, respectively

Table 3

Predicting Ties of Retention

	Total strength	Total number
Kentucky	-.01	-.06
Minnesota	.27**	.41*
Wisconsin	.17	-.17
Kennesaw	-.03	-.18
Gender	.24***	.26*
Age	-.01	-.01
Career changer	-.21*	-.36*
Years teaching	-.04**	-.03
Network size	-.12***	-.24***
Total frequency	.00	.00
Total energizing	.04***	.07***
Bridge overall	.09**	.15*
Constant	1.62	.36
Log likelihood	-421	-275
Pseudo R2	.25	.22



What predicts ties of retention?

Demographics

- **Noyce teacher preparation** – Minnesota reports more ties of retention
- **Gender** – Men report more
- **Career changer** – Those who changed careers report less
- **Years teaching** – Teaching experience negatively related to one of the retention measures

Relational properties

- **Network size** – Larger networks are negatively associated
- **Energizing ties** – More positive ties are positively associated
- **Structural holes** – Bridging ties are positively associated

Figure 2. Summary of Findings

Figure 2 above summarizes our findings. In keeping with our social network approach, we again organize our predictor variables by demographics (i.e., attributes) and relational (i.e., network) properties.

Discussion

This article advances the ongoing conversation about the turnover problem among new STEM teachers, a historic and enduring problem that has surely been exacerbated by the COVID-19 pandemic (Lachlan et al., 2020; Steiner & Woo, 2021). Our goal in this paper is to demonstrate a broader way to think about turnover based on the application of a Social Network Analysis model. Instead of looking solely at characteristics of the person or features of the environment, this paper points to the importance of considering both demographic *and* network features in predicting retention. We find that demographics (i.e. site of Noyce preparation, gender, career changer, and years teaching) and network features (i.e. network size, energizing ties, and structural holes) are all correlated with ties of retention. We now consider why these effects are there. In terms of the site of the Noyce preparation site, the Minnesota site is positively related to ties of retention. This could be due to a couple processes: 1) Teachers who went through this program may be more likely to teach in disadvantaged districts, increasing the likelihood that they really need ties of support in the workplace. 2) Conversely, teachers from this site may have picked up advantageous social skills, through cohort program structures, that helped them connect early on with their peer teachers. Future work could fruitfully explore these possibilities.

In terms of gender, men report more ties of retention than women. This could be due to the underrepresentation of men in the teaching workforce and a greater need for support in tackling classroom challenges (Ofem et al., 2021). Conversely career changers and prior teaching experience are both negatively associated with ties of retention. This could be due to the greater self-efficacy and confidence that comes with a prior career and prior teaching experience. Teachers with such prior experience may be less dependent on peer teachers in carrying out their job functions. Again, future work could explore these possibilities

In terms of network properties, we find that positive affect (i.e., energizing ties) and perceptions of bridging (i.e., structural holes) increase the likelihood that new teachers identify colleagues in their workplace as important for retention. The explanation for these positive network affects can be attributed to the social capital associated with such beneficial network structures. Teachers connected to "energizing" individuals and that bridge structural holes are more likely to value their networks, increasing the likelihood that they identify others in their ego networks as "important for retention". Conversely, sheer ego network size is negatively associated with ties of retention. This could be due to the burdensome effect of having too many relational obligations.

In sum, we need to combine the traditional human capital approaches with social capital approaches in modeling voluntary turnover (Cross et al., 2018). This should include both demographics of the workforce, features of induction programs, and properties of workplace relationships. People stay at their jobs not only because they see a fit between their own background and preferences (i.e. person-environment fit), but also because of the social networks that push or pull them in certain directions (Cross et al., 2018). Our findings point to the importance of healthy relationships and culture in tackling the high school turnover problem among new STEM teachers working in high-needs districts.

Implications for Practice

Directing scholarly attention to the overall patterning/structure of teachers' professional ego networks is a useful diagnostic lens. A social network approach is aptly suited for studying and addressing problems of voluntary turnover (Ballinger et al, 2016). For example, the *ties of retention* construct, which we conceived for this study, could be a useful litmus test in diagnosing a school's culture. We would expect more positive and healthy ties and ones important for retention in schools that have healthier and more positive cultures. To build such healthy cultures, schools should focus on establishing and maintaining relationship-focused school cultures. They need to make everyone feel like they belong. Healthy cultures contribute to "energizing ties" that promote employee wellbeing and happiness, reducing the likelihood of voluntary turnover. It is the responsibility of school leaders to effectively demonstrate the social and emotional skills required to support one another (and their students) in challenging environments (Hoerr, 2020). This includes encouraging and cultivating positive ties. A growing body of evidence suggests that developing teachers' social and emotional competencies improves teacher well-being, reduces stress and burnout, and can reduce teacher turnover (Hoerr, 2020). In addition, our findings point to the importance of teachers bridging different people in their professional network. This likely gives them more autonomy and influence, contributing to their wellbeing and intention to stay in the school/profession.

In keeping with the tenets of social emotional learning (SEL; Hoerr, 2020), here are a few more specific and actionable ideas for promoting retention among new STEM teachers:

1. ***Demonstrate trust*** – Practice giving autonomy, voice, shared governance, and professional development opportunities to teachers and administrators.
2. ***Create a positive school culture***. Create policies that reward social support, peer mentoring, resilience, and boundary spanning in employees.

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3. ***Encourage the right networks at the right time***. New employees have different needs. Design targeted policies that facilitate mentorship and collegiality for employees who need it the most (Cross et al., 2018).
4. ***Measure correlates of teacher well-being, including both demographic and relational variables.*** Nearly 1 in 4 teachers reported that they were likely to leave their jobs in the 2020-2021 school year. Measuring the workplace conditions that affect that desire to leave is essential to improving turnover (Steiner & Woo, 2021).

Our study also offers some practical value for teacher educators and teacher preparation programs. Our study documents the importance of helping pre-service teachers become more cognizant of their professional networks and their effects (Korthagen et al., 2006; Polizzi et al., 2019; Polizzi et al., 2021). Our data provide evidence that networks do matter for retention, and this is information that educational policymakers and STEM teacher educators can use as they design programs to better equip our teacher workforce for the social realities of this critically important vocation (Eckman et al., 2016; Lambert et al., 2018; Theisen-Homer, 2021). Furthermore, our study opens up a new line of inquiry around our concept of “ties of retention”. We encourage future work to explore this construct more deeply and further specify the relational and demographic factors associated with it.

Conclusion

This study models a social network approach to exploring the factors associated with *ties of retention*, a construct we define as workplace relationships identified as important for STEM teacher retention in the school/profession. Our analysis of 120 new STEM teachers working in predominantly disadvantaged districts reveals both demographic (i.e., teacher preparation site, gender, career changer, years teaching) and relational (i.e., network size, positive affect, and perceptions of bridging) factors associated with ties of retention. We contend that ties of retention are directly associated with the *perceived desirability* of staying, and formulate practical tips to help school leaders address the ongoing and persistent turnover problem. We further argue that this relational lens can be useful in preparing new teachers for the social realties that they will face on the job. We hope our study inspires more research that considers the demographic and relational antecedents to voluntary turnover, especially among our STEM teacher workforce in high-needs districts.

References

Adler, P. S., & Kwon, S. W. (2002). Social capital: Prospects for a new concept. *Academy of Management Review*, *27*(1), 17-40.

Bailey, J. P., & Schurz, J. (2020). COVID-19 is creating a school personnel crisis. *American Enterprise Institute*. https://files.eric.ed.gov/fulltext/ED606250.pdf

Ballinger, G. A., Cross, R., & Holtom, B. C. (2016). The right friends in the right places: Understanding network structure as a predictor of voluntary turnover. *Journal of Applied Psychology*, *101*(4), 535.

Berry, B. (2008). Staffing high-needs schools: Insights from the nation's best teachers. *Phi Delta Kappan*, 89(10), 766-771.

Borgatti, S. P., & Halgin, D. S. (2011). On network theory. *Organization Science*, *22*(5), 1168-1181.

Borgatti, S. P., & Ofem, B. (2010). Overview: Social network theory and analysis. In A. J. Daly (Ed.), *Social network theory and educational change* (pp. 17-31). Harvard Education Press.

Coburn, C. E., Mata, W. S., & Choi, L. (2013). The embeddedness of teachers' social networks: Evidence from a study of mathematics reform. *Sociology of Education*, *86*(4), 311-342.

Coyle, D. (2018). *The culture code: The secrets of highly successful groups*. New York, NY: Bantam Books.

Cross, R., Opie, T., Pryor, G., & Rollag, K. (2018). Connect and adapt: How network development and transformation improve retention and engagement in employees' first five years. *Organizational Dynamics*, 47, 115–123.

Eckman, E. W., Williams, M. A., & Silver-Thorn, M. B. (2016). An integrated model for STEM teacher preparation: The value of a teaching cooperative educational experience. *Journal of STEM Teacher Education*, *51*(1), 8.

Garcia, E., & Weiss, E. (2019). *US schools struggle to hire and retain teachers: The second report in "The perfect storm in the teacher labor market*" Series. Economic Policy Institute. https://files.eric.ed.gov/fulltext/ED598209.pdf

Gerbasi, A., Porath, C. L., Parker, A., Spreitzer, G., & Cross, R. (2015). Destructive de-energizing relationships: How thriving buffers their effect on performance. *Journal of Applied Psychology*, *100*(5), 1423.

Gershenson, S., Hart, C., Hyman, J., Lindsay, C., & Papageorge, N. W. (2018). The long-runimpacts of same-race teachers (No. w25254). National Bureau of Economic Research.

Hamilton, L. C. (2012). *Statistics with Stata: Version 12*. Cengage Learning.

Hoerr, T. R. (2020). *The formative five: Fostering grit, empathy, and other success skills every student needs*. Alexandria, VA: ASCD.

Hutchison, L. F. (2012). Addressing the STEM teacher shortage in American schools: Ways to recruit and retain effective STEM teachers. *Action in Teacher Education*, *34*(5-6), 541-550.

Ingersoll, R. M. (2001). Teacher turnover and teacher shortages: An organizational analysis. *American Educational Research Journal*, *38*(3), 499-534.

Ingersoll, R., Merrill, E., Stuckey, D., Collins, G., & Harrison, B. (2021). The demographic transformation of the teaching force in the United States. *Education Sciences*, *11*(5), 234.

Ingersoll, R. M., & Strong, M. (2011). The impact of induction and mentoring programs for beginning teachers: A critical review of the research. *Review of Educational Research*, *81*(2), 201-233.

Kirchhoff, A., & Lawrenz, F. (2011). The use of grounded theory to investigate the role of teacher education on STEM teachers' career paths in high-need schools. *Journal of Teacher Education*, *62*(3), 246-259.

Korthagen, F., Loughran, J., & Russell, T. (2006). Developing fundamental principles for teacher education programs and practices. *Teaching and Teacher Education, 22*(8), 1020-1041.

Lachlan, L., Kimmel, L., Mizrav, E., & Holdheide, L. (2020). Examining the Impact of COVID-19 on the Teaching Workforce. *American Institutes for Research.* https://gtlcenter.org/sites/default/files/Examining_Impact_COVID19_Workforce.pdf

DOI: 10.30707/JSTE57.1.1664998343.93078

Lambert, J., Cioc, C., Cioc, S., & Sandt, D. (2018). Making connections: Evaluation of a professional development program for teachers focused on STEM integration. *Journal of STEM Teacher Education*, *53*(1), 2.

Mehra, A., Borgatti, S. P., Soltis, S., Floyd, T., Halgin, D. S., Ofem, B., & Lopez-Kidwell, V. (2014). Imaginary worlds: Using visual network scales to capture perceptions of socialnetworks. In D. J. Brass, G. Labianca, A. Mehra, D. S. Halgin, & S. P. Borgatti (Eds.), *Contemporary perspectives on organizational social networks* (pp. 315-336). Emerald Group.

Ofem, B., Polizzi, S.J., Rushton, G.T., Beeth, M., Couch, B., Doering, J., Konz, R., Mohr-Schroeder, M., Roehrig, G. and Sheppard, K., (2021). Looking at our STEM teacher workforce: How to model self-efficacy. *Economic Development Quarterly*, 35(1), 40-52.

Polizzi, S. J., Ofem, B., Coyle, W., Lundquist, K., & Rushton, G. T. (2019). The use of visual network scales in teacher leader development. *Teaching and Teacher Education*, *83*, 42-53.

Polizzi, S.J., Zhu, Y., Reid, J.W., Ofem, B., Salisbury, S., Beeth, M., Roehrig, G., Mohr-Schroeder, M., Sheppard, K. and Rushton, G.T. (2021). Science and mathematics teacher communities of practice: Social influences on discipline-based identity and self-efficacy beliefs. *International Journal of STEM Education*, *8*(1), 1-18.

Steiner, E.D. & Woo, A. (2021). Job-related stress threatens the teacher supply: Key findings from the 2021 State of the U.S. Teacher Survey. Santa Monica, CA: RAND Corporation, https://www.rand.org/pubs/research_reports/RRA1108-1.html

Sutcher, L., Darling-Hammond, L., & Carver-Thomas, D. (2016). A coming crisis in teaching? Teacher supply, demand, and shortages in the U.S. *Learning Policy Institute*. https://files.eric.ed.gov/fulltext/ED606666.pdf

Theisen-Homer, V. (2021). Preparing teachers for relationships with students: Two visions, two approaches. *Journal of Teacher Education*, *72*(3), 271-283.

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