

# Journal of STEM Teacher Education

---

Volume 58 | Issue 1

Article 7

---

2023

## Volume 58-1 Complete Issue

Follow this and additional works at: <https://ir.library.illinoisstate.edu/jste>

---

### Recommended Citation

(2023) "Volume 58-1 Complete Issue," *Journal of STEM Teacher Education*: Vol. 58: Iss. 1, Article 7.

DOI: <https://doi.org/10.61403/2158-6594.1520>

Available at: <https://ir.library.illinoisstate.edu/jste/vol58/iss1/7>

This Complete Issue is brought to you for free and open access by ISU ReD: Research and eData. It has been accepted for inclusion in Journal of STEM Teacher Education by an authorized editor of ISU ReD: Research and eData. For more information, please contact [ISURed@ilstu.edu](mailto:ISURed@ilstu.edu).



## Articles

---

- 1 Teachers' Perceptions on Women in STEM: Breaking the Stereotypes  
*Lili Zhou, Alankrita Chhikara, Stephanie Oudghiri, Araba A. Z. Osei-Tutu, Razak Kwame Dwomoh*
- 21 Designing a Program to Develop Computer Science Master Teachers for an Underserved Rural Area  
*Susie Morrissey, Thomas Koballa, Robert Allen, Judy Godfrey, Michael Dias, Shawn Utley, and DeAnnia Clements*
- 41 Impact of Covid-19 Pandemic on Experienced Introductory STEM Instructors' Teaching Practices  
*Sarah Boesdorfer*
- 50 Pre-service Science Teachers' Understanding of Science and Engineering Practices, Engineering Design Process, and Scientific Inquiry  
*Frackson Mumba, Alexis Rutt, Paul Asunda, and Reid Bailey*
- 70 Investigating an Instructional Model for Integrated STEM in Teacher Education  
*Laurie O. Campbell and Nicole Damico*

# Editorial Team

## Editors

**Ryan A. Brown**, *Illinois State University*

**Allison Antink-Meyer**, *Illinois State University*

## Contact Information

### **Ryan A. Brown**

College of Education, Campus Box 5300

Illinois State University

Normal, Illinois, USA 61790-5960

*Phone:* (309) 438-3964

*Email:* [rbrown@ilstu.edu](mailto:rbrown@ilstu.edu)

### **Allison Antink-Meyer**

School of Teaching and Learning, Campus Box 5330

Illinois State University

Normal, Illinois, USA 61790-5960

*Phone:* (309) 438-0193

*Email:* [aameyer@ilstu.edu](mailto:aameyer@ilstu.edu)

### **Website**

[www.jstemteachered.org](http://www.jstemteachered.org)

ISSN: 19381603

## **Teachers' Perceptions on Women in STEM: Breaking the Stereotypes**

Lili Zhou

*California State University, Los Angeles*

Alankrita Chhikara

*Purdue University*

Stephanie Oudghiri

*Purdue University*

Araba A. Z. Osei-Tutu

*University of Ghana, Legon*

Razak Kwame Dwomoh

*Northern Illinois University*

### **Abstract**

Drawing on an online professional development modular course that addressed critical approaches to the issues of race, immigration, English Language Learners (ELLs)/Emerging Bilinguals (EBs), and gender and sexual orientation, this paper reports teachers' perceptions on gender stereotypes in Science, Technology, Engineering, and Mathematics (STEM) education. In particular, building on the course readings, we discuss teachers' emergent approaches to address gender stereotypes in teaching practice that improve girls' participation in STEM fields. Data is collected from a pre-course survey and teachers' discussions during the course. Centering on the course readings from theoretical and empirical research that address gender issues, discussion prompts were used to elicit teachers' insights on gender stereotypes in education. A thematic analysis method was then employed to discuss strategies for challenging gender stereotypes in teaching practice from teachers' discussion posts. Teachers recognize that gender stereotypes have been embedded in the social norms that influence teachers' practice in an underlying way. Three promising strategies are identified to address gender stereotypes in STEM education, including integrating role models into the curriculum, developing a growth mindset, and promoting justice classroom discourse. We also discussed ways to support teachers in addressing gender stereotypes in their practices.

*Keywords:* Gender Stereotype, STEM, Classroom Discourse, Role Model

According to the National Center for Educational Statistics (2019), women earned less than 43% of bachelor's degrees in mathematics and statistics in 2016. Women's share of bachelor's degrees in computer sciences, engineering, and physical sciences were 19%, 21%, and 19%, respectively. However, the trend is different in psychology, biological sciences, and social

sciences. In psychology, women received around 75% of degrees at all degree levels—bachelor’s, master’s, and doctorate degrees. In biological sciences, women received more than half of the degrees at each level. In the fields of social sciences, women earned more than half of their bachelor’s degrees. Although women are generally underrepresented in Science, Technology, Engineering, and Mathematics (STEM) fields, they are undoubtedly underrepresented in traditionally male-dominated STEM fields (Ceci et al., 2014). Though overt gender bias is waning in K-12 educational contexts, underlying negative messaging persists concerning the fallacy of females’ inferior mathematics and science skills and continues to influence assumptions about girls in STEM careers (Dou & Cian, 2022; Hill et al., 2010; Master, 2021). Gender stereotypes negatively impact teachers’ expectations and evaluations of their students in the classroom, which determine the external support students receive from teachers (e.g., Alan et al., 2018). Thus, teachers play an important role in shaping students’ beliefs about gender implications and norms. Increasing teachers’ awareness of gender stereotypes through professional development is an urgent need to promote gender equity in STEM fields and improve social justice in K-12 education (Kuchynka et al., 2022).

The authors (hereafter, “we”) designed and taught a Professional Development (PD) course for K-12 in-service teachers and educators across a Midwestern State to explore critical theory on race, immigration, English Language Learners (ELLs), and gender. In this study, we investigate teachers’ perceptions of gender stereotypes in STEM from the perceptions expressed in the PD course. We report our findings by analyzing teachers’ responses from pre-course surveys and structured discussions during the course. The survey data revealed that the majority of teachers clearly described the prevalent negative stereotypes about females in STEM. Some teachers used personal experiences as evidence to illustrate the stereotypes and other teachers shared counter perspectives aimed at reducing and addressing them. Building on the course readings, the discussion questions aimed to further teachers’ awareness of gender stereotypes in education and promote strategies to challenge and disrupt stereotypes in K-12 classrooms. We used a thematic analysis approach (Braun & Clarke, 2012) to interpret teachers’ responses. We reported teachers’ initial perspectives on gender role stereotypes in education and their perceptions of girls and women’s particular ways of learning. In addition, we identified three promising strategies to address gender stereotypes in STEM, including integrating role models into the curriculum, developing a growth mindset, and promoting justice in classroom discourse. Based on the findings from this study, we discuss practical classroom implications and suggestions for addressing gender bias in teachers’ development.

### **Literature Review**

Stereotypes embodied in sociocultural influences play a part in shaping individual beliefs and motivation over time (e.g., Lubienski & Ganley, 2017). Individuals’ negative stereotypes of STEM are a predictor of their math/science self-efficacy, career interests, and goals (Garriott et al., 2017). Women’s free career selection might be influenced by underlying gender roles that expect women to be family oriented. Hill et al. (2010) warned that even individuals who consciously refute gender stereotypes can still hold that belief at an unconscious level. This means that stereotypes are particularly worrisome because they are indirect, and we may be entirely unaware of them. As we continue to overlook them, these unconscious stereotypes ultimately remain within the U.S culture (Corbett & Hill, 2015). In this literature review, we explored gender stereotypes that permeate K-12 education, and strategies addressing gender stereotypes in K-12 education.

## Gender Stereotypes

Upon analyzing 400 studies and developing a causal framework to explain the dearth of women in STEM, especially in math-intensive fields, Ceci et al. (2009) concluded that women's preferences, representing both free and constrained choices, constitute the primary factor in making a career choice. The choices which seem to be made from personal intentions are also shaped and limited by sociocultural circumstances. As Eccles (1994) pointed out, an individual sometimes does not actively or consciously consider the full range of objectively available options in making their selections. He continues to explain that "many options are never considered because individuals are unaware of their existence. Other options are not seriously considered because individuals have inaccurate information regarding either the option itself or the possibility of achieving the option" (Eccles, 1994, p. 589).

Traditionally, gender-stereotyped roles posit that women prefer to work with people doing service work, whereas men prefer assuming leadership or individual work. Su et al.'s (2009) meta-analysis on gender differences in career interests revealed that men gravitated toward things-oriented careers and women gravitated toward people-oriented careers. Diekmann et al. (2010) speculated that women's avoidance of STEM careers might be because STEM careers are often perceived as incompatible with their communal preference (e.g., working with or helping other people). Eccles and Wang (2016) investigated the personal aptitudes and motivational beliefs in 12<sup>th</sup> grade that move an individual toward or away from STEM fields at age 29 ( $n=1200$ ). They found that among STEM disciplines, female students have a preference for people-oriented work, which is a strong predictor of their choice to pursue people-oriented STEM fields (such as health, biological, and medical sciences) rather than other STEM fields (such as mathematics, physical, engineering, and computer sciences) (Eccles & Wang, 2016).

In addition, women's advancement in STEM fields is shunted and hindered due to institutionalized gendered and intersectional barriers. Bird and Rhotan (2021) explore whether STEM faculty members working in universities perceive systemic barriers to equity in STEM, as a legitimate obstacle. They argue that despite meritocratic beliefs, certain groups of employees in higher education are held back due to the enforcement of systemically inequitable policies and practices.

## Gender Stereotypes in K-12 Education

Students' gender stereotypes on mathematics and sciences significantly associate with their mathematics and science identity, which in turn was an influence on their STEM course taking and performance (Starr & Simpkins, 2021). In the book *Women's Ways of Knowing*, Belenky et al. (1986) claimed that girls and women prefer collaborative learning that is based on care and communication. Scholars have also envisioned a collaborative learning environment in which students were working in small groups, sharing experiences, and discussing different ideas; where teachers trust their students' thinking and encourage alternative methods (Becker, 1995). In such educational environments, instead of seeking confirmation about right or wrong, students gain confidence from different ways of solving problems (Anderson, 2005). Furthermore, successful collaboration in a classroom provides students with a supportive environment to engage in intellectual risk-taking to solve challenging problems and exchange mathematical ideas.

On the other hand, there are serious negative consequences when such supportive and caring environments are not available to all students. Implicit gender stereotypes and differential expectation for male and female students that teachers hold negatively impact girls' mathematics learning and diminish girls' performance in mathematics (Matheis et al., 2020; Robinson-Cimpian et al., 2014). In terms of students' mathematical abilities, Copur-Gencturk et al. (2020) found that teachers rated White-sounding names higher than Black and Hispanic-sounding names. When the authors examined non-White teachers' perceptions of students' abilities, they found that the teachers favored White students, of both genders, over students of color, whereas White teachers favored boys over girls. Alan et al. (2018) found that teachers' beliefs on gender disparity play a crucial role in mitigating or widening the gender gap in STEM. They reported that teachers who are gender-biased in their beliefs in STEM and specifically Mathematics had a striking detrimental effect on female students' test scores, both written and verbal. Thus, by transmitting their biased-laden traditional role of gender beliefs to the girls in their classrooms, teachers condition young girls to pursue other fields.

Also, the attitudes and behaviors of male peers, such as taking over girls' work or belittling the contributions of girls, worsen the discouragement of girls (Allan & Madden, 2006). In a recent study of 1500 participants from four informal science learning sites, McGuire et al. (2020) examined stereotypes about STEM within informal science learning sites. The participants ranged from early childhood to adolescents. Findings from the study revealed that boys, more than girls, identified that their gender 'should' be better at STEM than girls. In addition, underlying gender stereotypes play a role through curricula. Kerkhoven et. al. (2016) examined how educational resources within visual content of online education databases perpetuate gender bias. The analysis revealed that men were more likely to be depicted as science professionals compared to women and fewer men were depicted as social science professionals.

### **Addressing Gender Stereotypes in Teacher Education**

Teachers play an important role in communicating stereotypes with students which shape how STEM is perceived, learned, and practiced (Liu, 2020). Due to the integration and interdisciplinary nature of STEM, teachers often have limited PD opportunities to develop an awareness of critical issues (Pourdavood & Yan, 2020). Thus, without developing teachers' awareness of gender bias and stereotypes, it is likely that teachers will continue reinforcing stereotypes when they communicate with students daily. In addition, teachers often feel that they lack the necessary knowledge and skills of STEM content to engage students in STEM investigations. More specifically, STEM is a growing field in education therefore, addressing equitability and representation is a critical need in teacher education. Nesmith and Cooper (2019) found opportunities for professional development over multiple years beneficial for "providing opportunities for the teachers to discuss and reflect on each experience within campus and grade level teams" (p. 495).

Stereotypes of females' inferior mathematics ability shape the personal evaluations of teachers of the students in their classrooms (Riegle-Crumb & Humphries, 2012). Teachers often use adjectives like 'hard-working' to refer to girls but use 'bright' to refer to boys who perform at the same level (Walkerdine, 1998). In Wang's (2012) study, the teachers held lower expectations for girls to perform well in mathematics than for boys. Thus, girls may have less external support in developing interests in mathematics (Wang, 2012). In middle or high school classrooms, "teachers

were more likely to stress the association of mathematics with activities, careers and domains that interest boys, such as engineering or physical domain” (Wang, 2012, p. 1653).

Teachers can, thus, break gender stereotypes by creating a supportive learning environment and inclusive classroom culture (Rogers et al., 2021). Using inclusive and non-discriminatory pedagogies could improve equity for women and minorities, promote connected knowing, and value girls’ voices (Anderson, 2005; Dersch et al., 2022). A supportive learning environment demonstrates care about the girls’ needs, recognizes their contributions, and offers opportunities for recognition and development (Rogers et al., 2021). Having conversations with students about women’s contributions in STEM fields and acknowledging girls’ intellectual achievement would counter stereotypical messages and promote girls’ confidence in STEM learning. Through reflecting on their own beliefs and stereotypes, teachers have opportunity to develop their awareness of their behaviour in teaching. Thus, they have the opportunity to restructure their perceptions of female students in STEM (Matheis et al., 2020).

In addition, providing role models could be another intervention for teachers to disrupt stereotypes (Sears et al., 2021). In STEM fields, female role models demonstrate that women can overcome stereotypes. It may be especially critical for women to know someone like themselves has been successful (Lockwood, 2006). Evidence has shown that STEM women hold weaker implicit gender-STEM stereotypes than non-STEM women (Smeding, 2012). Creating welcoming communities can help girls break stereotypes and reinforce their STEM identities. By surrounding girls with female role models, girls are more likely to perceive positive messages about women in STEM, which weakens stereotypes, and, in turn, enhances ingroup identities (Smeding, 2012). Girls are the most eager and participatory in teams that have either gender parity or a female majority and far less engaged in teams with female minorities (Dasgupta & Stout, 2014).

The reviewed literature informs us that teachers’ perceptions of gender stereotypes in STEM fields impact students’ stereotypes in gender and STEM, self-efficacy in STEM learning, and career interests. The culture of the classroom, discourse, and learning environments the teacher creates would be a space for students to either interrupt stereotypes or continue to communicate stereotypes. Therefore, it stands to reason that a foundational step in helping teachers create an inclusive learning environment would be to understand their perceptions of the stereotypes and what strategies they have recognized to address stereotypes. Thus, the following two research questions guide this study:

1. What are teachers’ experiences and understanding of women in STEM?
2. What strategies did the teachers develop based on their experiences and engagement in the course that can be used to break gender stereotypes in K-12 education?

### **Methods**

The participants in the study were in-service teachers and educators who enrolled in an online professional development course designed to raise understanding and knowledge of critical perspectives on race, gender, ELLs and immigration. All teachers consented to participate in the study. In this paper, we use the terms “participants” and “teachers” interchangeably. As stated before, the purpose of the study was to understand teachers’ conceptualizations and development in the knowledge of gender stereotypes in STEM.



## Data Sources

The data for the study includes the class materials that were collected in the form of a pre-course survey, as well as online discussions to which the teachers contributed weekly in response to the readings the facilitators assigned. The pre-course survey consisted of a set of questions that addressed participants' range of engagement with diversity, equity and social justice, critical perspectives on gender, and their expectations for taking the course which is further examined through their reflection papers for women and STEM (Osei-Tutu et al., 2021). The pre-course survey questions that teachers responded to were:

- What is your understanding of diversity?
- What do you think about when you hear: Diversity, Equity, Inclusion, and Social Justice?
- How would you define Equity and social justice in education?
- Describe gender stereotypes you have heard in learning math, science, engineering, sexuality, etc.
- Briefly discuss any engagement in conversation about diversity, inclusivity, and social justice.
- Why are you interested in these topics? What do you hope to gain from these workshops?

We have a total of 158 survey entries which were collected at the beginning and end of the course. During the semester, the number of participants were reduced to 67 due to their inability to keep up with the pace and rigor of the course.

The module on gender issues consists of two themes: women in STEM and gender minorities in K-12 education. We selected three readings including two theoretical articles and one practical report that focus on the issue of women in STEM. Clance and Imes's (1987) article focuses on the therapeutic intervention to address the imposter phenomenon that successful and high achieving women experience; Dasgupta's (2011) article discusses that developing ingroup identity can address stereotypes and build girls' confidence in STEM; Hill et al.'s (2010) work unpacks the environmental factors that shape girls' achievement and interests in STEM and proposes recommendations to support women in STEM and counteract stereotypes. These readings' historical perspectives shed light on gender stereotypes in education, in particular, girls and women in STEM fields. We selected these readings to prompt participants' engagement in the issues of women in STEM and engage them in the further discussion. These readings also were used to develop the discussion questions with the intention to collect the participants' views as well as their own experiences of women and STEM. Building on the content of the articles, teachers engaged in online discussion with group members supported by a facilitator. The discussion prompts for this module were:

- Do you think that girls or women have distinct ways of knowing? Please provide evidence to support your answer.
- What strategies can we use in practice to address negative gender stereotypes?
- What factors influence women's participation in STEM? Since the last decade, in terms of women in STEM, what has changed, and what remains?

## Data Analysis

The research method employed to analyze the data is thematic analysis, to systematically review the data and actively seek out themes (Braun & Clarke, 2012). Thematic analysis is a

---

flexible and accessible qualitative research method to analyze data in educational settings. For our project, we sought out repeated meanings across our data sets (Vaismoradi et al., 2013) between all the researchers to capture information that illuminates and addresses the research questions. After independently reviewing the data, the researchers identified and assigned themes by using attributes that were “summative, salient, essence-capturing, and or evocative” to categorize the data (Saldana, 2016, p. 4). Subsequently, all the themes were compiled, and these were further sorted by the researchers collectively after deliberation and clarification. We discussed the usefulness and relevance of each theme, and only after a mutual understanding among the researchers. Member checking was not incorporated as the participants of the study were enrolled in the course. The themes were finally distilled to align with and answer the research questions. A summary of teachers’ notable comments has been highlighted in the findings section below.

### **Findings**

In this section, we report our findings from analyzing teachers’ initial survey results and their responses to the discussion questions. First, we describe teachers’ initial perspective of gender role stereotypes. Then we report teachers’ perceptions of girls’ and women’s particular ways of learning. Finally, we summarize the promising strategies to address gender stereotypes in STEM, including integrating role models into the curriculum, developing a growth mindset, and promoting justice in classroom discourse. We provide direct quotes of the participants to feature our participants’ voices without adulteration in an effort to engage in dialogue with the readers about the interpretation for the quotes. Additionally, the selected quotes highlight the significance of participants’ experiences as they relate to each theme.

#### **Teachers’ Initial Perspective of Gender Role Stereotypes in Education**

In the pre-course survey, teachers shared stereotypes they have heard or experienced in education. They recognized that gender stereotypes are a cause and also a reason for women’s underrepresentation in STEM fields. Common stereotypes teachers identified were that women are emotional while men are rational; women are good at social science, language, and art while men are good at math and science; and the perception that women are less capable in logically oriented fields such as STEM.

The existence of gender stereotypes in K-12 education was further evidenced in teacher’s personal and classroom teaching experiences that illustrates the perception of women as caregivers and not equal partners. These norms permeate the culture in society, norms in the classroom, and curricula. A teacher shared,

*My own daughter was treated discriminatorily at a university where she worked in psychology. The men there treated her as if she were to take care of them, not be their peers.*

Similarly, another teacher described her experience of being fed stereotypes that demoralized her and dissuaded her from pursuing the field altogether,

*When I entered high school, not only did my parents discourage me but my teachers as well. Even though I was very good in physics and mathematics, they all encouraged me to consider health-related programs rather than engineering because engineering was for boys and not lucrative to girls. The truth is that their*

*words made an impact on me and that is how I left the idea of becoming an engineer behind.*

The participants also explained that stereotypes were steeped in patriarchal thinking and disciplines were recommended to students based on their gender role as illustrated in the following quote,

*From personal experience; "you can't be a veterinarian, that's a man's job." That was in 5th grade coming from my own teacher. I changed my mind along the way to become a teacher, but her words still stick with me, and I would never tell one of my students that. She also believed that women were better served in the home.*

Similar to the previous participant's response, the following participant also recognized that teachers play an important role in instilling stereotypes and that stereotypes did not just impact the participants when they were younger but are also reinforced in schools and the curriculum today. A science teacher said,

*I heard a high school counselor tell a student that my course is better suited for women as they need to know this skill for life, males should be in a more "manly" curriculum.*

*As a science teacher, there are always gender stereotypes about men being more in the STEM fields and so on. Even in my curriculum, the scientists we learn about are all men.*

*When I was growing up and in school, it was a given that the boys went into the math and science fields and girls went into teaching. Robotics clubs and science extras were always made available to the boys.*

In addition to the stereotype of females' having less capability in STEM, another stereotype that plays out as a microaggression is that women in STEM fields are exceptional and remarkable, and to succeed in these fields, they have to sacrifice or hide feminine attributes. A teacher shared this experience,

*I also know from a college course on gender and women in the sciences that women in science are often viewed as being more masculine, less social, and often meaner and less capable. Women are also often viewed as being less analytically minded.*

Women who were doing well in STEM were thought as exceptional, which reinforced the stereotypes that women in general are not capable of learning the subjects that traditionally, men dominated. Teachers recognized that girls and women are not incapable in mathematics and science, but stereotypes confirm their negative beliefs and have an impact on their education. As a teacher said, "*Women are less likely to enter careers in math and STEM; it is more due to the shaping of mindset. It is not reflective of ability or skill.*" The fixed mindset of gender roles in STEM undermines girls' performance as well as their interests in STEM fields.

### **Teachers' Perception of Girls and Women's Particular Ways of Learning**

Teachers' responses to whether girls/women have distinct ways of knowing exposed a nuanced understanding of learning differences and its impact of academic achievements. Even for those that agree with gender differentiated learning styles, their view was oriented towards supporting ALL students to succeed. Based on the responses we received, participants shared anecdotal

evidence about the gender variation in approaches to learning. In the section below, we share examples and personal experiences that help elucidate the perceptions. The first one below is an example of a participant's personal experience suggesting that gender norms did not always dictate the kinds of activities girls and boys have. A teacher shared interesting stories about her family,

*My older brother and I [female] are perfect examples of this. My brother is an attorney, very smart, high I.Q. and excellent in math. Unfortunately, if you give him a hammer, he hurts himself. For me, I am the hands-on learner, figuring things out usually by common sense, and not particularly interested in that A+. I can change a flat tire, rewire the house, and fix the toilet. I approach all challenges with some common sense and humor. We both have excelled in our fields and did it by hard work, determination, and grit even though we have completely different approaches to learning.*

As we explored the ways in which gender roles inform learning styles, participants offered specific examples based on their experience of working with students as catering to the individual styles also maximizes learning. The following examples offer valuable insight into learning about learning differences so that students, regardless of gender, may succeed academically. A teacher said,

*Yes, I think girls and women have a distinct way of learning. Often within my classroom, my female students require more visual explanations of new material. They seem to grasp it quickly when they can see how to do the skill. Whereas my male students typically show more interest and understanding when they are working with the skill being taught and discovering through exploration. Neither way is wrong, but I think it is very important as an educator to make sure and teach using a variety of teaching methods to help all learners to learn.*

Yet, others were of the view that the expression of emotions accounts for this distinctiveness. They explain that women find it easy to express emotions. A teacher said, “*many girls take on a bit more emotional labor than boys and that can change the way they think, but that is more of a case-by-case basis and based on culture and family environment.*” Aligning with the above comment, a participant expanded on this view by discussing decision-making processes,

*Because they acknowledge their emotional side more than men, they have a different way of knowing based on emotions. In a decision, women might consider many different factors being affected by their decision where men may have a narrower focus of just making a quick decision.*

However, there is a second group of teachers who do not believe that girls' or women's distinct ways of knowing are shaped by biological differences, but rather oriented by social norms. As one participant expounded,

*I am aware of the plethora of books on the line of “men are from Mars; women are from Venus” in terms of personal/social relationships but I have no evidence to support that any of this is true other than from my own observations. I would prefer to stick with the context of this set of readings and say that women and men are equally equipped to gain new knowledge and apply their knowledge to new situations. What is different is the opportunities presented to them.*

Among the participants' there was also evidence to deny the presence of differences in learning styles among males and females. Participants accounted for the individual differences rather than ascribing generalized views as the following participant explained that "*I do not believe that females have a distinct way of learning. I believe that both males and females can have strong math and language arts skills. I think it is more about the individual, than the sex.*" Instead, the plethora of social and cultural norms that are still remarkably present and persisting in this yet changing world, are what these groups of teachers use to explain why such perceptions of distinction exist. Approaching it from the professional field, one participant finds that,

*In many ways, girls and women are required to have distinct ways of knowing in order to be successful and reach particular achievements. The cultural expectation for women to fulfill a particular role that both edifies and impresses men (but not too much of either) requires a specific instinct—at once we must be both independent and dependent, smart, but not too smart, attractive, but not overly-to maintain desirability, the highest currency in heteronormative relationships.*

How various cultures perceive and treat women also accounts for these major differences that people have come to associate with men or women. Teachers shared various examples of how these cultural and societal norms are reinforced. In this study, we are not focusing on whether girls and women have different ways of learning, rather we aim to encourage teachers to be aware of how social norms and bias influence students' learning and impact on their career selection later.

### **Promising Strategies for Addressing Gender Stereotypes in STEM**

Building on their understanding of the readings in the course, participants identified promising strategies that can be adopted in the fight against gender stereotypes in education. We carefully analyzed the participants' responses to addressing negative gender stereotypes in practice. We identified three themes that teachers proposed to counter stereotypes in education, including integrating role models into curriculum, developing growth mindset, and promoting a justice-oriented classroom discourse.

#### ***Integrating Role Models into Curriculum***

Participants proposed that integrating female role models in the curriculum will engender a sense of belonging for girls and women when they make career decisions. Thus, the knowledge of women and their contributions in STEM fields, would encourage girls to pursue their future careers in STEM fields. Teachers recognized that introducing female role models could be a strategy to reduce gender stereotypes e. A participant said, "*For young students, seeing is believing and if more young girls see women in STEM roles, then the more likely they will become interested in selecting roles in math and science.*"

Another participant illustrated through their own experiences the impact that integrating role models in the curriculum had on inspiring and motivating young girls to pursue STEM fields. The teacher tells the story of representation below:

*Our school has made a focus on doing STEM units for each grade level. We have started to pair the STEM projects with books for the primary grades. The books that have been read include women in STEM roles. For example, my students heard the story *Hidden Figures* during the month of March. The story sparked interest in boys and girls alike to learn more about space and science-type jobs.*

Some female teachers who taught mathematics and/or science in the K-12 setting position themselves as role models for their female students. They are conscious of girls' representation in STEM courses and make efforts to advocate for increasing girls' participation in their courses. A participant stated,

*One change that I am aware of as a science teacher is an effort in schools to bring in more STEM courses, and to have representation when talking about STEM subjects. Girls are more likely to see, during their grade school education, examples of women in STEM careers than they were a decade ago. I personally have been making efforts in this to make sure that my students see someone who looks like them working in scientific fields.*

Seeing themselves as role models, female teachers play a crucial role in supporting and encouraging girls to pursue careers in the STEM field. A participant shared, "As a child, I never saw myself in any of those roles. When I became a teacher, I found myself changing the names in equations to represent all genders." Similarly, another participant stated,

*I teach in a science-based program, but one that is dominated by women on one level and men on another. I am working on a lesson to show that we all bring excellent points of view to the table. My goal is to remove some of his male chauvinistic ways and humble this student a bit. (Any suggestion would be appreciated for this). The young ladies had to take a step back, but they did come out swinging and showed their worth in our lab.*

In addition to the explicit or seen aspects of curriculum, there is the implicit or hidden curriculum which is harder to identify. Therefore, teachers suggested being aware of the implicit messaging or hidden curriculum that is being promoted in their institutions. Teachers can consciously select or adapt curriculum including female figures and integrate role models in teaching which is an effective way to inspire girls. A participant pointed out,

*Children's picture books have images of women in aprons and dresses cooking or cleaning, and muscular men doing work outside or sitting behind a desk in their own office. These stereotypes are often subtle (in the illustrations) and go unnoticed, but in elementary school we teach students to use the illustrations to help them make meaning. In order to challenge these stereotypes, they need to be openly acknowledged and discussed.*

With that said, teachers who were focused on an inclusive STEM curriculum recognized that they were pushing against societal gender norms. Teachers recognized that stereotypes on gender roles are harmful for both boys and girls. Therefore, integrating female role models in curriculum would possibly break down the social expectations on gender roles.

### ***Developing Growth Mindset***

Participants argued for a growth mindset teaching approach to be used with girls in order to teach them that with effort, skills can be learned, and that failure is not always negative in this journey. Specifically, teachers discussed advanced coursework necessary for cultivating and maintaining specific skills needed to support female students. A teacher suggested the need to,

*Encourage high school girls to take Calculus, Computer Science and Physics, etc., showing them their potential for success in these fields and to help them on that*

---

*path. I am helping them to develop their spatial skills through different games and challenges that could be fun for them and entertaining as well.*

Exposing students to STEM early in their academic journey and introducing STEM as a part of extracurricular activities can be a way to support building girls' confidence and developing a growth mindset. Teachers also saw a connection between engaging STEM curricula and female student engagement. A teacher expressed,

*If girls are not exposed to cool STEM activities, they are not interested in science, technology, engineering, and math. Hill points out that poor or underdeveloped spatial skills can also be a reason why we have so few in STEM. Many women do not have the confidence to participate in STEM activities; therefore, they believe they will not succeed in the STEM field.*

Participants also call for school efforts in developing a growth mindset to promote girls' participation in STEM. A teacher said,

*Schools should promote and encourage females in math-oriented programs, such as math or science bowls. This will give them the confidence that girls can perform well in STEM academics.*

Developing a growth mindset is not an instantaneous process; it does not happen all at once. To actively reject gender stereotypes in STEM education, teachers should counteract the underlying stereotypes by reflecting on their own biases and engaging in new discourse. As previously described, teachers have recognized the stereotypes which are implicitly embedded in the culture and curriculum. Thus, teachers not only need to be constantly mindful of stereotypes, but also, they need resources and support to address these stereotypes. Integrating female role models into the curriculum is a feasible strategy for teachers to use in their daily teaching. In particular, female teachers can position themselves as role models for girls which could greatly encourage girls to develop belonging.

### ***Promoting a Justice-oriented Classroom Discourse***

Stereotypes are often embedded in everyday life and infused in daily communications. To curb stereotypes in teaching, teachers need to intentionally create classroom norms to conquer the negative perspectives on gender stereotypes. Classroom discourse, therefore, plays a critical role in sending messages to students about gender roles and careers, including teaching students what they should and should not say. Participants shared strategies they have implemented or plan to use in their day-to-day teaching to reduce gender stereotypes. Through classroom discourse, teachers proposed blurring the perspective and learning practice boundaries regarding gender in the classroom. A participant shared,

*Another strategy is to be vocal when hearing a stereotype being used. A simple "why do you think that?" or "we don't use that language in this classroom" or "I don't find that funny." can be a useful tool to stop the stereotype and to get others to think about why they've developed an assumption/bias.*

Another participant shared a scenario in teaching and strategy used for communicating with a male student who condemned his female peers in group work,

*I teach in a science-based program, but one that is dominated by women on one level and men on another. I am working on a lesson to show that we all bring*

*excellent points of view to the table. My goal is to remove some of his male chauvinistic ways and humble this student a bit. (Any suggestion would be appreciated for this). The young ladies had to take a step back, but they did come out swinging and showed their worth in our lab. I experienced one in class today. I had a male student quite loudly say, "I am screwed in my lab assignment because I am stuck with two girls." After gathering my thoughts and not exploding on said student, I explained to him that he should be honored to be graced with such talented ladies that know far more than he does in terms of this assignment and that he was placed in that group for a reason.*

Creating a justice-oriented environment and promoting classroom discourse requires teachers not only to fight against negative messages but also to recognize and champion girls' talents in work and provide opportunities for them to show their talent. A participant shared,

*I try to challenge all of my students, especially my girls, if they show a huge interest in math. It's amazing to see a positive dynamic in my classroom where both boys and girls are encouraging each other rather than trying to "fit the mold" that society has tried to create.*

Classroom discourse can be extended in communicating with parents. A participant shared her experience with parents' concerns about their sons playing with girls' toys or their daughters playing with boys' games. The participant expressed the way she discussed gender roles with parents as below:

*I would reply that playing with dolls encouraged a nurturing/gentle behavior and would later help their son to be a good parent/that playing with Legos encouraged fine motor development and spatial awareness. I would frequently tell my students that "we don't have girl/boy colors" and addressed similar stereotypes with examples: "My uncle is a nurse. Boys can be nurses, too." The idea was to address them casually but firmly and not in an embarrassing manner.*

Classroom discourse sends underlying messages to students about gender roles and career expectations. Promoting justice discourse requires teachers to recognize gender stereotypes and potential biases and to develop a mindset to intentionally fight gender stereotypes. The findings reveal that teachers recognized gender stereotypes in education. The shared experiences from their own learning and teaching remind us that gender stereotypes need more attention in classroom practices.

### **Discussion**

The pre-survey data and findings reveal that teachers recognize an implicit proliferation and exacerbation of gender stereotypes in K-12 education. Not only do teachers recognize the gender stereotypes plaguing the STEM fields, but they also encounter, experience, and perpetuate gender stereotypes during classroom instruction. From such experiences, teachers expressed that gender stereotypes prevalent in schools result in women's underrepresentation in STEM fields (Alan et al., 2018; Dou & Cian, 2022). Teachers' knowledge, experiences, and understanding of women in STEM and gender stereotypes were twofold: personal encounters and reports from other information resources.



Experiences and understandings from personal encounters include experiencing discrimination by peers or teachers, evidencing a higher representation of men than women in STEM courses and the availability of Robotics or Science clubs for boys rather than girls. Second, teachers' understanding of women in STEM and gender stereotypes from report or people or hearsay include (a) STEM fields being considered as male talents and attributes; (b) a falsified assumption that males are better at math, science, computers, and engineering while females are better at reading, writing, social studies, art, and other creative things; (c) school authorities, such as teachers or school counselors, categorize programs for students based on assumptions regarding the students' professional goals; and (d) a misconception that women in science are often viewed as being more masculine, less social, and often meaner and less capable, as the teachers indicated. Teachers' shared experiences and perceptions of gender stereotypes align with literature that girls and women have lower self-efficacy and face more challenges in STEM fields (e.g., Bird & Rhoton, 2021; Ceci et al., 2014; Dersch et al., 2022). From personal experiences and hearsay, these narratives informed teachers' perceptions and conceptualization of women in STEM fields and the gender stereotypes (Allan & Madden, 2006).

Additionally, a sentiment reflected in teachers' personal and shared experiences, is that women have distinct ways of learning and knowing (Belenky et al., 1986). From personal experience, teachers indicated that women gather and assimilate information differently than men. Though it may not be clear if this is a case of nature versus nurture, they believe that women are more intuitive and process multiple information holistically, whereas men compartmentalize information. Teachers proposed that men and women would approach answers very differently when a question is posed. They shared that some female students in their class require more visual explanations of new material because they can grasp concepts faster through simulation. However, the male students show interest and comprehend faster when working with the skill being taught and discovered through exploration. From shared experiences, teachers expressed how the distinctiveness can be attributed to how women express their emotions. As women openly share their emotions, they develop the strength of knowing through emotions. However, some women feel inadequate in the same job or working space as their male counterparts. Teachers, therefore, play a critical role in communicating stereotypes with students. Teachers' knowledge about the disparity in learning and knowing between boys and girls necessitates differentiated instruction and scaffolding in teaching STEM courses (Anderson, 2005; Master, 2021).

### **Curriculum Integration and Growth Mindset**

A prominent perspective we argue is the role curriculum plays in perpetuating gender stereotypes and biases. As Kerkhoven et al. (2016) and Bird and Rhotan (2021) have expounded, the curriculum is fundamental in centering these databases and institutionalized gender biases. However, beyond affirming this view, teachers discuss strategies to mitigate these biases and disrupt these stereotypes through several approaches. First, there is the need to integrate role models in the curriculum that reflect successful women in the STEM field (Dasgupta, 2011). By emphasizing the major contributions women have made, and continue to make, in the field of STEM, an atmosphere of possibilities will be created that propels young women toward the field. Another approach to inverting the STEM curriculum will be to address the gender roles in the curriculum. As teachers explained, women are barely mentioned in the STEM field as examples of successes, but when they are, they are often placed in supporting roles (Robinson-Cimpian et al., 2014). By providing representations of women who are leaders in the STEM field, a clear message is sent to both boys and girls that the field is not the sole prerogative of men. This means

that teachers first have to be reflective on their complicity in maintaining gender stereotypes and consciously adapt their curriculum and approach to teaching to support change (Copur-Gencturk et al., 2020; Riegle-Crumb & Humphries, 2012).

Project-based learning is another aspect of curriculum adaptation that is crucial to dismantling gender stereotypes. Creating opportunities in the curriculum for girls and boys to learn, engage, and intern with women in the STEM field throughout their education, will engender positive mindsets for all involved. For girls, the myth of inability will be broken, while the “boys club” mentality for boys will be shattered (Dasgupta, 2011). With such mindsets, women and girls’ sense of belonging in the STEM field would be strengthened. When people feel a sense of belonging, they are enabled to succeed. To push back against what Herzig (2004) finds, a sense of belonging will mean that females “fit” perfectly in the STEM field.

Breaking stereotypes in the STEM field also requires the development of a growth mindset. Teachers who are educated, aware and conscious of gender biases in the curriculum and teaching are better able to break the barriers. This growth mindset is what will retain women in the STEM fields (Corbett & Hill, 2015) while encouraging women to resist the societal gender norms that condition women to relinquish their desires to succeed in the field in order to support their husbands’ careers (Lubienski & Pinheiro, 2019). Additionally, teachers who are conscious of gender bias in teaching will bring a reflective attitude towards building a classroom and school culture of equity where all genders thrive.

Developing a growth mindset also means paying attention to societal influences of gender stereotypes. Many of our teachers discussed how gender norms in the society or community affect how women engage in STEM, as well as fields they gravitate towards due to their upbringing. Thus, women in the field should work towards mentoring and supporting young women to pursue STEM careers: they should encourage them to take calculus, chemistry, engineering and all the courses that have been rendered as shrines for men. As one participant aptly puts it, “*girls should be taught to use a growth mindset, understanding that skills can be learned, effort is just as important as intelligence, and failure can lead to growth.*”

One major issue that affects equity and change is the fear and refusal to engage in conversations about controversial issues. “Teachers report often avoiding these types of discussions due to concerns about the unpredictability of student reactions, accusations of trying to push a political agenda, and insufficient knowledge or skills to work through complex issues” (Fournier-Sylvester, 2013, p. 1). Therefore, it is important as a major part of the growth mindset, to be ready and open to discussions on gender biases and stereotypes in the field. It is important to create spaces for such conversations to take place in and outside of the classroom, including project-based learning environments. It tells the students, society, and girls and women in particular, that they have the potential and ability to succeed in STEM and it is our responsibility to help them reach it.

### **Promoting Justice Classroom Discourse and Improving Teacher Education**

By supporting teachers through professional development, school districts are ultimately supporting student learning and growth. Within STEM education, professional development often focuses on how teachers conceptualize curricula (Ring et al., 2017) and implement integrated approaches (Shernoff et al., 2017) to STEM learning. Providing teachers with opportunities to collaborate with their colleagues about the successes and challenges of implementing STEM lessons has a positive correlation with teachers’ improved self-efficacy (Nesmith & Cooper, 2019).

Similarly, many in-service teachers lack experience with professional development that focuses on social justice issues. While the diversity of U.S. classrooms continues to increase, the demographics of teachers remain White, female, and monolingual. Therefore, professional development is needed to support teachers whose cultural and linguistic backgrounds differ from their students. Several factors must be considered when providing in-service teachers with transformative pedagogy, therefore becoming a social justice-minded educator requires a shift in mindset. Active implementation of multicultural education required a gradual and in-depth awareness of shifting one's attitudes toward students' learning (Pourdavood & Yan, 2020).

Based on our teachers' responses, STEM educators seek professional development grounded in social justice (Ring et al., 2017). For many, their teacher education programs did not expose them to culturally responsive, sustaining, and relevant pedagogy that aims to develop teachers' critical perspectives in education. Furthermore, while they recognize the importance of role models in promoting STEM education for young female students, overall, our teachers felt that they lacked the necessary knowledge and training to support their students. Therefore, bridging the gap between STEM education and social justice pedagogy has the potential to promote a shift in classroom discourse that is more equitable and inclusive. Not only does STEM for social justice provide teachers with a toolkit to support students of diverse backgrounds, in terms of women in STEM, but it also has the potential to amplify females' contributions by making them visible and explicit within K-12 settings (Dou & Cian, 2022).

### **Conclusion**

Regarding the professional development course, it can be said that teachers presented critical insights into the reasons for the lack of female representation in STEM fields. In this paper, we analyzed the teachers' responses to two research questions that explore teachers' understanding of women's experiences or lack thereof in STEM. The authors of the course designed and implemented a four-modular-course to cultivate teachers' critical knowledge of issues of intersectional identities (race, gender, immigration status, and language ability). Our experience teaching the course highlights the need for prioritizing social justice issues of women and the representation of women in STEM in teaching, learning, and curriculum. The challenge of teacher professional development and teacher education is to identify the spaces to address gender stereotypes. Based on teachers' responses, we have confirmed the existence of the stereotypes in the minds of the teachers, the potential or perceived impacts on the participants and their classrooms and propose three strategies for addressing gender stereotypes in education, namely, integrating role models in curriculum, developing a growth mindset and promoting justice-oriented classroom discourse.

The outcome of the professional development course and teachers' learning has implications for teacher professional development and teacher education. Our course is a good example of a learning community for teachers to acknowledge gender stereotypes and how they perpetuate them. We discuss curricular development that integrates role models and project-based learning helps dismantle gender stereotypes as well as promote a growth mindset.

---

## References

- Alan, S., Ertac, S., & Mumcu, I. (2018). Gender stereotypes in the classroom and effects on achievement. *Review of Economics and Statistics*, 100(5), 876-890. [https://doi.org/10.1162/rest\\_a\\_00756](https://doi.org/10.1162/rest_a_00756)
- Allan, E. J., & Madden, M. (2006). Chilly classrooms for female undergraduate students: A question of method?. *The Journal of Higher Education*, 77(4), 684-711. <https://doi.org/10.1080/00221546.2006.11772311>
- Anderson, D. L. (2005). A portrait of a feminist mathematics classroom: What adolescent girls say about mathematics, themselves, and their experiences in a "unique" learning environment. *Feminist Teacher*, 15(3), 175-194. <http://www.jstor.org/stable/40546037>
- Becker, R. J. (1995). Women's ways of knowing in mathematics. In P. Rogers & G. Kaiser (Eds.), *Equity in mathematics education: Influences of feminism and culture* (pp. 163-174). Falmer. <https://doi.org/10.1080/00221546.2006.11772311>
- Belenky, M. F., Clinchy, B. M., Goldberger, N. R., & Tarule, J. M. (1986). *Women's ways of knowing: The development of self, voice, and mind* (Vol. 15). Basic Books.
- Bird, S. R., & Rhoton, L. A. (2021). Seeing isn't always believing: Gender, academic STEM, and women scientists' perceptions of career opportunities. *Gender & Society*, 35(3), 422-448. <https://doi.org/10.1177/08912432211008814>
- Braun, V., & Clarke, V. (2012). "Thematic analysis." In *APA handbook of research methods in psychology: Vol 2, Research designs*, edited by Harris Ed Cooper, Paul M. Camic, Debra L. Long, A. T. Panter, David Ed Rindskopf, & Kenneth J. Sher, pp. 57-71. Washington, DC: American Psychological Association. <https://doi.org/10.1037/13620-004>
- Ceci, S. J., Ginther, D. K., Kahn, S., & Williams, W. M. (2014). Women in academic science: A changing landscape. *Psychological Science in the Public Interest*, 15(3), 75-141. <https://doi.org/10.1177/1529100614541236>
- Clance, P. R., & Imes, S. A. (1978). The imposter phenomenon in high achieving women: Dynamics and therapeutic intervention. *Psychotherapy: Theory, Research & Practice*, 15(3), 1-8.
- Copur-Gencturk, Y., Cimpain, J., Lipinski, S., & Thacker, I. (2020). Teachers' bias against the mathematical ability of female, black and Hispanic students. *Educational Researcher*, 49(1), 30-43. <https://doi.org/10.3102/0013189X19890577>
- Corbett, C., & Hill, C. (2015). *Solving the equation: The variables for women's success in engineering and computing*. American Association of University Women. <https://files.eric.ed.gov/fulltext/ED580805.pdf>
- Dasgupta, N. (2011). Ingroup experts and peers as social vaccines who inoculate the self-concept: The stereotype inoculation model. *Psychological Inquiry*, 22, 231-246. <https://doi.org/10.1080/1047840X.2011.607313>
- Dasgupta, N., & Stout, J. G. (2014). Girls and women in science, technology, engineering, and mathematics: STEMing the tide and broadening participation in STEM careers. *Policy Insights from the Behavioral and Brain Sciences*, 1(1), 21-29. <https://doi.org/10.1177/2372732214549471>
- Dersch, A. S., Heyder, A., & Eitel, A. (2022). Exploring the Nature of Teachers' Math-Gender Stereotypes: The Math-Gender Misconception Questionnaire. *Frontiers in psychology*, 1728. <https://doi.org/10.3389/fpsyg.2022.820254>
-

- Diekman, A. B., Brown, E. R., Johnston, A. M., & Clark, E. K. (2010). Seeking congruity between goals and roles: A new look at why women opt out of science, technology, engineering, and mathematics careers. *Psychological Science*, 21(8), 1051-1057. <https://doi.org/10.1177/0956797610377342>
- Dou, R., & Cian, H. (2022). Constructing STEM identity: An expanded structural model for STEM identity research. *Journal of Research in Science Teaching*, 59(3), 458-490. <https://doi.org/10.1002/tea.21734>
- Eccles, J. S. (1994). Understanding women's educational and occupational choices: Applying the Eccles et al. model of achievement-related choices. *Psychology of Women Quarterly*, 18(4), 585-609. <https://doi.org/10.1111/j.1471-6402.1994.tb01049.x>
- Eccles, J. S., & Wang, M. T. (2016). What motivates females and males to pursue careers in mathematics and science? *International Journal of Behavioral Development*, 40(2), 100-106. <https://doi.org/10.1177/0165025415616201>
- Fournier-Sylvester, N. (2013). Daring to debate: Strategies for teaching controversial issues in the classroom. *College Quarterly*, 16(3), 1-9. <https://files.eric.ed.gov/fulltext/EJ1018000.pdf>
- Garriott, P. O., Hultgren, K. M., & Frazier, J. (2017). STEM stereotypes and high school students' math/science career goals. *Journal of Career Assessment*, 25 (4), 585-600, <https://doi.org/10.1177/1069072716665825>
- Herzig, A. H. (2004). 'Slaughtering this beautiful math': graduate women choosing and leaving mathematics. *Gender and Education*, 16(3), 379-395. <https://doi.org/10.1080/09540250042000251506>
- Hill, C., Corbett, C., & Rose, A. (2010). *Why so few? Women in science, technology, engineering and mathematics*. American Association of University Women (AAUW). <https://files.eric.ed.gov/fulltext/ED509653.pdf>
- Kerkhoven, A.H., Russo, P. Land-Zandstra, A. M., Saxena, A., & Rodenburg, F. J. (2016) Gender stereotypes in science education resources: A visual content analysis. *PLoS One*, 11 (11), 1-13, <https://doi.org/10.1371/journal.pone.0165037>
- Kuchynka, S. L., Eaton, A., & Rivera, L. M. (2022). Understanding and Addressing Gender-Based Inequities in STEM: Research Synthesis and Recommendations for US K-12 Education. *Social Issues and Policy Review*, 16(1), 252-288. <https://doi.org/10.1111/sipr.12087>
- Liu, F. (2020). Addressing STEM in the context of teacher education. *Journal of Research in Innovative Teaching & Learning*, 13(1), 129-134.
- Lockwood, P. (2006). "Someone like me can be successful": Do college students need same-gender role models?. *Psychology of women quarterly*, 30(1), 36-46. <https://doi.org/10.1111/j.1471-6402.2006.00260.x>
- Lubienski, S., T & Ganley, C. (2017). Research on gender and mathematics. In J. Cai (Ed.), *Compendium for research in mathematics education* (pp. 649-662). National Council of Teachers of Mathematics.
- Lubienski, S., & Pinheiro, W. A. (2020). Gender and Mathematics: what can other disciplines tell us? What is our role?. *Journal of Urban Mathematics Education*, 13(1), 1-14. <https://journals.tdl.org/jume>
- Master, A. (2021). Gender stereotypes influence children's STEM motivation. *Child Development Perspectives*, 15(3), 203-210. <https://doi.org/10.1111/cdep.12424>
- Matheis, S., Keller, L. K., Kronborg, L., Schmitt, M., & Preckel, F. (2020). Do stereotypes strike twice? Giftedness and gender stereotypes in pre-service teachers' beliefs about student characteristics in Australia. *Asia-Pacific Journal of Teacher Education*, 48(2), 213-232. <https://doi.org/10.1080/1359866X.2019.1576029>

- McGuire, L., Mulvey, K., Geoff, E., Irvin, M., Winterbottom, M., Fields, G., Hartstone-Rose, A., & Rutland, A. (2020). STEM gender stereotypes from early childhood through adolescence at informal science centers. *Journal of Applied Developmental Psychology*, 67, 1-9. <https://doi.org/10.1016/j.appdev.2020.101109>
- National Center for Science and Engineering Statistics. (2019). *Women, minorities, and persons with disabilities in science and engineering* (Special Report NSF 19-304). National Science Foundation, Directorate for Social, Behavioral, and Economic Science. <https://www.nsf.gov/statistics/wmpd>
- Nesmith, S. & Cooper, S. (2018). Engineering process as a focus: STEM professional development with elementary STEM-focused professional development schools. *School Science and Mathematics*, 119, 487-198. <https://doi.org/10.1111/ssm.12376>
- Osei-Tutu, A. A. Z., Dwomoh, R., Chhikara, A., Zhou, L., Oudghiri, S., & Bell, T. (2021). Diversity, Equity, and Inclusivity in a Time of Crises: A Reflection on Educators' Perspectives of Critical Theory and Social Justice Issues. In *The Kaleidoscope of Lived Curricula: Learning Through a Confluence of Crises*, 13th Annual Curriculum & Pedagogy Group 2021 Edited Collection (pp. 367-382). Information Age Publishing.
- Pourdavood, R. & Yan, M. (2020). Becoming critical: In-service teachers' perspectives on multicultural education. *International Journal of Learning, Teaching and Educational Research*, 19(2), 112-135. <https://doi.org/10.26803/ijlter.19.2.8>
- Riegle-Crumb, C., & Humphries, M. (2012). Exploring bias in math teachers' perceptions of students' ability by gender and race/ethnicity. *Gender & Society*, 26(2), 290-322. <https://doi.org/10.1177/0891243211434614>
- Ring, E., Dare, E., Crotty, E., & Roehrig, G. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education*, 28(5), 444-467. <https://doi.org/10.1080/1046560X.2017.1356671>
- Robinson-Cimpian, J. P., Lubienski, S. T., Ganley, C. M., & Copur-Gencturk, Y. (2014). Teachers' perceptions of students' mathematics proficiency may exacerbate early gender gaps in achievement. *Developmental Psychology*, 50(4), 1262-1281. <https://doi.org/10.1037/e578192014-126>
- Rogers, A. A., Boyack, M., Cook, R. E., & Allen, E. (2021). School connectedness and STEM orientation in adolescent girls: The role of perceived gender discrimination and implicit gender-science stereotypes. *Sex Roles*, 85(7), 405-421. <https://doi.org/10.1007/s11199-021-01224-7>
- Saldana, J. (2016). *The coding manual for qualitative researchers* (3rd ed.). Sage.
- Sears, D., Razeghi, S., Gaidos, J., & Charabaty, A. (2021). Overcoming imposter syndrome, addressing microaggressions, and defining professional boundaries. *The Lancet Gastroenterology & Hepatology*, 6(11), 881-884. [https://doi.org/10.1016/S2468-1253\(21\)00339-3](https://doi.org/10.1016/S2468-1253(21)00339-3)
- Smeding, A. (2012). Women in science, technology, engineering, and mathematics (STEM): An investigation of their implicit gender stereotypes and stereotypes' connectedness to math performance. *Sex Roles*, 67, 617-629. <https://doi.org/10.1007/s11199-012-0209-4>
- Shernoff, D., Sinha, S., Bressler, D., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, 4(13), 1-16. <https://doi.org/10.1186/s40594-017-0068-1>
- Starr, C. R., & Simpkins, S. D. (2021). High school students' math and science gender stereotypes: relations with their STEM outcomes and socializers' stereotypes. *Social Psychology of Education*, 24(1), 273-298. <https://doi.org/10.1007/s11218-021-09611-4>

- Su, R., Rounds, J., & Armstrong, P. I. (2009). Men and things, women and people: a meta-analysis of sex differences in interests. *Psychological Bulletin*, 135(6), 859-884. <https://doi.org/10.1037/a0017364>
- Vaismoradi, M., Turunen, H., Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing & Health Sciences*, 15(3), 398-405. <https://doi.org/10.1111/nhs.12048>
- Walkerdine, V. (1989). *Counting girls out*. Virago.
- Wang, M. T. (2012). Educational and career interests in math: A longitudinal examination of the links between classroom environment, motivational beliefs, and interests. *Developmental Psychology*, 48(6), 1643-1657. <http://dx.doi.org/10.1037/a0027247>

### Authors

#### Lili Zhou

Assistant Professor  
California State University, Los Angeles, Division of Curriculum and Instruction  
Email: [lzhou18@calstatela.edu](mailto:lzhou18@calstatela.edu)

#### Alankrita Chhikara

Research Assistant  
Purdue University, Curriculum and Instruction  
Email: [achhikar@purdue.edu](mailto:achhikar@purdue.edu)

#### Stephanie Oudghiri

Clinical Assistant Professor  
Purdue University, Curriculum and Instruction  
Email: [stoudghi@purdue.edu](mailto:stoudghi@purdue.edu)

#### Araba A. Z. Osei-Tutu

Lecturer  
University of Ghana, Legon, Department of Teacher Education  
Email: [aazosei-tutu@ug.edu.gh](mailto:aazosei-tutu@ug.edu.gh)

#### Razak Kwame Dwomoh

Assistant Professor  
Northern Illinois University, Curriculum and Instruction  
Email: [rkdwomoh@gmail.com](mailto:rkdwomoh@gmail.com)

## **Designing a Program to Develop Computer Science Master Teachers for an Underserved Rural Area**

Susie Morrissey  
*Mercer University*

Thomas Koballa  
*Mercer University*

Robert Allen  
*Mercer University*

Judy Godfrey  
*Mercer University*

Michael Dias  
*Kennesaw State University*

Shawn Utley  
*Wiregrass Georgia Technical College*

DeAnnia Clements  
*Wiregrass Georgia Technical College*

### **Abstract**

Due to a shortage of rural computer science teachers, researchers used a three-phase method to design a computer science endorsement, which will be coupled with an instructional coaching endorsement within an Educational Specialist degree program. The team conducted interviews of teachers as well as school and district level administrators in rural areas to determine needs and resources available to develop computer science master teachers. Interviewers also investigated recruitment, preparation and support processes pertinent to the program. Findings included that, although infrastructure for wireless access is lacking, school and district administrators are very interested in supporting teachers to become computer science master teachers. STEM teachers are especially interested in computer science content related to their teaching field. Partners indicated an interest in developing teacher leaders, in order to encourage a sustainable computer science program in the school and district. Information gathered was used to design a program that intends to meet the needs of potential rural computer science master teachers.

*Keywords:* Computer Science Education, Teacher Leadership, Rural Education

*Funding:* This project was supported by the National Science Foundation, Award #1949866



Job reports indicate there were over 400,000 open computer science (CS) positions in the United States in 2020, with only about 70,000 CS students graduating and joining the job force (Code.org Advocacy Coalition, 2021). Contributing to this is the nation's CS teacher capacity deficit. In 2020, only 47% of high schools nationwide taught CS (Code.org et al., 2020). Moreover, CS courses are disproportionately distributed, as "schools in rural communities and schools with higher percentages of economically disadvantaged students are less likely to teach computer science" (Code.org et al., 2020, p. 15). To address the CS teacher deficit, the Southeastern state where this project took place has a pre-service CS certification pathway, a testing option for CS professionals wanting to transition from industry into teaching, and a CS endorsement for teachers who are certified in other teaching areas to obtain CS certification. However, none of the CS endorsement program providers target rural, high-need school systems.

In addition to creating certified CS teachers, supporting those teachers in becoming teacher leaders would provide a pathway for integration of CS instruction into schools and districts in high-needs areas. This was seen in Lotter et al. (2020), where teacher leaders saw part of their role as providing opportunities to their students that would not otherwise be available. These teacher leaders improved their relationships with students, colleagues, and the community, which can lead to improved teacher retention (Burton & Johnson, 2010). Driven by the need for certified CS teachers, as well as the leadership needed to implement CS education school- or district-wide, this project seeks to develop an investigative process that will result in a Master Teacher CS program with ongoing support in a high-needs area.

### **Literature Review**

This project was informed by four areas of thought regarding CS teacher education: teacher endorsement, teacher recruitment, teacher professional development (PD), and teacher leadership development. Initial teacher preparation efforts are not meeting the demand for highly-qualified CS teachers (Code.org, 2017b; Montoya, 2017). This is due to the limited number of CS teacher preparation programs and that few CS graduates choose to pursue teaching (Code.org Advocacy Coalition & CSTA, 2018). Thus, providing certification options for experienced teachers wanting to transition into CS is seen as a viable means to address the increased push for CS education in schools (Code.org, 2017a).

#### **Teacher Endorsement**

CS endorsement programs serve as a means for teachers to add CS as a new area of certification to their current teaching certificate (Code.org, 2017a). CS endorsement programs are offered through universities and, in some states, through non-university providers. A university provider may incorporate the CS endorsement as a track within a graduate degree program. Guided by CS teaching standards that vary from state to state (Code.org Advocacy Coalition & CSTA, 2018; Code.org et al., 2020), the learning experiences of most CS endorsement programs require a year or more to complete and include content and pedagogical coursework along with a CS-focused field experience (Columbus State University, undated; Oconee Regional Educational Service Agency [RESA], undated). CS endorsement programs use face-to-face, as well as hybrid and online delivery formats (Vivian et al., 2014) and, because they are structured to meet the needs of practicing teachers, tend to reflect the learning tenets of teacher PD.

## **Teacher Recruitment**

Efforts to recruit experienced teachers from other content areas into a CS endorsement program must be strategic and comprehensive (Luft et al., 2011), which involve helping experienced teachers explore the field of CS teaching and determine if preparing to become a CS teacher is a good choice for them. When attempting to recruit CS teachers from the corps of experienced STEM teachers, the professional trajectory of these teachers must be considered. In science education, Luft et al. (2019) describe teachers' professional trajectories in the context of continuous learning and use Mezirow's (1978, 2012) transformative learning theory to frame the process of teacher professional growth aided by supportive communities. The professional trajectories that teachers chart for themselves can help them determine if transitioning into CS teaching is an appropriate choice for them as well as the knowledge, practices, and attributes they would need to develop (Luft et al., 2019). Research by Qian et al. (2018) also highlights the importance of understanding the backgrounds and motives of teachers when recruiting for CS. They found that teachers may have "hidden computing backgrounds" that are not always apparent, such as the mathematics teacher with informal programming experience. Moreover, experienced teachers tend to be committed professionals and much less likely to leave the profession than early career teachers (Garcia & Weiss, 2019), making experienced STEM teachers ideal recruits for pathways that enable them to transition into CS teaching (Code.org, 2017b). Additionally, as in all STEM areas, recruiting efforts must target teachers who reflect the diversity of the students they will teach (Montoya, 2017).

## **Teacher Professional Development**

CS teacher preparation research is clear that the knowledge base for effective teaching includes CS content knowledge and pedagogical content knowledge (PCK) (Yadav & Korb, 2012). The CS content that teachers should know is aligned with the five core concepts of computer systems, networks and the internet, data and analysis, algorithms and programming, and impacts of computing in addition to the seven core practices that support computational thinking (K-12 Computer Science Framework, 2016). Fundamental to PCK in CS are the teacher's knowledge of common student misconceptions and areas where students encounter learning challenges (Yadav et al., 2016).

Besides content and PCK, CS teachers should be prepared to engage economically, ethnically, and linguistically diverse students (Montoya, 2017). Teachers need to understand the importance of culturally relevant interactions to the persistence and success of students traditionally underrepresented in CS (Charleston et al., 2017). These cultural interactions may be reflected in CS course curriculum as well as in culturally sensitive teaching and assessment strategies that focus on what diverse groups of students know and can do (Ladson-Billings, 1995). In addition, cultural interactions presented through peer and community modeling, familial cultivation, and multifaceted mentoring can be strategically encouraged by teachers. These need to be a part of CS teacher preparation, as these interactions have been shown to broaden the participation of African Americans and others in the CS educational pipeline (Charleston et al., 2017). Budge (2006) pointed out the importance of teacher leaders' understanding the culture in rural schools in order to be successful. Rural students have particular needs to be addressed in PD, such as lack of access to experiences and resources, that can be supplied through community connections, field trips and contests (Lotter et al., 2020). In addition, school and school system leadership are critical in supporting teacher change (Whitworth & Chiu, 2015).

CS preparation for experienced teachers transitioning into CS teaching is further informed by research on effective PD. Desimone's (2009) conceptual framework highlights key features of successful PD identified from research (Borko, 2004; Knapp, 2003): content focus, active learning, coherence, duration, and collective participation. The framework has been used in STEM fields, including CS, to guide the development of PD experiences. For example, Qian and colleagues (2018) used the framework to design a PD program for teachers preparing to teach a new CS course for the first time. The program was delivered online and spread out over many months, which was viewed as advantageous because teachers could access the program's materials when their schedules allowed. In addition, Buczynski and Hansen (2010) found PD that attends to the features of Desimone's framework and considers factors that promote engagement increases the likelihood of teacher learning and changes that benefit student achievement.

### **Teacher Leader Development**

The importance of teacher leadership to school improvement and student learning has drawn attention to the need for PD that prepares teachers for leadership roles (Angelle & DeHart, 2011; Berry, 2019; Wenner & Campbell, 2017). The need for teacher leadership development in STEM areas, including CS, is particularly critical due to the unique characteristics of STEM teacher leadership (Criswell et al., 2017). Criswell and colleagues argue that the demands of STEM teacher leadership are different than those of non-STEM teacher leadership, particularly with regard to new national standards, the constantly changing knowledge base in STEM fields, the limited emphasis on STEM learning in schools, and the paucity of school leaders with STEM backgrounds (Criswell et al., 2018). Competencies deemed central for STEM leadership PD include those in the areas of leadership, beliefs about STEM learning, STEM discipline content knowledge, and the capacity to integrate STEM and non-STEM disciplines (US Department of Education, undated). Of particular relevance to the proposed project is the structure of the National Science Foundation (NSF) Noyce Initiative to Increase and Mentor Physics and Chemistry Teachers (I-IMPACT) program and the conceptual framework that guided this work to prepare teacher leaders (Criswell et al., 2018). The concepts of STEM teacher leader as effective practitioner, as learning partner, as productive scholar, and as policy voice functioned as drivers for this multi-year PD effort. During PD the I-IMPACT Master Teacher Fellows engaged in sessions that focused on the development of content and PCK, teacher leadership skills and dispositions, mentoring and professional learning community practices, and dissemination of new understandings and practices. Additionally, Lotter et al. (2020) investigated STEM teacher leadership in rural areas, and noted that teacher leaders built strong relationships with students, provided students with new academic pathways to success, and built strong connections in the community.

### **Research Questions**

The literature review informed the processes of this study, as seen by the importance of strategic and comprehensive recruitment of experienced teachers (Garcia & Weiss, 2019; Luft et al., 2011; Qian et al., 2018). Preparing teachers involves PCK, knowledge of common misconceptions, culturally responsive interactions, and CS content (Charleston et al., 2017; Qian et al., 2018; Yadav et al., 2016; Yadav & Korb, 2012). Supporting teachers as they move into leadership is central to the idea of creating master teachers, requiring school system support and guidance on the unique demands of STEM teacher leaders (Criswell et al., 2018; Whitworth & Chiu, 2015). Development of a program to provide CS Master Teachers relied on investigations into current program offerings at other institutions, as well as state requirements for CS endorsements. However, before attending to processes and development, viability concerning

infrastructure and interest in the targeted area had to be considered, for without those elements the project could not move forward.

In response to the current conditions in rural, high-need school systems this project investigated recruitment, preparation, and support necessary for 6-12 grade teachers to transition into CS from other STEM fields. The project was guided by questions in these three categories:

- Viability
  - o What is the nature of the infrastructure needed to support CS instruction in rural, high-need school systems?
  - o What is the interest among exemplary and certified 6-12 STEM teachers to engage in CS teaching and leadership opportunities and to participate in a Master Teacher learning experience that would enable them to do so?
- Processes
  - o What processes could be used to recruit CS teachers from among the corps of exemplary and certified 6-12 STEM teachers?
  - o What processes could be used to prepare exemplary and certified 6-12 STEM teachers with the CS content and culturally-responsive pedagogical content knowledge to teach CS to all students?
  - o What processes could be used to support the success of new 6-12 CS teachers in the classroom and as teacher leaders?
- Development
  - o What are the design elements and structure of a CS Master Teacher endorsement track for 6-12 teachers that is based on our developing understandings of CS teacher recruitment, preparation and support as well as the needs of rural, high-need schools?

Central to the project was the process of evidence-based decision making that led to the design of a model CS teacher endorsement track, along with a teacher leadership endorsement, embedded within an existing Educational Specialist (EdS) degree program to support the transitioning of teachers into Master CS teachers from other STEM teaching fields. The EdS degree, which is more common in the Southeast and Midwest, is between a Master's degree and Phd or EdD, and, in many districts, provides a pay increase (EdD Programs, 2022).

### **Methodology**

To address the need for CS teacher leaders, a partnership was formed between a four-year university and a technical college. A Noyce capacity building grant was proposed and funded by the NSF, with a plan to gather information about the infrastructure needed to support grades 6-12 CS instruction in rural, high-need schools; interest among STEM teachers to pursue CS teaching and leadership opportunities; and the recruitment, preparation, and support processes pertinent to CS teaching.

The goal of the project was to engage in a structured process leading to the informed development of a CS/leadership program. Team members followed these steps:

- Step 1 (addressed viability): Conducted a needs assessment to determine the infrastructure needed to support CS instruction in rural school systems and interest among exemplary and certified 6-12 STEM teachers to pursue CS teaching and leadership opportunities,
- Step 2 (addressed processes): Investigated recruitment, preparation, and support processes pertinent to CS teaching and leadership, and

- Step 3 (addressed development): Designed a CS Master Teacher endorsement track within an existing EdS degree program that is based on our developing understandings of CS teaching, leadership, and the needs of rural schools.

### Project Phases

The project had three phases, aligned with each of the steps listed above. The first phase involved visiting schools (virtually) and collecting information about the infrastructure to support CS instruction in rural school systems from grades 6-12 teachers, technology specialists, school administrators, and school supporters in this Southeastern state. Due to limited school access resulting from the COVID-19 pandemic, 23 interviews were conducted via Zoom with stakeholders from nine different rural school systems before March 2021. School system interviewees are detailed in Table 1. Additionally, one female learning coordinator from a regional support center that provides PD to teachers in some of the included districts was interviewed.

Table 1  
*School System Interviewees*

District	Percent economically disadvantaged	Type of School	Position	Gender	Teaching Subject
A	47	Secondary	Teacher	Male	CS
		Elementary	Teacher	Female	n/a
		Secondary	Career/Technical/Agricultural education director	Male	n/a
B	54	Elementary	Curriculum director	Male	n/a
		Elementary	Curriculum director	Female	n/a
C	18	Secondary	Teacher	Female	CS
D	55	Secondary	Teacher	Male	CS
		Secondary	Teacher	Female	Science and Business
		District level	Technology director/specialist	Male	n/a
		District level	Technology director/specialist	Male	n/a
		Secondary	Career/Technical/Agricultural education director	Female	n/a
E	42	Secondary	Teacher	Female	Math
		District level	Technology director/specialist	Male	n/a
		District level	Technology director/specialist	Female	n/a
F	28	Elementary	Curriculum director	Female	n/a
		Secondary	Curriculum director	Female	n/a
G	44	Middle	Teacher	Female	CS
		Middle	Teacher	Female	CS
		District level	Technology director/specialist	Female	n/a
H	45	District level	Technology director/specialist	Female	n/a
J	50	Secondary	Teacher	Female	Business
		Middle	Teacher	Female	CS
		Elementary	Teacher	Male	n/a

Information sought included CS teacher interest, availability, qualifications, learning opportunities for teachers in CS content as well as in school and professional learning community leadership, and administrative and community support for CS instruction. The focus was on infrastructure to support CS instruction in high-need rural school systems. The project involved the development and refinement of interview protocols for interviews with School System Leaders, Teachers, and School Supporters. The interview protocols were built from protocols and surveys used in other NSF Noyce projects and described in the CS education literature (Burton & Johnson, 2010; Criswell et al., 2017; Lotter et al., 2020; Yadav et al., 2016). The interview protocols are presented in the Appendix.

The second phase of the project addressed recruitment, preparation, and support processes for CS teachers in rural school systems. To begin, data pertaining to programs that prepare CS teachers and those that provide leadership training to STEM teachers were collected. Programs were examined, with a focus on program structure, context, and content as well as outcomes. Attention was given to programs that support the transition of teachers into CS teaching from other fields with outcomes related to (1) culturally-responsive pedagogical knowledge to engage all students in CS learning and (2) leadership understandings and skills to support and sustain CS instruction within rural, high-need schools.

Next, data pertaining to the recruitment of participants to programs that prepare CS teachers and that provide leadership training to STEM teachers were collected. Phase two data in this area consisted of documenting different approaches to recruiting experienced, exemplary and certified teachers into programs that prepare them as CS teachers and those that provide leadership training to STEM teachers. Finally, data were gathered regarding strategies that support the success and persistence of new CS teachers and strategies that enable STEM (including CS) teacher leaders to position themselves as critical members of school and school system leadership teams and to promote the legacy of STEM (including CS) instructional programming and support leadership succession.

The third phase involved the design of a CS Master Teacher endorsement track within an existing EdS degree program, along with contextually-appropriate strategies that will be used to recruit exemplary and certified 6-12 STEM teachers to the program's CS Master Teacher endorsement track and support their post-program experiences.

With the lifting of COVID-19 restrictions in March 2021, one researcher visited middle and high schools in five districts, accompanied by either the superintendent, assistant superintendent, or curriculum coordinator. Meetings were held with school principals, curriculum coordinators, and teachers to discuss the program. Visits with three additional superintendents were made during regional superintendent gatherings. The visits allowed confirmation of the interview data and interpretations, validation of the design of the CS endorsement track within the EdS degree program, and identification of teacher participants for a program to develop CS Master Teacher Fellows.

### **Data Collection and Analysis**

Of significance to our information gathering efforts and directly to the design of our endorsement track is the cultural milieu of K-12 education in rural school systems. Many students are members of groups traditionally underrepresented in STEM fields, particularly CS (Code.org et al., 2020). Experienced STEM teachers, like those we hope to involve in the program, may not reflect the diversity of their students (Tio, 2018), which could impact their students' learning

opportunities and success. Yet, many experienced teachers in rural areas have ties to the local community (Monk, 2007). These ties tend to ensure their longevity in the local school system and enable opportunities for long-term collaborations. Historically, rural school systems have suffered from lack of resources and isolation (National Association of State Boards of Education, 2016). These factors may mitigate against curricular and instructional innovation and improvement. Besides the review of research, these considerations influenced the collection and analysis of data as well as the design of the CS Master Teacher endorsement track.

### **Question set 1. Data collection and analysis: Infrastructure and teacher interest**

This question set aligns with phase one. Researchers identified the data sources and interviews protocol items, informed by literature related to interview protocol design (e.g., Castillo-Montoya, 2016), strategic and representative sampling (e.g., Check & Schutt, 2012), and qualitative data analysis (e.g., Creswell & Guetterman, 2019).

To understand the infrastructure needed to support CS instruction in rural high-need school systems of this Southeastern state, researchers interviewed the leadership of a sample of nine school systems (see School System Leader Interview, Appendix). This sample represented about one-third of the 30 rural, high-need rural school systems to be the target of the program. Data gathered from the School System Leader Interview protocol was used to guide requests for two other interviews—one with 6-12 STEM teachers (Teacher Interview, Appendix) and the second with regional support centers and technical college staff members that serve the rural area (School Supporters Interview, Appendix). The Teacher Interview protocol was used to collect information from certified 6-12 STEM teachers with at least three years of teaching experience in the sampled school systems. The School Supporters Interview was conducted with staff and faculty working with rural, high-need school systems to support CS or teacher leadership efforts.

The interview data were analyzed qualitatively using descriptive coding (Creswell & Guetterman, 2019) to understand (a) the infrastructure needed to support CS instruction in rural, high-need school systems, including elements from outside the school system, such as regional support center and technical college staff, and (b) the interest among experienced and certified grades 6-12 STEM teachers in preparing for CS teaching and leadership as well as benefits and challenges associated with their decision. One researcher coded interview transcripts using NVIVO, scrutinizing interviewees' comments in response to questions on the interview protocols. Initial codes were developed based on the areas of interest in the research questions, which corresponded with questions in the protocols. Codes were further refined based on interview responses, with new codes added until saturation was reached. Data were shared with three other researchers who checked the consistency of coded material within each of the codes, as suggested by Krathwohl (2009). Discussions were held until agreement was reached on the coded interviews. Attention within the analysis was directed to understanding how to increase the diversity of teacher participants along with the benefits and challenges that may impact participation.

### **Question set 2. Data collection and analysis: CS recruitment, preparation, and support**

This question set aligns with phase two. A set of Teacher Interview questions asked about affordances and challenges that 6-12 STEM teachers associate with participation in an endorsement track that leads to CS certification as well as incentives that may encourage their participation. Similarly, School Supporter and School System Leader Interview questions asked about recruiting strategies found or believed to be successful in recruiting a diverse cadre of teachers to participate in voluntary PD, especially PD that focuses on CS and teacher leadership.

In addition, the Teacher, School Supporter and School System Leader Interviews included questions about the concepts and topics that should be included in a CS endorsement track as well as desirable means of content delivery and ongoing support for CS teaching and teacher leadership. These data were analyzed using the same method as described for Question set 1 above to understand the views of teachers, supporters, and school leaders regarding recruitment for a CS endorsement track and the content and delivery of a CS endorsement track.

Additionally, information was collected from the existing CS endorsement tracks embedded in degree programs and stand-alone CS endorsement programs operated by universities and regional support centers throughout this Southeastern state. Information sought was about teacher recruitment, endorsement track components, and the qualifications of endorsement track instructors. From these CS endorsement providers, information was also sought about CS endorsement track completers, with attention to the kinds and duration of support provided them. Information collected from these providers was compared with state CS certification requirements and guidelines proffered by national and state leaders in CS education (e.g., Coding.org., Georgia Learns, CS4GA). The information was sought from online sources. However, telephone conversations and email exchanges were also used as needed to secure the desired information.

The reviews of CS endorsement tracks and stand-alone CS endorsement programs were integrated with the interview findings as well as state certification requirements and information gathered from CS education leaders. The CS endorsement tracks and stand-alone CS endorsement programs were compared to determine commonalities and unique strategies and features. Information synthesized from these sources and coupled with the data gathered via interviews was used to guide the design of the CS endorsement track, including recruiting approaches and means of supporting CS teaching and leadership.

### **Question set 3. CS Master Teacher endorsement track design**

Phase three, designing a viable CS Master Teacher endorsement track, required multiple points of consideration. Understandings constructed as a result of the project's data collection and analysis phases provide guidance regarding the infrastructure needed to support CS teaching, means for recruiting CS teachers from the corps of 6-12 STEM teachers, and the processes for preparing and supporting CS teachers for the classroom and leadership roles.

Standards that govern the approval of CS endorsement programs in this Southeastern state were reviewed and guided the development of a CS endorsement program. In addition, investigated were means for embedding the CS endorsement and an instructional coaching endorsement in an EdS degree suitable for grades 6-12 STEM teachers.

### **Results**

In order to assess the need and readiness to implement this project, the researchers conducted targeted interviews with individuals potentially impacted by the project. Over 20 interviews were conducted with questions focused on the four areas of research – infrastructure to support technology initiative in this rural area, technology content preparation for P-12 CS requirements, teacher and leadership development for CS focused roles, and support to participants following credentialing. The interviewees were representative of individuals in the target area and included principals, teachers, technology leaders, school district and regional support center leaders, and technical college representatives. These individuals responded to questions that would provide



guidance to the next steps of the project. The interviews were conducted in a question/discussion format to specifically determine the needs of teachers and school systems in the rural area.

## **Viability**

### ***Infrastructure to support technology initiative***

For phase one, in discussions with representatives from the partner districts and regional support centers with regards to technology availability, questions were posed related to the availability of hardware and internet service within the area of the grant target. Of the more than 20 interviews conducted, 12 discussed this topic. Most of the respondents, 8 out of 12, characterized their hardware availability as minimal. Seven out of eight stated that wi fi options were minimal or unavailable. Comments from interviewees included those that highlighted in-school challenges, such as, "...we have one laptop cart for the whole grade level with 25 teachers sharing," as well as strengths, as seen in these comments: "...our wi fi infrastructure is huge. It's very important to us", "...we have the best infrastructure, the best resources, the best online learning resources I think available" and "...we have no connectivity issues at all."

However, the following comments demonstrate that technology access in the community is lacking: "But when they get away from our school campus. Then the ball game changes. Big time. And that's where we're at a disadvantage", and "...between 40 and 50% of our kids have good reliable fast internet connectivity at their home." Additionally, one respondent commented that a large number of students, as well as some teachers, in their rural area did not have internet access at home at all. Districts have tried to address this lack of access by providing hotspots, as seen in this comment: "...we can either send it [hotspot] home with kids or place them on buses in strategic locations throughout the county."

### ***Interest among teachers***

Incentives played an important part in appealing to experienced STEM teachers. Offering an online program with flexibility built in to the courses would increase interest, as teachers were reluctant to engage in a program that would require travel and did not take their needs into consideration. One interviewee mentioned the importance of additional coursework to "...build that coaching piece," increasing teacher interest by possibly offering an additional instructional coaching endorsement. Teachers and administrators also expressed their desires for CS education, as seen in these comments: "...So any type of professional development that can teach me how to be better at allowing my students to produce things. That's what they like to do in that class. It made it more interesting for them" and "...But ideally, if I had some teachers who could get the endorsement, they would be more comfortable in what they were doing and it would be, it would be better."

## **Recruitment, Preparation and Support Processes**

### ***Recruitment potential***

Of the over 20 interviews, 18 spoke to the importance of developing a recruitment strategy. The topics that arose during the interview discussions included that alignment to current teaching or STEM topics would make the program more compelling, which was mentioned by 13 interviewees. For example, comments included: "...how computer science is used in biology or mathematics or physics" and "...data science and data analytics and everything really has a place in every single subject, you know, for the STEM fields." Another important recruiting strategy that was mentioned during the interviews was the option through the grant to offer a stipend or

tuition for completion of the endorsement, as seen in this comment: "...So I think doing something like that, it just shows that you're putting an actual value on the teachers' time."

### ***Technology content preparation for P-12 CS requirements***

This Southeastern state requires that CS courses be offered in middle and high schools. Beginning in the 2021-2022 school year each local school system was required to have at least one high school in its school system that offers a CS science class, and all middle schools in the school system were required to offer instruction in exploratory CS. Each state charter school that has high school students must offer a course in CS and each charter school that serves middle school students must offer a class in exploratory CS. Beginning in the 2022-2023 school year each local school system was required to have at least 50% of their high schools offer a course in CS and in the 2023-2024 school year, all high schools are required to offer a course in CS.

Interviews with individuals in the target area included questions about preparation for the upcoming state requirement that CS be offered in every district. Respondents stated that though most had heard of this new requirement that little had taken place in order to prepare for full implementation. Some districts have access to the CS endorsement, mainly through area technical colleges and regional support centers. Even though rural areas had access to the CS Endorsement, most technical colleges and regional support centers offered it in a face-to-face format. Those that were interviewed indicated that this was a barrier to completion due to travel time and costs associated with enrolling. As a result of this barrier, only a small number of teachers in our target area had completed the endorsement.

Interviewees had over 40 comments about preparations that were taking place in order to meet the CS requirements, such as past PD: "...I went to the AP Summer Institute for the class itself so that I could teach you know that particular AP class. And that was helpful in as far as you know, the course itself" and "...by going to a couple of technology conferences and things like that. That's kind of where I would go to the code.org class or I would go to the ... robotic class and that kind of thing."

### ***Culturally responsive pedagogy content***

Content that was responsive to the needs of students and their communities was one focus of interviewees' wishes. For example, one administrator mentioned "Find community businesses that rely on CS...see a potential career associated with CS" as important components of building a CS program within the school or district. Another comment mentioned areas of interest to students such as "...gaming, robotics, agricultural aspect...farmers using drones." Other possible areas of interest in the specific rural communities include military and medicine, two career pathways available to interested students. To address these areas of opportunity for rural students, researchers partnered with a medical school, an agricultural extension, and a local military base to provide field trips and information to teachers in the EdS program, and their students. Teachers in the EdS program will also be provided guidance on establishing student organizations and community partnerships.

### ***Teacher & leadership development to support CS focused roles***

A major focus of this endorsement development was to determine the interest/value in developing those enrolled in the CS Endorsement for a leadership role following credentialing. Many of the interview respondents, especially those who are currently teaching, felt very strongly about having specific information about how to support others and serve in a leadership role in CS after earning the endorsement. Some of the interviewees were already being called upon by their

district to assist on CS development teams or were serving to support new teachers in CS. They were positive about offering this support; however, they felt they needed additional knowledge about serving in these roles. Comments included: "...helping the teachers that are in the endorsement to see themselves, not as just teachers, but as teacher leaders. And to build those skills and to be able to communicate" and "...if they were to get endorsed, I would love for them to be the expert in that field to provide some professional learning to other teachers as well as administrators as well to do that."

### ***Support to participants following credentialing***

It became clear as the interviews were being conducted that the participants had varying levels of commitment to participating in an endorsement. Some of these feelings were due to the lack of contact/support from instructors of the courses, others because of feeling that they did not have sufficient information to lead their classroom CS instruction. What came to light from many of the interview participants was a need for follow-up support/coaching. Many commented that just having someone to talk to about CS instruction/lessons or to hear about successes was critical in the outcome of this project. Positive comments about having a mentor include: "... He's somebody that I can go to, because I know that he's had that problem before or with a project that he used to do. Like, I can't get it to work. You know, brainstorming" and "...it just provides that safety net for these teachers that are jumping into something that they've never done before and having somebody that they can go to and have a conversation with I think is really important."

### **CS Master Teacher Endorsement Track Development**

Additional goals included developing a program that would enable completers to obtain a CS endorsement as well as an instructional coaching endorsement on their teaching license. Resources used to inform creation of the endorsement were reviews of CS endorsement tracks and stand-alone CS endorsement programs, interview findings, state certification requirements, and information gathered from CS education leaders. Researchers also analyzed the CS tracks available to high school students, and the CS endorsement practice test and information. Advice and desires for included components in the program, as seen in interviews, were content that could be incorporated into an existing math or science course, synchronous online courses, office hours so teachers could ask questions outside of class time, and ideally a length of three courses for the endorsement, with multiple program entry points. Faculty also defined key assessments and points within the program where those will be administered, in order to assess teacher progress as well as program success. Three faculty members from a local technical college will provide mentoring for teachers as they learn and practice CS content. Partnerships with a medical school, agricultural extension and military base were formed to provide relevant experiences to teachers and their students. Additionally, field experiences were incorporated into the coursework.

Struggles with the creation of the CS endorsement included the initial desire to include relevant content knowledge at a depth appropriate for a CS student in college, as well as adequate practice in pedagogical dimensions such as lesson creation, anticipation of student errors, planned purposeful questions, practice teaching the lessons, assessment, and analysis of student work. An initial program plan was created, with options for three, four or five courses. Discussions of interview results and information about existing programs, as well as university program constraints on the length of endorsement programs, led to the final creation of a three-course sequence. The division of content for the three courses, as determined by the state CS teacher certification standards, was undertaken several times, in an attempt to have a logical structure for the endorsement program. The realization that the proportion of standards devoted

to a specific topic did not have to be matched by the proportion of those standards in the courses allowed for the development of a program with emphasis on areas of most importance to teaching CS in high schools, along with adding CS content into existing STEM-related disciplines, as was desired by teachers (see Table 2). Once it was decided that the endorsement would be three courses, design began on incorporating the CS endorsement along with an instructional coaching endorsement into an EdS program, to provide the necessary instruction and support for developing master CS teachers.

Table 2  
*CS Endorsement Courses*

Course title	Course description	Rationale
Securely Navigating the Digital World (no prerequisite)	This course introduces components of computers and networks, including data representations and types of storage. Network components and their effects on performance will be discussed. Computer and network threats and vulnerabilities will be examined. Students will be able to identify safe, secure, ethical digital behavior.	Course content addresses required state standards. Interviewees recommended fitting content into three courses. Teachers indicated that flexibility would increase their interest, so this course was created as a stand-alone course to allow multiple entry points into the three-course endorsement.
Ubiquitous World of Programming (no prerequisite)	The focus of this course is on creating algorithms to solve problems, and developing those algorithms into robust programs. Students will become proficient at using a third-generation programming language, including testing, debugging, and documenting programs according to industry best practices. Students will use their knowledge of program development to plan lessons for P-12 students to use computer science in problem-solving and decision-making situations	Course content addresses required state standards. Two programming courses are provided, as programming knowledge and fluency were desired by teachers. This course begins with algorithms to build confidence in programming and provide a model of CS pedagogy.
Applications and Data Science (prerequisite: Ubiquitous World of Programming)	Programming skills will be used to develop robust programs addressing problems in the community or in the areas of mathematics, business, and various science disciplines. Students will create lesson plans and assessments for implementing equitable computer and data science instruction related to those areas. In addition, strategies for developing leadership opportunities to further computer science education, establishing community partnerships, and building student organizations will be discussed.	Course content addresses required state standards. This course continues to build confidence in teachers while providing content related to current area of teaching, such as business, math, or science, as requested in interviews. This course also addresses interviewees' desire for relevance to students by providing guidance on community partnerships and creating student organizations.

## Discussion

A process of evidence-based decision-making, informed by interviews conducted with stakeholders, resulted in the design and development of a model CS and instructional coaching teacher endorsement sequence within an EdS program. The sequence supports the transitioning of grades 6-12 teachers into CS from other STEM teaching fields, positioning them to be leaders in incorporating CS instruction into their schools. The aim of the EdS degree program is to increase the number and diversity of well-prepared CS teachers and their leadership potential for rural, high-need school systems. The development of a program for CS teacher leaders was similar to that seen in the Criswell et al. (2018) project developing STEM teacher leaders.

Vivian et al. (2014) found CS endorsements were offered in face-to-face, hybrid, and online formats; to address interview comments that face-to-face format was a barrier, the EdS program will be delivered online. In line with other programs (Columbus State University, undated; Oconee Regional Educational Service Agency [RESA], undated), the CS endorsement is three semesters and includes content, pedagogy, and a CS-focused field experience.

The CS endorsement is situated in a four-semester EdS program that also includes an instructional coaching endorsement. The program will provide learning opportunities specific to CS teacher leadership in schools, such as assessing a school system's CS offerings and alignment of the offerings in grades K-12, and developing and delivering CS-related PD to teachers and school leaders. This answers the desires expressed in interviews for information about how to support others and serve in a leadership role, as well as the call from Criswell et al. (2017) concerning the critical need for teacher leadership development in STEM areas.

Stakeholder interviews revealed multiple considerations when recruiting certified 6-12 STEM teachers to participate in a CS endorsement embedded within an EdS degree program. Interview protocols addressed areas of concern identified in the literature, such as support from their communities (Luft et al., 2011), backgrounds, motives, and experience (Qian et al., 2018). School system leader interviews found that school leaders were supportive of teachers who wished to earn a CS endorsement. Teachers interviewed for the program were living in the communities in which they teach, and thus understand the culture of their students, as recommended for success (Budge, 2006). Teachers were motivated by the potential to increase student engagement, and indicated that stipends would be an additional motivation. For this reason, funding for stipends will be sought. Teachers also indicated that CS endorsement courses need to help teachers connect the CS content they are learning to other STEM courses they teach. For example, biology students could model the growth of bacteria. This ability to integrate CS into other disciplines was highlighted by the US Department of Education (undated) as an important competency for STEM leadership.

The CS endorsement courses were informed by literature on CS teacher preparation, PD, standards, and stakeholder interviews. Coursework includes both content and pedagogy, as recommended by Yadav and Korb (2012). The endorsement courses also highlight CS career options available to 6-12 students living in rural communities. Three career options were identified as medical fields, agriculture, and the military, and researchers focused on finding candidates for partnerships and working to solidify those partnerships. These partnerships will provide community connections, experiences and resources, which are particular needs of rural areas (Lotter et al., 2020). The CS endorsement meets tenets of successful PD as outlined in Desimone (2009), such as content focus, duration, and collective participation. The cohort of teachers will support each other as they move through the program together, focused on CS, for three semesters.

Interviews revealed that teachers desired some form of collaboration and mentoring, which will be provided with some synchronous and collaborative sessions. Mentoring will continue after the endorsement, in the form of follow-up support and instructional coaching. Instructors from a local technical college will provide mentoring for the first cohort, and, in turn, the first cohort will provide mentoring for future cohorts. In this way, support for CS education in rural schools is strengthened and sustainable.

### **Implications**

This project responds to the need for well-prepared and certified CS teachers with leadership potential in rural, high-need school systems. Team members used a three-phase investigation of viability, processes, and development to identify obstacles and affordances related to the development of a CS Master Teacher endorsement track. The project highlights a mechanism that over time has the potential to increase CS learning opportunities for students in rural, high-need school systems utilizing well-prepared teachers. An expected outcome of this project was the presentation of an evidence-based process to examine the recruitment, programming, and support associated with the development of CS teachers for rural, high-need school systems. The process provided a better understanding of the affordances and challenges associated CS instruction in rural schools. In addition, a model CS Master Teacher endorsement track to support rural, high-need school systems was designed and coupled with an instructional coaching endorsement in an EdS degree program, to increase the number and diversity of CS teachers in rural, high-need school systems by drawing from the corps of exemplary and certified 6-12 STEM teachers. Through iterative study and discussion of curricular possibilities, CS and education faculty used findings from stakeholder interviews and existing programs to make decisions about the number of courses, course content, and learning outcomes of the CS endorsement portion of the EdS degree program.

Moreover, the project strengthened partnerships between the university, regional support centers, school systems, a technical college, non-profits, and state government agencies. For example, researchers formed close partnerships with eight rural districts, who will commit to recommending teachers for the program in the upcoming year. Partnerships with the state department of education and state-wide CS initiatives will serve to strengthen and guide CS course content, including future learning opportunities in such areas as web design, cybersecurity, and robotics. The continuing partnership with a local technical college will provide mentoring support for teachers in the EdS program. In addition, partnerships with non-profits in the areas of military, medicine and agriculture will provide knowledge of those areas to the teachers, and opportunities for future career pathways for their students. Overall, these partnerships will function to advance the statewide agenda to increase the number and preparedness of CS teachers.

### **Future Directions**

The development of the Master Teacher CS program, which consists of a CS endorsement and an instructional coaching endorsement within an EdS program, has provided an opportunity for teachers in high-needs rural areas to gain credentials in leadership in CS. Future plans include enactment of the described recruiting process to channel existing STEM teachers into the EdS program, through an NSF Master Teaching Fellowship grant. This would provide stipends to teachers, which was mentioned in the recruiting interviews as an incentive. Having a cohort of STEM teachers participating in the EdS program will allow for program evaluation, and give direction for future improvements to the CS endorsement as well as the program as a whole. Continuing research on the effectiveness of the program will include investigations into the

teaching practices of the teachers who complete the EdS program, concerning CS courses as well as the use of CS content in the existing STEM classes taught by the teachers. In addition, opportunities exist for teachers to add to their CS knowledge through future courses provided through partnerships developed in this project.

### Limitations

Although portions of the process may be usable to endorsement program designers and researchers in other geographical areas, this project was specifically designed to address the need for CS teachers in rural, high-need school systems. Partnerships were formed with non-profits in the fields of medicine, agriculture, and military, which may not be appropriate partnerships in all geographical areas. Furthermore, state standards were part of the guidance in the content of the CS endorsement. Therefore, the findings relative to technology infrastructure needs, course delivery methods, endorsement content, and situation of the CS endorsement within an EdS program may not generalize to urban or suburban geographical areas, or to rural areas that do not have high-need systems.

### References

- Angelle, P. S., & DeHart, C. A. (2011). Teacher perceptions of teacher leadership: Examining differences by experience, degree, and position. *NASSP Bulletin*, 91(2), 141-160. <https://doi.org/10.1177/0192636511415397>
- Berry, B. (2019). Teacher leadership: Prospects and promises. *Phi Delta Kappan*, 100(7), 49-55. <https://doi.org/10.1177/0031721719841339>
- Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher*, 33(8), 3-15.
- Buczynski, S., & Hansen, C. B. (2010). Impact of professional development on teacher practice: Uncovering connections. *Teaching and Teacher Education*, 26(3), 599-607.
- Budge, K. (2006). Rural leaders, rural places: Problem, privilege, and possibility. *Journal of Research in Rural Education*, 21(13), 1-10.
- Burton, M., & Johnson, A. S. (2010). "Where else would we teach?": Portraits of two teachers in the rural south. *Journal of Teacher Education*, 61(4), 376-386. <https://doi.org/10.1177/0022487110372362>
- Castillo-Montoya, M. (2016). Preparing for Interview Research: The Interview Protocol Refinement Framework. *The Qualitative Report*, 21(5), 811-831. <https://doi.org/10.46743/2160-3715/2016.2337>
- Charleston, L. J., Charleston, S. A., & Jackson, J. F. L. (2017). Using culturally responsive practices to broaden participation in the educational pipeline: Addressing the unfinished business of Brown in the field of computing science. *The Journal of Negro Education*, 83(3), 400-419.
- Check, J., & Schutt, R. (2012) *Research methods in education*. SAGE Publications, Inc.
- Code.org. (2017a). Recommendations for states developing computer science teacher pathways. <https://code.org/files/TeacherPathwayRecommendations.pdf>
- Code.org. (2017b). Universities aren't preparing enough computer science teachers. <https://medium.com/@codeorg/universities-arent-preparing-enough-computer-science-teachers-dd5bc34a79aa>
- Code.org Advocacy Coalition & CSTA. (2018). 2018 state of computer science education. <https://advocacy.code.org/>
- Code.org Advocacy Coalition (2021). See what's happening in your state. <https://advocacy.code.org/>

- Code.org, CSTA, & ECEP Alliance. (2020). 2020 state of computer science education: Illuminating disparities. <https://advocacy.code.org/stateofcs>
- Columbus State University (undated). Computer science endorsement. [https://te.columbusstate.edu/endorsement\\_computer\\_science.php](https://te.columbusstate.edu/endorsement_computer_science.php)
- Criswell, B. A., Rushton, G. T., McDonald, S. P., & Gul, T. (2017). A clearer vision: Creating and evolving a model to support the development of science teacher leaders. *Research in Science Education*, (1), 1-27. <https://doi.org/10.1007/s11165-016-9588-9>
- Criswell, B. A., Rushton, G. T., Nachtigall, D., Staggs, S., Alemdar, M., & Capelli, C. J. (2018). Strengthening the vision: Examining the understanding of a framework for teacher leadership development for experienced teachers. *Science Education*, 102(6), 1265-1287.
- Creswell, J. W. & Guetterman, T. C. (2019). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*, (6th ed.). Pearson Education.
- Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, 38(3), 181-199. <https://doi.org/10.3102/0013189X08331140>
- EdD Programs. (2022). Ed.S. vs Ed.D. programs: What is an Education Specialist (EdS) degree? <https://www.eddprograms.org/eds-degrees/#How-to-Choose-EdS-and-EdD>
- Garcia, E. & Weiss, E. (2019). The teacher shortage is real, large and growing, and worse than we thought: The first report in "The Perfect Storm in Teacher Labor Market" series. Economic Policy Institute. <https://www.epi.org/publication/the-teacher-shortage-is-real-large-and-growing-and-worse-than-we-thought-the-first-report-in-the-perfect-storm-in-the-teacher-labor-market-series/>
- K-12 Computer Science Framework. (2016). <http://www.k12cs.org>.
- Knapp, M. S. (2003). Professional development as a policy pathway. *Review of Educational Research*, 27(1), 109-157. <https://doi.org/10.3102/0091732X027001109>
- Krathwohl, D. R. (2009). *Methods of educational and social science research* (3rd ed.). Waveland Press, Inc.
- Ladson-Billings, G. (1995). But that's just good teaching! The case for culturally relevant pedagogy. *Theory Into Practice*, 34(3), 159-165. <https://www.jstor.org/stable/1476635>
- Lotter C, Yow J. A., Lee M., Zeis J. G., & Irvin M. J. (2020). Rural teacher leadership in science and mathematics. *School Science and Mathematics*, 120, 29-44. <https://doi.org/10.1111/ssm.12383>
- Luft, J. A., Whitworth, B. A., Berry, A., Navy, S., & Kind, V. (2019). Science education trajectories: Charting the course for teachers, educators, researchers, and policy makers. *Journal of Science Teacher Education*, 30(1), 63-79. <http://doi.org/10.1080/1046560X.2018.1535226>
- Luft, J. A., Wong, S. S., & Semken, S. (2011). Rethinking Recruitment: The Comprehensive and Strategic Recruitment of Secondary Science Teachers. *Journal of Science Teacher Education*, 22(5), 459-474. <https://doi.org/10.1007/s10972-011-9243-2>
- Mezirow, J. (1978). Perspective transformation. *Adult Education*, 28(2), 100-110. Retrieved from <https://doi.org/10.1177/074171367802800202>
- Mezirow, J. (2012). Learning to think like an adult: Core concepts of transformation theory. In E. W. Taylor & P. Cranton (Eds.), *The handbook of transformative learning: Theory, research, and practice* (pp. 73-98). Jossey Bass.
- Monk, D. H. (2007). Recruiting and retaining high-quality teachers in rural areas. *The Future of Children*, 17(1), 155-174. Retrieved from



<https://www.jstor.org/stable/pdf/4150024.pdf?refreqid=excelsior%3A3d411280ee4e8d10047d9aa032064fbd>

- Montoya, A. (2017). Computer science for all: Opportunities through a diverse teaching workforce. *Harvard Kennedy School Journal of Hispanic Policy*, 22, 47-62.
- National Association of State Boards of Education. (2016). Educating students in rural America: Capitalizing on strengths, overcoming barriers. National Association of State Boards of Education. <https://wsuwp-uploads.s3.amazonaws.com/uploads/sites/90/2015/09/Educating-Students-in-Rural-America-Capitalizing-on-Strengths-Overcoming-Barriers.pdf>
- Oconee RESA. (undated). Computer science endorsement. [https://www.ciclt.net/sn/resa/recl\\_application.aspx?CL\\_ID=102939&ClientCode=oconee](https://www.ciclt.net/sn/resa/recl_application.aspx?CL_ID=102939&ClientCode=oconee)
- Qian, Z., Hambruch, S., Yadav, A. & Gretter, S. (2018). Who needs what: Recommendations for designing effective online professional development for computer science teachers. *Journal of Research on Technology in Education*, 50(2), 164-181. <https://doi.org/10.1080/15391523.2018.1433565>
- Tio, R. (2018). 2017 Georgia K-12 teacher and leader workforce report. The Governor's Office of Student Achievement. <https://gosa.georgia.gov/sites/gosa.georgia.gov/files/2017%20K-12%20Teacher%20and%20Leader%20Workforce%20Report%2020180105.pdf>
- U. S. Department of Education. (undated). What knowledge, skills, and dispositions are required to be a STEM teacher leader? <https://innovation.ed.gov/what-we-do/stem/building-stem-teacher-leadership/skills-and-dispositions/>
- Vivian, R., Falkner, K., & Falkner, N. (2014). Addressing the challenges of a new digital technologies curriculum: MOOCs as a scalable solution for teacher professional development. *Research in Learning Technology*, 22, 1-19.
- Wenner, J. A., & Campbell, T. (2017). The theoretical and empirical basis of teacher leadership: A review of the literature. *Review of Educational Research*, 87(1), 134-171. <https://doi.org/10.3102/0034654316653478>
- Whitworth, B. A., & Chiu, J. (2015). Professional development and teacher change: The missing leadership link. *Journal of Science Teacher Education*, 26(2) 121-137. <https://www.tandfonline.com/doi/full/10.1007/s10972-014-9411-2>
- Yadav, A., Gretter, S., Hambruch, S., & Sands, P. (2016). Expanding computer science education in schools: Understanding teacher experiences and challenges. *Computer Science Education*, 26(4), 235-254. <http://dx.doi.org/10.1080/08993408.2016.1257418>
- Yadav, A. & Korb, J. T. (2012). Learning to teach computer science: The need for a methods course. *Communications of the Association for Computing Machinery*, 55(11), 31-33. <https://cacm.acm.org/magazines/2012/11/156579-learning-to-teach-computer-science/fulltext?mobile=false>

## Authors

### Susie Morrissey

Assistant Professor

Mercer University, Tift College of Education

Email: [morrissey\\_gs@mercer.edu](mailto:morrissey_gs@mercer.edu)

**Thomas Koballa**

Dean  
Mercer University, Tift College of Education  
Email: [koballa\\_tr@mercer.edu](mailto:koballa_tr@mercer.edu)

**Robert Allen**

Professor and Chair  
Mercer University, Computer Science Department  
Email: [allen\\_r@mercer.edu](mailto:allen_r@mercer.edu)

**Judy Godfrey**

Adjunct, Citizens and Scholars Mentor  
Mercer University, Tift College of Education  
Email: [godfrey\\_jb@mercer.edu](mailto:godfrey_jb@mercer.edu)

**Michael Dias**

Professor  
Kennesaw State University, Bagwell College of Education  
Email: [mdias@kennesaw.edu](mailto:mdias@kennesaw.edu)

**Shawn Utley**

Project Analyst  
Wiregrass Georgia Technical College  
Email: [shawn.utley@wiregrass.edu](mailto:shawn.utley@wiregrass.edu)

**DeAnnia Clements**

President  
Wiregrass Georgia Technical College  
Email: [deannia.clements@wiregrass.edu](mailto:deannia.clements@wiregrass.edu)

## Appendix

### Interview Protocols

#### *School System Leader Interview*

What are your school system's CS offerings?

What are the number, qualifications, certifications, and years of service of grades 6-12 teachers teaching CS courses?

What are the instructional materials used by teachers of CS courses?

What are the CS and leadership professional development opportunities for 6-12 teachers in your school system?

What opportunities for teacher leadership of CS instruction exist within the school system?

What is the likely interest among the school system's 6-12 STEM teachers to participate in an endorsement program that leads to CS certification?

What are the affordances and challenges associated with 6-12 STEM teachers' participation in an endorsement program that leads to CS certification?

To what extent does your school system collaborate with RESAs, technical colleges, and Mercer University in supporting CS instruction and teacher leadership development?

What recruiting strategies have you found or think might be successful in recruiting a diverse cadre of teachers to participate in voluntary PD, especially PD that focuses on CS and teacher leadership?

What concepts and topics should be included in a CS endorsement program?

What are desirable means of content delivery and ongoing support for CS teaching and teacher leadership?

### ***Teacher Interview***

How many years have you been teaching?

In what areas have you taught and what certifications do you hold?

What have been your experiences in school leadership?

What is your interest in participating in an endorsement program that leads to CS certification? What do you see as the benefits and challenges associated with your participation?

What incentives might encourage you to participate in an endorsement program that leads to CS certification and leadership development?

What recruiting strategies do you think might be successful in recruiting a diverse cadre of teachers to participate in voluntary PD, especially PD that focuses on CS and teacher leadership?

What concepts and topics should be included in a CS endorsement program?

What are desirable means of content delivery and ongoing support for CS teaching and teacher leadership?

### ***School Supporters (e.g., university faculty and support center staff) Interview***

What is the nature of the CS support you have provided to area schools?

What are the number and background of the teachers you supported in CS?

What have been the length and the outcomes of CS or teacher leadership activities and initiatives supported?

What are possible future opportunities to support CS instruction and teacher leadership development in rural school systems?

What is your interest in partnering with Mercer University to support CS instruction and teacher leadership development in rural school systems?

What recruiting strategies have you found or think might be successful in recruiting a diverse cadre of teachers to participate in voluntary PD, especially PD that focuses on CS and teacher leadership?

What concepts and topics should be included in a CS endorsement program?

What are desirable means of content delivery and ongoing support for CS teaching and teacher leadership?

## **Impact of Covid-19 Pandemic on Experienced Introductory STEM Instructors' Teaching Practices**

Sarah Boesdorfer  
*Illinois State University*

### **Abstract**

Professional development for STEM instructors and facilitating change in their instruction requires understanding current practices along with what motivates or causes them to change their teaching practice. Teaching during the Covid-19 pandemic caused a lot of change in how courses were delivered in-person or online, but it also provided opportunities for instructors to change the teaching method used in the courses, potentially shifting towards more student-centered practices. Some commonly cited barriers to faculty changes were removed or lowered during this time and instructors had to think about their teaching due to the nature of the pandemic. Opportunity for change was present which could provide lessons for professional development and STEM reform efforts. This article reports on the analysis of experienced introductory STEM instructors' syllabi before, during, and after the full Covid-19 pandemic academic year 2020-21. Focus group interviews were also conducted to explore how teaching was impacted by the Covid-19 pandemic. Findings suggest that little changed in instructional strategies, and that the experience likely reinforced teaching practices from prior to Covid. There was no indication of intent to improve or change instruction in anyway. Take aways for professional development and teaching reform with experienced STEM faculty are discussed.

*Keywords:* Faculty change, Covid-19, STEM Instruction, Instructional Change

*Funding:* This study was funded by the Scholar in Residence program from the Center for Integrated Professional Development (formally the Center for Teaching, Learning, and Technology) at Illinois State University.

There are numerous efforts, supported by research, to change teaching practices in higher education to be more active and inclusive of all students in the Science, Technology, Engineering and Mathematics (STEM) disciplines (Dewsbury et al., 2022; Freeman et al., 2014; Theobald et al., 2020). However faculty have continued to use mainly traditional, passive teaching strategies within these classes (Stains et al., 2018). Barriers to changing their teaching practice often cited by STEM faculty include limited time to instill the change, their teaching practice not valued as part of their job, and relatedly a lack of a culture of support to instill the change (Henderson et al., 2012; Jacobson & Cole, 2020; Sturtevant & Wheeler, 2019). In addition, if instructors are content with their pedagogy and student success, they will not perceive a need to change their practices, but discontentment with their pedagogy can lead to changing their practice (Southerland et al., 2011). Instructors who feel supported in their attempts to change their teaching practice (Bathgate

et al., 2019), along with discontentment about their teaching and the need to change their practice (Henderson et al., 2011; Southerland et al., 2011) are in an environment in which teaching change can occur. The Covid-19 pandemic teaching, especially in the 2020-21 academic year, potentially provided this environment to invoke change in STEM instructors' teaching. By its very nature there was new environmental features for the classes, class structures, and support systems. All of these can be change agents (Borrego & Henderson, 2014), and the reflecting on their teaching during this time could have led to discontentment, and thus to change (Carlson et al., 2019). Because instructors had no choice to go online and interrupt their normal teaching practices, pandemic teaching might have led to instructional change in their teaching as they returned to 'normal.'

With some conditions supportive of teaching change during the Covid-19 pandemic, the questions become: Did it inspire change for instructors, specifically experienced instructors?, And in what way? Given the importance of introductory STEM courses in students' continued pursuit of or initial interest in STEM majors (Graham et al., 2013) and the general resistance of these courses to reformed teaching practices (Stains et al., 2018), the impact of the Covid-19 teaching on these courses specifically was of interest. Could the pandemic help motivate lasting change in introductory STEM teaching? Lessons from the impact of the pandemic on teaching practice can be used for faculty professional development and our understanding of how to support and inspire instructional change among collegiate STEM instructors. This article provides a description of the impact of the Covid-19 pandemic on the teaching practices of experienced introductory STEM instructors at one Midwestern public university, R2: Doctoral Universities – High research activity classified (The Carnegie Classification of Institutions of Higher Education, n.d.), to better understand how enforced sudden change impacted teaching practices in introductory STEM courses of experienced instructors.

### **Context**

Like most institutions, in March 2020 the university shifted all courses online mid-semester and finished the semester online and away from campus. Due to social distancing requirements in Fall 2020, more than 80% of courses shifted to completely online courses for the semester. This declined some in Spring 2021 with more smaller classes choosing some version of a blended or hybrid course, but a large majority of the courses offered were still online, especially at the introductory level. In Fall 2021, social distancing requirements were lifted for classrooms and classes could meet in person again with little restriction on spacing, but masking was required. There were still options to teach courses online or with a blended method, but a large majority of courses returned to their pre-covid meeting structure.

Like many places, numerous additional opportunities for professional development were available to instructors in Summer 2020 and Fall 2020, and even still in Spring 2021, though this semester was closer to the typical number of professional learning opportunities available to instructors. Many of these opportunities involved learning technologies like Zoom, recording and creating videos, or other educational technologies. However, this was not the sole focus of the professional learning; some mixed the technology with the teaching strategy, e.g. incorporating groupwork or group discussions in an online course, while others focused mainly on teaching strategies that might help with the difficulties seen in an online course, e.g. strategies for alternative assessments. There were opportunities for instructors to learn through formal campus professional development workshops/courses as well as through informal groups and resources, which had not been available previously. In addition, some potential barriers to change were removed, including

the waiving of the use of student surveys as an evaluation of teaching and a ‘stop the clock’ options for all in tenure-track positions.

### Methods

With Institutional Review Board (IRB) approval, a survey was sent out through email to all introductory STEM instructors at the institution who had taught the same introductory STEM course prior to the Spring 2020 semester, during the 2020-2021 academic year (pandemic teaching), and teaching it in Fall 2021 (return to ‘normal’ semester). Because the course needed to be taught by the same instructor over this period, it significantly limited the pool of instructors compared to the total number of introductory STEM instructors. The short survey had demographic questions, an assessment practice question, and then asked the participant to attach syllabi from the three semesters. They were also asked if they were willing to participate in a follow-up focus group interview. In addition to collecting syllabi through the survey, requests were made to each STEM department for the syllabi for the semesters in question. Syllabi from the three focus time periods instructed by the same person each semester were located for 14 introductory STEM courses (N =14) including the disciplines of biology, chemistry, geology, physics, agriculture, accounting, and mathematics. Instructors of these courses included both tenure-track and instructional (non-tenure track) faculty.

From the survey volunteers, focus group interviews were conducted with six instructors in mid-November. The semi-structured interviews occurred in pairs through Zoom lasting 30-45 minutes. Only two of the interviewees were from the same department, and they were not interviewed together. Five of the six interviewees were instructional (non-tenure track) faculty; but all had more than five years teaching experience at the collegiate level. The open-ended interview questions asked the instructors to talk about their teaching during the pandemic and in the current semester, including changes they made and why or things they kept and why. They were also asked what impact they thought the Covid-19 pandemic had on their teaching. Focus group volunteers received a \$50 gift card for their time.

### Data Analysis

The syllabi were analyzed using the *Measuring the Promise* syllabi rubric (Palmer et al., 2014). Using the components present in the syllabus, this rubric provides a score for the syllabus, categorizing the syllabus as content-focused (0-16 points), transitional (17-30 points), or learner-focused (31-46). As Palmer et al. states, this score is indicative of the syllabus not necessarily the classroom practices. Each syllabus was scored independently then scores were collected and compared by course. In addition, after scoring for each course, a list of differences in assignments, procedures, objectives, scoring, and any other part of the syllabus was created, keeping track of the changes by semester using the pre-pandemic syllabus as the ‘baseline’ for the course.

Focus group interviews were audio recorded and transcribed verbatim for analysis. The transcripts were read and a constant comparative method for coding was used to identify categories or codes for the statements from the interviewees (Maykut & Morehouse, 1994). The codes which emerged included technology/technology use, student engagement, student attendance, teaching methodologies, and student expectations.

## Results

Syllabi from fourteen (N=14) introductory STEM courses taught by the same instructor prior to the Covid-19 pandemic (Fall 2019 or prior), during pandemic teaching restrictions (2020-2021 academic year), and in the return to ‘normal’ semester (Fall 2021) were collected.

### Course Meeting Structure Changes

All the courses were taught in person prior to the pandemic, ranging in size from 20-25 person sections to large lectures with 50 - 300 students. Some of large lectures had a separate smaller lab section once a week but was considered part of the course. Since not all courses had labs associated with them, this laboratory aspect of the courses was not examined in this study. As mentioned, during the 2020-21 academic year (pandemic teaching) social distancing placed limitations on the number of people allowed in rooms, thus all of these courses, no matter what size, shifted fully online. Five courses (36%) met synchronously online during their scheduled times, three courses (21%) shifted to completely asynchronous courses with no scheduled meeting times for the course, and five courses (36%) shifted to recorded lectures with one weekly synchronous online discussion or ‘work time’ scheduled. There was one course for which the structure of the course was not clear from the syllabus. During Fall 2021, all courses could return to ‘normal’ which meant they could resume in person with no limitation on number of people (masks required) in the classroom. Twelve of the fourteen (86%) returned to their original pre-pandemic structure, meeting in person at the scheduled times. One course stayed fully online as it had been during the 2020-21 academic year, and one indicated it would start online for the first three weeks, and then shift to in person lectures. Thus, for the most part by Fall 2021 the introductory STEM courses collected returned to the pre-pandemic course meeting structure.

### Course Activities Changes

When these syllabi were scored with the *Measuring the Promise* rubric (Palmer et al., 2014), only one of the courses shifted categories from transitional to learner-focused for all three time periods (See Table 1). This course had a high score prior to the 2020-21 school year and added a more detailed and specific course schedule to the syllabus bumping its score higher and into the next category.

**Table 1**

*Summary of Category Scores for Collected Syllabi by Academic Year*

	Content-Focused (0-16 pts)	Transitional (17-30 points)	Learner-Focused (31-46 pts)
Fall 2019 or prior	1	11	2
2020-21 year (Covid teaching)	1	10	3
Fall 2021 semester (Return to ‘normal’)	1	11	2

*Note.* N = 14 syllabi for each year. The numbers in each category represent the same syllabi. Only 1 course’s syllabus shifted categories over each academic year.

This was a similar change for most of the syllabi. Most of the courses changed scores by 2 or 3 points due to the addition or removal of a course calendar/schedule from the syllabus or the

change in assessments (typically the number) in their courses, but this was not enough to change their categorization. Comparing raw scores from prior to the pandemic (Fall 2019) to the return to normal semester (Fall 2021), 5 of the 14 scores (36%) lowered 1-3 points, 3 (21%) had no change in score, and 6 (43%) increased their raw scores by 1-4 points. As seen in Table 1, most courses were in the transitional category before the Covid-19 pandemic, so there was opportunity to become more learner-focused, but based on what was given on the syllabi, they did not significantly (>4 points) change. Almost the same number reduced their scores as improved it, but again not by enough to change categories and suggest a change in the overall focus (content or learner) of the course.

In terms of specific changes made to the courses as evident in the syllabi, the consistent change that was seen across all the courses was the distribution of points over course assessments. Nine courses (64%) changed the points structure for the course during the 2020-21 school year, reducing the portion of the total points in the course which come from exams; exams were less determinate of the course grade by 5% to 20%. This change however did not last; only 3 out of the 9 kept the same points structure in Fall 2021, the other 6 changed again increasing the portion of the course grade from exams. However, they were all still below the pre-pandemic level. Three of the courses (21%) removed exams all together during the 2020-21 school year replacing them with papers or weekly quizzes, but all three returned to exams in Fall 2021. Most of the changes made in the 2020-21 academic year that were sustained into Fall 2021 were minor and related to technology. For example, students started turning in homework online which continued, or two extra homework assignments were added in the semester (and thus typically more opportunity to drop the lowest scores). It was not a change in the assignment or requirements for the course. Language or the tool used might have shifted slightly as well; for example, one course went from calling them units to modules and a switch in the type of “clicker” being used by students to collect formative assessment data was present in another.

### **Focus Group Interviews**

The focus group interviews (N= 6) provided some clarity and details to the syllabi review and the impact of 2020-21 school year teaching on their teaching practices. As mentioned above across the three focus groups, the instructors commented on topics of technology/technology use, student engagement, student attendance, teaching methodologies, and student expectations. All six instructors discussed a piece of new technology they had learned and were continuing to use in their classes (e.g., recording lectures or online homework system). Three of the six discussed a technology they learned that was helping with students’ accessibility to course materials (e.g., a simulation that replaced an activity that was continuing to be used for absent students or as extra engagement for students who wanted it). None of the instructors mentioned the technology changing how they approached teaching or what they did with their students; the technologies just helped them do what they had been doing and “getting it” to the students. They all saw these technology skills and available technology resources they now had as a positive outcome of Covid-19.

The biggest topic the instructors discussed in all the focus groups was student engagement in classes and student attendance. All six instructors agreed that student engagement in their courses during 2020-21 school year was extremely poor overall and they were not seeing much change during the Fall 2021 academic year; attendance was down, with almost all (4) explicitly stating or agreeing that it was the worst they had seen in their careers. When it came to questions about how it was impacting their teaching practices or what they saw in the future for their teaching as a



result, only 1 of the 6 indicated they were considering any changes to their teaching because of the pandemic teaching experiences: “It’s going to change a lot how I teach the gen ed courses for sure.” He went on to mention trying to create a more problem-based course in future semesters as the plan. The rest indicated that it provided support for what they had been doing prior to the pandemic was what they should be doing in the course: “It did cement my belief in the way that I teach this class” or the changes mentioned were rather minor detail of content and not larger structure: “so I created PowerPoints again, which were completely from scratch, so I really had to re-, I had to look at every class session, kind of with fresh eyes.” Other than the single instructor, no one indicated that they had changed or plan to make significant changes in the way they taught or approached their introductory STEM course, nor did they indicate that they saw a need to change it.<sup>1</sup>

### Limitations

As mentioned previously, due to the focus on experienced instructors, introductory STEM courses, and a single university, the data sources for this study are limited and thus may not apply broadly. In addition, the research depended on written syllabi and teacher reported descriptions of their teaching practices to understand the classrooms; instruction was never directly observed. Reported practices might be different from what occurred in classes. However, the sample does include a range of experienced instructors across numerous disciplines and syllabi; as syllabi are ‘contracts with students’, they tend to capture at least the requirements that lead to course grades. Finally, this study looked at teaching immediately following the return to ‘normal’ teaching from the Covid-19 pandemic, but it could take longer for the pandemic teaching experience to impact teaching.

### Discussion

As described above, the Covid-19 pandemic did not significantly change the teaching of introductory STEM courses by experienced instructors when compared to their pre-Covid teaching practices. Despite reduction of some barriers (e.g., student evaluations not used, time given for teaching) and greater opportunity for professional development, the instructors continued their courses as they had; they just learned a new piece or two of technology to help them do what they were already doing in their classes (e.g., technology to collect and grade homework rather than on paper or technology to record a lecture). They could have added flipped classroom methodologies, replaced exams for more authentic forms of assessments, or other active learning strategies and structures shown to improve student learning in STEM (Freeman et al., 2014), but they did not and did not indicate that they even were wanting to try it in a partial format moving forward. As another change they could have even added metacognitive strategies or strategies shown to improve student success (McGuire, 2015) after their students struggled during the full pandemic teaching year, but again there was no indication that they did this or planned to. There were hints of changes to practice towards more methods shown to support all students. For example, removal of exams or reduction of percentage of the grade which comes from exams can support all students, but these changes did not stick. They returned to pre-pandemic teaching practices or close to it. For the participants in this study, with the exception on one interviewee, there does not seem to have been

---

<sup>1</sup> Issues with cheating were mentioned in two of the three focus group sessions, but it never became a significant topic of conversation. An instructor mentioned it, another commented on it, and then they moved on in the conversation.

enough pedagogical discontentment (Southerland et al., 2011) or proper conditions for known strategies that support STEM teaching change (Borrego & Henderson, 2014), like changes in policy, to cause a change in the instructors' teaching practices. In fact, the focus group interviews suggest that for many experienced instructors the experience teaching during Covid reinforced their current teaching strategies rather than challenged them, which could be problematic for future change especially if current practices lack much active learning.

While there were opportunities for teaching change given the environment and reduction in barriers cause by teaching during the Covid-19 pandemic, the other conditions of life and teaching during the Covid-19 pandemic may have brought up other barriers to teaching change (Musgrave, 2022). In addition, while barriers were removed to support teaching change, much of the work was still on the individual instructor due to the nature of the pandemic itself. The professional development was on Zoom, and the development of learning communities, again unless on Zoom, was halted. So while there was organizational support, there may not have been community for the support, and teaching change often needs community, stagnating if it must come from individual instructors (Reinholz et al., 2021; Sturtevant & Wheeler, 2019). And change is hard, especially in higher education STEM (Reinholz et al., 2021; Stains et al., 2018). That no change was seen for these instructors is understandable, but that does not mean we should not learn from the experience.

### Implications

This study provides evidence that evidence-based strategies to support teaching change such as those suggested by Borrego and Henderson (2014) must be implemented in the right conditions and likely without sudden mandates or upheavals if they are going to stay. The upheaval of Covid-19 had these experienced instructors looking for ways to do what they were already doing in the class, only now aided with technology, and convinced them that what they were doing was what they should have been doing. We likely need to motivate STEM instructors and help them find a reason to improve or change their teaching in the best of times, rather than the worst of times.

### References

- Bathgate, M. E., Aragón, O. R., Cavanagh, A. J., Frederick, J., & Graham, M. J. (2019). Supports: A Key Factor in Faculty Implementation of Evidence-Based Teaching. *CBE—Life Sciences Education, 18*(2), ar22. <https://doi.org/10.1187/cbe.17-12-0272>
- Borrego, M., & Henderson, C. (2014). Increasing the Use of Evidence-Based Teaching in STEM Higher Education: A Comparison of Eight Change Strategies: Increasing Evidence-Based Teaching in STEM Education. *Journal of Engineering Education, 103*(2), 220–252. <https://doi.org/10.1002/jee.20040>
- Carlson, J., Daehler, K. R., Alonzo, A. C., Barendsen, E., Berry, A., Borowski, A., Carpendale, J., Kam Ho Chan, K., Cooper, R., & Friedrichsen, P. (2019). The refined consensus model of pedagogical content knowledge in science education. In *Repositioning pedagogical content knowledge in teachers' knowledge for teaching science* (pp. 77–94). Springer.
- Dewsbury, B. M., Swanson, H. J., Moseman-Valtierra, S., & Caulkins, J. (2022). Inclusive and active pedagogies reduce academic outcome gaps and improve long-term performance. *PLOS ONE, 17*(6), e0268620. <https://doi.org/10.1371/journal.pone.0268620>

- Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415. <https://doi.org/10.1073/pnas.1319030111>
- Graham, M. J., Frederick, J., Byars-Winston, A., Hunter, A.-B., & Handelsman, J. (2013). Increasing Persistence of College Students in STEM. *Science*, *341*(6153), 1455–1456. <https://doi.org/10.1126/science.1240487>
- Henderson, C., Beach, A., & Finkelstein, N. (2011). Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature. *Journal of Research in Science Teaching*, *48*(8), 952–984. <https://doi.org/10.1002/tea.20439>
- Henderson, C., Dancy, M., & Niewiadomska-Bugaj, M. (2012). Use of research-based instructional strategies in introductory physics: Where do faculty leave the innovation-decision process? *Physical Review Special Topics - Physics Education Research*, *8*(2), 020104. <https://doi.org/10.1103/PhysRevSTPER.8.020104>
- Jacobson, W., & Cole, R. (2020). Motivations and Obstacles Influencing Faculty Engagement in Adopting Teaching Innovations. *To Improve the Academy*, *39*(1). <https://doi.org/10.3998/tia.17063888.0039.106>
- Maykut, P., & Morehouse, R. (1994). *Beginning qualitative research: A philosophic and practical guide*. Routledge/Falmer.
- McGuire, S. Y. (2015). *Teach students how to learn: Strategies you can incorporate into any course to improve student metacognition, study skills, and motivation*. Stylus Publishing, LLC.
- Musgrave, P. (2022). The Season of Our Professorial Discontent. *The Chronicle of Higher Education*. <https://www.chronicle.com/article/the-season-of-our-professorial-discontent>.
- Palmer, M., Bach, D., & Streifer, A. (2014). Measuring the promise: A learning-focused syllabus rubric. *To Improve the Academy: A Journal of Educational Development*, *33*(1), 14–36.
- Reinholz, D. L., White, I., & Andrews, T. (2021). Change theory in STEM higher education: A systematic review. *International Journal of STEM Education*, *8*(1), 37. <https://doi.org/10.1186/s40594-021-00291-2>
- Southerland, S. A., Sowell, S., Blanchard, M., & Granger, E. M. (2011). Exploring the construct of pedagogical discontentment: A tool to understand science teachers' openness to reform. *Research in Science Education*, *41*(3), 299–317.
- Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., & DeChenne-, S. E. (2018). Anatomy of STEM teaching in North American universities. *Science*, *359*(6383), 1468–1470.
- Sturtevant, H., & Wheeler, L. (2019). The STEM Faculty Instructional Barriers and Identity Survey (FIBIS): Development and exploratory results. *International Journal of STEM Education*, *6*(1), 35. <https://doi.org/10.1186/s40594-019-0185-0>
- The Carnegie Classification of Institutions of Higher Education. (n.d.). *Illinois State University, Normal, IL*. [https://carnegieclassifications.acenet.edu/lookup/view\\_institution.php?unit\\_id=145813](https://carnegieclassifications.acenet.edu/lookup/view_institution.php?unit_id=145813)

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintrón, D. L., Cooper, J. D., Dunster, G., Grummer, J. A., Hennessey, K., Hsiao, J., Iranon, N., Jones, L., Jordt, H., Keller, M., Lacey, M. E., Littlefield, C. E., ... Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences*, *117*(12), 6476–6483. <https://doi.org/10.1073/pnas.1916903117>

**Authors**

Sarah Boesdorfer  
Associate Professor  
Illinois State University, Department of Chemistry  
Email: [sbboesd@ilstu.edu](mailto:sbboesd@ilstu.edu)

## **Pre-service Science Teachers' Understanding of Science and Engineering Practices, Engineering Design Process, and Scientific Inquiry**

Frackson Mumba  
*University of Virginia*

Alexis Rutt  
*University of Mary Washington*

Paul Asunda  
*Purdue University*

Reid Bailey  
*University of Virginia*

### **Abstract**

This study examined secondary pre-service science teachers' understanding of science and engineering practices, the engineering design process, and the scientific method before and after an intervention. Participants were ten pre-service science teachers. Data were collected through a survey and semi-structured interviews. Results show that after the intervention pre-service science teachers developed an understanding of science and engineering practices and used more engineering-specific language when describing them. They also developed an understanding that both engineering design process and scientific method are cyclical and iterative and that the two processes share many practices, but the biggest difference between them is in their purposes. Pre-service teachers also said that the redesign process in engineering design, and the repetition of steps can occur at any point in engineering design process and scientific method. These findings have implications for science teacher education, and teaching and learning of science and engineering design in schools.

*Keywords:* Engineering design, Pre-service Teachers, Science and engineering practices, Understanding, Scientific Method

The *Next Generation Science Standards* [NGSS] (NGSS Lead States, 2013) emphasize the integration of engineering design in science instruction. The NGSS define engineering design as, “an iterative cycle of design that offers the greatest potential for applying science knowledge in the classroom and engaging in engineering practices...” (NGSS Lead States, 2013). Although the NGSS accentuate the integration of engineering design in science instruction most science teachers lack the understanding of science and engineering practices (Antink-Meyer & Meyer, 2016), and the engineering design process (Mesutoglu & Baran, 2020; Hynes, 2012) to effectively teach

engineering design integrated science (EDIS) lessons to their students. In this paper, EDIS is described as teaching and assessing both engineering design and science core ideas and practices in a lesson. Researchers have attributed this problem to teachers' lack of training in engineering design (e.g. Haag & Megowan, 2015; Fantz et al., 2011; Custer & Daugherty, 2011; Carr & Strobel, 2011;). For example, Haag and Megowan (2015) found that high school science teachers lacked knowledge about engineering design because they never received training in engineering design during teacher preparation. Similarly, Banilower et al. (2018) reported that only 13% of high school teachers, 10% of middle school science teachers, and 3% of elementary school teachers had college coursework in engineering. Yet, the success of engineering design integration in science instruction will largely depend on science teachers' understanding of science and engineering practices, engineering design, and how to integrate engineering design in science lessons. For example, science teachers' superficial understanding of engineering design can lead them to simply relaying the steps of engineering design process to their students, instead of providing detailed explanations of the purpose and rationale for the steps (McCormick, 2004). Thus, there is need to develop science teachers' understanding of the NGSS practices, and engineering design process for them to provide effective EDIS instruction in schools.

Researchers are beginning to take note of this gap in teacher preparation and are investigating ways science teacher preparation programs can best prepare pre-service teachers to integrate engineering in science instruction. However, the research on this topic is still nascent. For example, at the secondary level, few studies (Kim et al, 2018; Mesutoglu & Baran, 2020; and Kilty & Burrow, 2019) have investigated pre-service science teachers' understanding of science and engineering practices. Most studies on engineering design in teacher education have focused on elementary teachers (e.g. Kang, Donovan, & McCarthy, 2018; Duncan, Diefes-dux, & Gentry, 2011). As such, researchers have called for more research on engineering design in secondary science teacher education (e.g. Aminger et al., 2021; Kilty & Burrows, 2019; Carr & Strobel, 2011; Custer & Daugherty, 2009). We also believe that more research on pre-service science teachers' understanding of the NGSS practices, and engineering design is warranted as the findings will contribute to teacher training, and the teaching and learning of science and engineering design in schools. Teachers can effectively infuse engineering design into coursework, if they are familiar and comfortable with the engineering design process.

With these considerations in mind, the purpose of this study was to examine secondary pre-service science teachers' understanding of the NGSS science and engineering practices, as well as their understanding of engineering design process and scientific inquiry before and after an intervention in a science methods course. This study was guided by two research questions, (a) what are secondary pre-service science teachers' understanding of science and engineering practices, engineering design process, and scientific inquiry before and after the intervention? And (b) what are secondary pre-service science teachers understanding of the relationship between engineering design process and scientific inquiry before and after the intervention?

### **Literature Review**

As noted above, research is beginning to emerge on how to develop secondary science teachers' understanding of science and engineering practices, and engineering design process. In the review that follows, we briefly highlight research on the call for engineering design integration in science instruction before turning our attention to science teachers' understanding of engineering design process.

Inherent in both engineering and science disciplines are the eight science and engineering practices prescribed in the NGSS (NGSS Lead States, 2013) which are: Asking questions (for science) and defining problems (for engineering); Developing and using models; Planning and carrying out investigations; Analyzing and interpreting data; Using mathematics and computational thinking; Constructing explanations (for science) and designing solutions (for engineering); Engaging in argument from evidence; and Obtaining, evaluating, and communicating information. However, researchers contend that there are differences between science and engineering. For example, Cunningham and Carlsen (2014) posited that the *Developing and using models* practice in science assists in explanation and prediction, while engineers use this practice for analysis and evaluation.

Although the NGSS emphasize science and engineering practices in science teaching, studies show that teachers lack understanding of the NGSS practices. For example, Antink-Meyer and Meyer (2016) explored teachers' understanding of science and engineering practices in relation to authentic research and design case studies. They found that teachers' understandings of these practices were plagued by four misconceptions. First, teachers identified outcomes as the driver of the process, rather than the initial research questions. That is, their focus was primarily on how the information would be used to understand the processes in which the scientists or engineers engaged, rather than on the process for generating that information. The second misconception was that science and engineering were part of a hierarchical relationship, in which full realization and maturation of science is only evident when applied through engineering design. The third misconception was that creativity in scientific investigation was inappropriate because creativity was closely tied to subjectivity. Fourth, teachers said the end result of research must be a tangible product or idea, rather than a process. In a similar study, Mesutoglu & Baran (2020) reported that teachers held low understanding of "identifying problem" practice in engineering design process, confirming earlier findings (e.g., Hynes, 2012). However, teachers had a good understanding of the contribution of engineering to the society and the iterative nature of engineering design process. Such gaps in teachers' knowledge of engineering design process can pose a huge challenge in their attempt to integrate it in science instruction. Likewise, Frantz (2011) said science teachers with limited engineering design experience are not likely to integrate certain design elements such as optimization techniques involving mathematical and analytical reasoning in science instruction. Yet, these practices are critical for students to be successful in science learning through engineering design process.

Other studies have reported on teachers' self-reported knowledge of the NGSS practices. For example, Kang et al., (2018) asked teachers to self-report which science and engineering practices they felt most knowledgeable about and confident in teaching them to their students. Teachers reported having the most knowledge and confidence in teaching the following two practices: *Analyzing and interpreting data* and *Asking questions and defining problems*. On the other hand, teachers reported having less knowledge of and confidence in teaching the practices of *Using mathematics and computational thinking* and *engaging in argument from evidence*. In another study, Yasar et al., (2006) surveyed science teachers' perceptions and understanding of design, engineering, and technology (DET). They found that teachers felt that DET was important and should be included in K-12 curriculum. Middle school teachers placed the greatest amount of importance on incorporating DET into the curriculum, followed by high school teachers and then elementary teachers. Despite this, teachers at all levels indicated that they were unfamiliar with DET and did not feel confident in teaching it, though the least experienced teachers felt the most prepared by their preservice teacher training, possibly because of the emphasis of engineering

design in recent standards and preservice preparatory programs. Similarly, Hsu et al (2011) reported that while elementary teachers identified DET as an important component of K-12 curriculum, they expressed unfamiliarity with DET and were neutral about their ability to teach it.

Research also shows that teacher professional development (PD) workshops on engineering have enhanced teachers' understanding and perceptions of engineering design. For example, Kilty and Burrows (2019) reported that before the intervention, teachers held novice understanding of engineering and how to teach it. After the intervention they demonstrated a better understanding of engineering design, and their perceptions improved. They attributed teachers' change in their understanding and perceptions of engineering to the explicit instruction on engineering design. Similarly, French and Burrows (2018) reported that the intervention on engineering design in teaching Methods course reinforced preservice teachers' focus on planning lessons which included science and engineering practices.

On the other hand, some researchers have reported that professional development had minimal impact on teachers' conceptions of engineering design. For example, Boesdorfer (2017) engaged high school chemistry teachers in an active one-day PD workshop on the NGSS practices and the engineering design process followed by monthly meetings online, during which the teachers learned more about integrating engineering design into their classrooms and created integrated activities. Prior to the intervention, teachers' conceptions of engineering in the classroom involved simple definitions with "a real-world problem to design for -- and missed the important aspects of engineering design" (p.4). Post-intervention, many teachers still held this belief and struggled with student-centered problem definition. While post-PD teachers did incorporate more NGSS practices into their lesson plans (i.e. developing solutions and carrying out investigations), they struggled to incorporate the iterative nature of the engineering design process.

The NGSS also emphasize on teachers' understanding of scientific inquiry for effective engineering design integrated science teaching in K-12 classrooms (NRC, 2012). However, studies continue to show that teachers do not have sound understanding of scientific inquiry. For example, Barnes et al. (2015) reported that teachers felt that there was an exact or correct scientific inquiry that needed to be followed to collect accurate results. Gauch (2003) also stated that the presentation of scientific inquiry as a set of linear steps, oversimplifies and misconstrues real scientific investigation process. Similarly, Windshitl et al. (2008) argued that the scientific inquiry as it is presented in K-12 science classrooms is a misrepresentation of contemporary scientific practices as it positions experimentation as the only means to generate data, and it focuses on reporting patterns rather than providing explanations.

It is evident in the literature that research on engineering design in secondary science teacher education is still nascent. Literature review also revealed that most science teachers have not received training in engineering design and how to integrate engineering design in science instruction. As such, teachers' misconceptions about the NGSS engineering practices, may be rooted in their lack of exposure to engineering design. Thus, there is a need to provide training to science teachers for them to develop the understanding of engineering design (Kim et al., 2019), and how to integrate it into science instruction (French & Burrows, 2018). In addition to providing opportunities to improve teachers' understanding of science and engineering practices and engineering design, researchers suggest that such professional development programs should also address the similarities and differences between science and engineering (Antink-Meyer & Meyer, 2016; Bybee, 2014).



Therefore, this study reports secondary pre-service science teachers' understanding of science and engineering practices, the engineering design process, and the scientific inquiry before and after an intervention.

## Methodology

### Design and Participants

One group pre-posttest design was employed in this study. Participants were seventeen pre-service science teachers enrolled in a secondary science teacher education program at a research university. Participants were ten female and seven male pre-service teachers from the post-graduate Master of Teaching (PGMT) program and the Bachelor of Arts and Master of Teaching (BMT) program. Specifically, 13 pre-service teachers (4 in Chemistry, 5 in Biology, 2 in Physics, and 2 in Earth Sciences) were in the PGMT while the remaining four were in BMT. The age range for PGMTs was 24-29 years while the age range for BMT was 22-25 years. The PGMT pre-service teachers enrolled in the program after earning their bachelor's degrees prior to pursuing the MT degree. Fourth year BMT pre-service and first year PGMT students take the same courses over a 2- year period in our science teacher education program. Upon completion of the program both BMT and PGMT pre-service teachers receive a Masters in Teaching (MT) degree, and a science teaching license for grades 6–12. We have used pseudonyms of the participants throughout this paper. None of the participants had formal K-12 science teaching experience. Additionally, none of them had experienced NGSS in high school because NGSS were published and implemented after they had all entered college. However, three PGMTs had degrees in engineering and worked in industries before enrolling in our program.

### Intervention

Before the intervention on engineering design integrated science teaching in science methods course, participant pre-service teachers took courses that addressed the following topics: educational contexts; adolescents' learning and development; integration of language and literacy in content areas; special education; learning theories; and history of science. They also took a science method course that covered the nature of science, and active-learning instructional strategies (e.g., inquiry, problem- and project-based learning, engineering design integrated science, argumentation, case-based learning, and the Predict-Observe-Explain and 5E models of instruction). For each instructional method, pre-service teachers participated in a lesson taught by the instructor modeling the instructional method, and then designed lesson plans, activities, or units exemplifying the instructional method. The intervention on the NGSS practices, engineering design, scientific inquiry, and how to integrate engineering design in science teaching was done in a second science methods course in two spring semesters. In each semester, the intervention took six weeks. Four instructors led the intervention: Two engineering professors, one engineering education professor, and one science education professor. The intervention was designed for pre-service science teachers to: Become familiar with the *New Framework for K-12 Science Education* (NRC, 2012) and the NGSS (NGSS Lead States, 2013); Learn how to read the NGSS; Understand and apply disciplinary core ideas, cross-cutting concepts, and science and engineering practices; Understand and apply engineering design process; Develop understanding of similarities and differences between engineering design and scientific inquiry; Develop engineering design integrated science (EDIS) units and activities; Develop teacher guide manuals for EDIS instruction; and Create a collection of EDIS teaching and learning resources.

**Instructional Model and activities.** We adopted the informed engineering design framework (Chiu et al., 2013) to guide our instruction during the intervention (See Fig. 1). The framework is

designed to help make engineering design processes explicit for teachers or students. Additionally, the informed engineering design framework guides learners to develop engineering design skills and science concepts through inquiry.

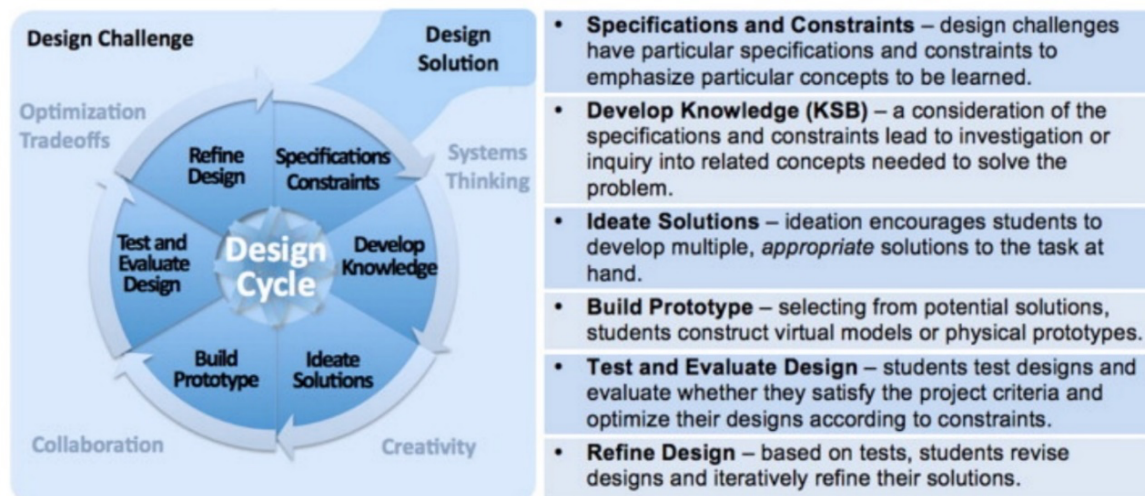


Figure 1: Informed Engineering Design Instructional Model. (Chiu et al.,2013)

The Intervention objectives were achieved through individual and group activities, and EDIS instructional materials development. First, pre-service teachers learned about the principles of engineering, the role of engineering in society, prominent engineers in the US. Second, pre-service teachers participated in an activity where they were challenged to build a solar-powered car using the materials (see Schnittka & Richards, 2016) that were provided. Pre-service teachers defined the challenge, developed knowledge, redefined the problem, ideated solutions, built prototypes, tested and evaluated the prototypes, and revised their prototypes. Pre-service teachers then presented their cars, the design process, energy transformation processes, and their reflections on the design process to the class. In this activity, pre-service teachers learned about solar energy, engineering design process, and NGSS practices by responding to the design challenge.

Third, pre-service teachers learned about the similarities and differences between scientific inquiry and engineering design process through activities that illustrated both processes. Specific examples were provided during the discussion. For example, during the solar-powered car activity pre-service teachers were asked to identify the NGSS practices that applied to engineering design process and scientific inquiry, and both.

Fourth, pre-service teachers were involved in analyzing commercially prepared engineering design integrated science activities for representation of engineering design process and science and engineering practices prescribed in the NGSS. The goal for this activity was for pre-service teachers to learn how to identify science and engineering practices in activities prepared by others before they started developing their own activities.

Fifth, pre-service teachers were engaged in characterizing engineering design integrated science activities from online sources (e.g. TeachEngineering- <https://www.teachengineering.org/>) for the nature of integration using a continuum model which identifies activities into five categories: *Independent engineering design*; *Engineering focused*; *Balanced engineering design and science*; *Science focused*; and *Independent Science* (Mumba & Ochs, 2018). The goal of this

activity was for pre-service teachers to gain the skill for determining the nature and extent to which engineering design and science are integrated in commercially prepared activities.

Sixth, participating pre-service teachers completed a resource collection assignment that was developed for pre-service teachers to create engineering design resources they you would use to teach engineering design integrated science in their classrooms. For each resource, the preservice teachers were asked to provide the following information, title, science concepts/topics the engineering design resource would address; brief description of how the resource would be used to teach science concepts and engineering design in science classrooms; science and engineering practices, disciplinary core ideas, and crosscutting concepts the resource is addressing; modification(s) they would make for the engineering design resource to effectively address the identified science concepts.

Seventh, each pre-service teacher created a teacher guide manual, and EDIS units. The creation of these artifacts demonstrated their knowledge of the engineering design process and skills for developing EDIS curriculum materials. Throughout the intervention, pre-service teachers frequently presented their work and discussed their EDIS units in groups to receive feedback, and thus reinforcing the iterative design process.

Below are summaries of additional example EDIS activities that were implemented in our intervention.

**Slime mold quarantine.** This engineering design integrated biology activity is designed to engage learners in engineering design process, while learning about the characteristics of slime mold (Holder et al., 2019). Additional goals of the activity are for students to: (a) to apply the steps of the engineering design process, (b) Understand that the engineering design process is fluid and iterative, (c) Understand that questions posed in science can be solved with solutions designed through engineering design, (d) Identify aspects of the slime mold quarantine lab as steps of the engineering design process, (e) Make observations to determine if they were successful and then use this data to make design revisions, and (f) Communicate their findings using scientific and engineering language.

**Energy-plus home design challenge.** Pre-service teachers were engaged in designing energy efficient home using the simulation created by Concord consortium (<https://concord.org/newsletter/2015-fall/designing-energy-plus-home/>). The Energy3D activity is designed to engage learners in the NGSS science and engineering practices. The integrated capability of concurrent design, simulation, and analysis within Energy3D enables participants to test and evaluate multiple design ideas through virtual experimentation. Pre-service teachers were tasked with designing an energy-efficient house that, over the course of a year, produces more renewable energy than the energy needed for heating and cooling. Pre-service teachers were also expected to meet a set of design criteria and constraints. For example, the house should have one of these specified architectural styles: the size cannot be too big or too small, and the cost must not exceed the budget. The activity enabled teachers (a) to apply engineering design process and learn more about energy concepts, (b) simulate situations that are not possible to create in a lab (e.g. waiting for very long time to collect data on energy use in a real house), and (c) to experience low-cost alternatives to expensive experiments.

**Teaching Osmosis through engineering design.** This engineering design integrated biology activity that is designed to engage learners in learning about osmosis through engineering design process (Rice et al., 2022) This unit encouraged pre-service teachers to apply their own scientific

understanding and engineering design skills to solve problems. Prior to the start of the unit, teachers were introduced to the engineering design process. Pre-service teachers learned that the engineering design process is both iterative and flexible. The unit is designed so that learners would achieve the following learning objectives: (a) understand the properties of the cell membrane; (b) understand types of cellular transport -- specifically osmosis; (c) learn about isotonic, hypertonic and hypotonic solutions; (d) learn and apply the engineering design process to solve a problem; (e) understand that engineering design is a process that involves redesigning the solution; and (f) demonstrate engineering design skills.

**Scientific inquiry and engineering design process.** Pre-service teachers learned how the engineering design process is similar to, but different from the scientific inquiry, as this is an area that is essential for teachers to understand for effective integration of engineering design and science in science classrooms. Similarities between the two processes emphasized during the intervention include: the cyclical (iterative) nature; the identification of a problem or question; the need for background research; the need to make observations; the need to conduct a test; data collection; and the need to communicate findings. When highlighting the differences between the two processes, central to the conversation was the fundamentally different purpose of each process: engineering design is used to create solutions for real-world problems and the scientific inquiry is used to discover information about the natural world. Table 1 shows additional differences between engineering design and scientific inquiry addressed in the intervention.

Table 1.

*Differences between Engineering Design Process and Scientific Inquiry*

<b>Engineering Design Process</b>	<b>Scientific Inquiry</b>
Purpose: Designing solutions for real world problems.	Purpose: Discovering information about the natural world
Creates a new thing	Creates new knowledge through describing existing things
Success = positive impact on people/society	Success = gaining new knowledge
Background research includes people.	Background research mainly scientific literature
Addresses needs of people	Addresses an investigative question
Works with the <b>artificial</b> world.	Works with the <b>natural</b> world
Frequently considers many ideas	Frequently considers only a single hypothesis once conducting experiment
Prototypes used to learn how to better meet people's needs (and to uncover those needs)	Experiments used to address an investigative question.
Work reviewed by consumers/users	Work reviewed by peers
At any point in time, lots of good solutions	At any point in time, only one best answer.

### **Data Sources**

Data was collected using a questionnaire and semi-structured interviews. This questionnaire has six main open-ended items designed to assess pre-service teachers' understanding of the NGSS science and engineering practices, engineering design process, and the scientific inquiry (see Appendix A). The questionnaire was developed by the researchers. The items are aligned with the concepts that were addressed in the intervention. After developing the questionnaire, it was evaluated for content validity by two experts, one in science education and the other one in engineering education. The questionnaire was revised based on the feedback from the experts. Then, the questionnaire was administered to four students, who were not part of the study, to establish if the items were clear to respondents. We revised the questionnaire items using the feedback from the four students. The participant pre-service teachers completed the questionnaire before and after the intervention. First, pre-service teachers were asked to describe the following terms: engineering, engineering design process, design challenge in engineering, and design solution in engineering. Second, the pre-service teachers were asked to explain the similarities and differences between the scientific inquiry and the engineering design process. Third, pre-service teachers were asked to describe each of the eight NGSS science and engineering practices.

Following the intervention, the pre-service teachers were interviewed using a semi-structured interview protocol (see Appendix B). All interviews were audiotaped and transcribed. Each interview was 30 minutes long. Pre-service teachers were asked to explain the meaning of the eight science and engineering practices. Pre-service teachers were asked to draw and explain their conceptions of the engineering design process and the scientific inquiry. Participants were also asked to describe the similarities and differences between engineering design process and scientific inquiry.

### **Data Analysis**

We used the inductive method as described by Thomas (2006) to analyze both the questionnaire responses and interview data. The questionnaire analysis occurred in two phases. In the first phase, two researchers independently reviewed preservice teachers' pre- and post-intervention responses, identifying emerging themes across participants' responses for each question. Following independent analysis, researchers met to discuss their findings. Any similarities in themes were retained for further review, and excerpts were identified that exemplified the theme across responses. Where differences existed, the researchers went back to the questionnaire responses to come to a consensus. In the second phase, the emerging themes were grouped into main themes. For example, all themes on science and engineering practices were combined. By doing so, we were able to look at more global themes regarding preservice teachers' understanding of the NGSS practices, engineering design, and scientific inquiry before and after the intervention. Interview transcripts were analyzed using the same two-phase procedure outlined above. Following analysis, interview themes were compared with those from the questionnaires to identify main themes across both data sources.

### **Findings**

Data analysis revealed the following four main themes (a) increased use of engineering-specific language among pre-service teachers when describing the NGSS practices; (b) increased understanding of the NGSS science and engineering practices among pre-service teachers; (c) pre-service teachers' understanding of both the engineering design process and scientific inquiry as cyclical and iterative processes, and that they have different purposes; and (d) pre-service teachers said the redesign process in engineering design, and the repetition of steps can occur at any point

in engineering design process and scientific inquiry. We present each theme in turn, below. Example excerpts have been provided to exemplify each theme.

### **Teachers' increased use of engineering-specific language**

Before the intervention, pre-service teachers' descriptions of the NGSS science and engineering practices were mainly situated in a scientific domain. After the intervention, there was increased use of engineering design-specific language among teachers when describing the NGSS practices. For example, when asked to describe the practice of *developing and using models*, words such as creation, representation, and explanation were used with consistent frequency across the pre and post intervention responses. However, after the intervention pre-service teachers used more engineering design terms, (e.g., prototype, design challenge, and design solutions) in describing the NGSS practices. Prior to the intervention, no participant pre-service teacher mentioned prototype in survey responses, while most post-intervention responses included the word prototype. For example, prior to instruction Sam described the "*developing and using models*" practice as "finding a tangible resource to understand a science concept," whereas after the intervention, he described the same practice as "creating prototypes in form of physical or digital models to solve the problem."

Similarly, prior to the intervention, pre-service teachers' understanding of *planning and carrying out investigations* practice was largely situated in a scientific inquiry-like procedure, in which scientists develop and implement a procedure to collect data and draw conclusions. After the intervention, most participants used engineering design specific language, (e.g. discussion of constraints, solving problems, and using prototypes), in addition to science-specific language. For example, prior to the intervention, Jena described the *planning and carrying out investigations* practice as "coming up with an inquiry that will test a hypothesis under a specific set of conditions." Following the intervention, she described the same practice as follows:

"...to plan an investigation, you have to think through the problem and come up with all the parameters, and constraints you will need to work within, then develop a procedure for running it. To carry out the investigation, you follow your procedure, collect data, analyze, redesigning or explaining failures when necessary"

The post-intervention emergence of engineering design language was also evident in preservice teachers' descriptions of the *analyzing and interpreting data* practice. Before the intervention, no participant pre-service teacher included engineering design language in the description of this practice.

### **Teachers' understanding of science and engineering practices**

In addition to the increased use of engineering design language displayed by the pre-service teachers, they also demonstrated understanding of the NGSS science and engineering practices following the intervention. For example, prior to the intervention the *using mathematics and computational thinking* practice was largely conceptualized as something that only occurs during data analysis to help researchers understand results. After the intervention, pre-service teachers identified additional application of *mathematical and computational thinking* practice in science and engineering, including the validity of the data collection process, expressing a concept or postulate in form of a formula, making predictions, creating mathematical or computational models, and representing data, relationships between variables, and design solutions. The expanded understanding of this practice among pre-service teachers is evident in the following interview excerpt:

“Originally, I thought that it was like literal math...and I guess in a way you do use a lot of math, but I think that it’s more focused on both math and computational thinking. So, can you break this problem down into smaller parts to look at it? Can you take this problem apart and identify what the constraints are for the best solution? You represent the main concept in a formula or model” (Anita)

Pre-service teachers also developed an understanding of the *Obtain, evaluate, and communicate information* practice. Prior to the intervention, none of the participant pre-service teachers attempted to describe “evaluate” information in science and engineering. After the intervention pre-service teachers were able to explain the *Obtain, evaluate, and communicate information* practice very well. For example, Selena said, “Obtaining is gathering background or contextual information or results. Evaluating is judging what information is relevant or useful for a particular argument or position. Communicating information is presenting what you know in clear and concise dictation”.

### Teachers’ Understanding of Engineering Design Process

To assess pre-service teachers’ understanding of the engineering design process (EDP), we asked them to describe the EDP both in the survey and interviews. Prior to the intervention, pre-service teachers viewed engineering design as a process engineers used to solve a problem. However, participants did not provide details on the type of problems engineers solve using engineering design process. For example, Jackson said “It is inquiry in which to test a problem and discover the solution”. None of the participants said the engineering design process is used by engineers to solve real-world human problems. Other participants described engineering design from a classroom instructional perspective. For example, Katie wrote “engineering design process is where students are presented with a problem, and they have to design a solution for it. In the process, they learn about the concepts”. Some participants provided more of a definitional response. For example, Victoria described the engineering design process as, “the application of science and technology in building something”. Additionally, most pre-service teachers tended to conceptualize the engineering design process primarily as building to the exclusion of other components of the process, such as gathering background information, testing, redesign or communicating the findings. Although pre-service teachers listed at least two steps of the engineering design process before the intervention engineering design steps were vaguely listed and uncoordinated, and mostly reflective of the steps of the scientific inquiry. Furthermore, most pre-service teachers viewed engineering design as a rigid linear process before instruction.

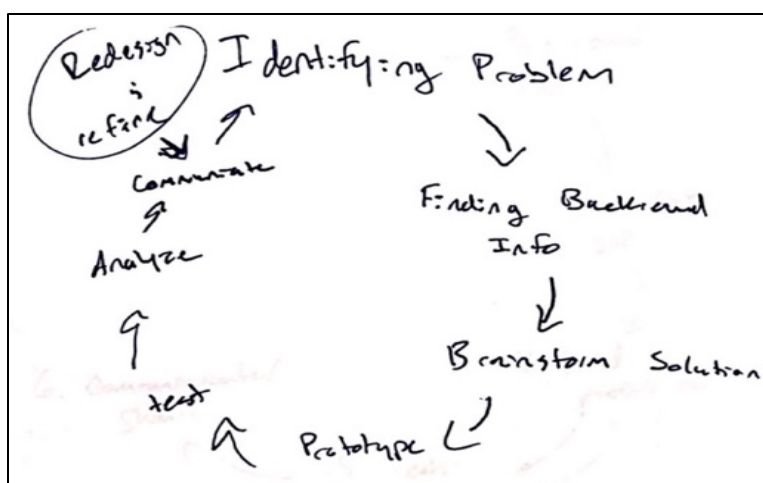
After the intervention, pre-service teachers provided detailed descriptions of the engineering design process. While words such as building, and designing were still prevalent, they were now situated within a multi-step engineering design process, which included the NGSS practices. For example, Sharon provided the following description of the engineering design process:

“Engineering design process can start by identifying a problem and following up with background research to get the full extent of the issue at hand. Then, engineers brainstorm a multitude of ideas for solving the problem and select the best or combination of best ideas to build a prototype out of. The Prototype is then run through tests which will assess the effectiveness of the solution in solving the problem. Usually, following testing engineers redesign their prototypes that it better meet the problems and specifications. However, redesigning can occur at any point in time during the engineering design process. Engineer's then share their process and product often in the form of a presentation or portfolio”

As shown in the excerpt above, Sharon included choosing the best solution, analyzing data, communicating findings, and justifying the design solution in her description of the engineering design process. Similarly, following the intervention, there was more reference to the cyclical and iterative nature of the engineering design process among pre-service teachers. Participant teachers subscribed to the importance of redesign, and the need to optimize solutions in engineering. For example, Jim provided the following response in the interviews:

“Before I didn't really know too much about engineering design. I thought it was . . . more linear process. Once you've found your solution to the problem, that's it. Whereas now, after having learned it, spent the semester talking about it, it's more circular in nature where you're constantly refining, and I guess it can really be applied to just about anything”

Pre-service teachers also acknowledged that the redesign process and the repetition of steps can occur at any point in the engineering design process. For example, in concluding his description of the engineering design process Jackson said, “... Everywhere throughout this process there is a potential to redesign and refine the solution.” Figure 2 shows the EDP diagram Jackson drew during the interviews. He viewed EDP as a cyclical process with redesign and



refining as a separate entity that could occur at any time.

Figure 2. Jackson's illustration of the EDP after intervention

After the intervention, pre-service teachers also indicated that one can start a design problem or challenge from any step in the engineering design cycle. Furthermore, pre-service science teachers acknowledged that there are other engineering design processes beyond the one described in the intervention.

Prior to the intervention, preservice teachers focused on the creation of only one design solution. Following the intervention, participants mentioned that one can suggest several design solutions and choose the best solution to develop a prototype. For example, during the interviews Andrea said:

“First, engineers identify the problem or challenge. Then, they do research to develop their background knowledge. From there, they come up with multiple solutions that they can narrow down to one best (for now) solution. They will create their prototype, test their prototype, and present their results”



Additionally, after the intervention participant teachers used more engineering design specific language (e.g., prototype, constraints, optimization, challenges, and design solutions) in describing engineering design. Pre-service science teachers also acknowledged that building and testing a prototype is an important element of the engineering design process.

### Teachers' understanding of the Scientific Inquiry & Engineering Design process

Pre-service teachers were asked to describe the scientific inquiry before and after the intervention. Before the intervention most participants viewed scientific inquiry as a linear process. For example, Selena wrote "Scientific inquiry is a linear process that involves conducting experiment, data collection, and analysis". After the intervention, most teachers provided detailed descriptions of the scientific inquiry and referenced the following steps: Formulating question; developing a hypothesis; performing background research; designing an experiment; testing the hypothesis through experimentation; analyzing the data; and communicating the results. Pre-service teachers also said that the scientific inquiry deals with the natural world. For example, Katie wrote that "scientific inquiry is a process of understanding the world around us (nature, environment, interactions) and developing knowledge". Additionally, in the interviews most participants said the scientific inquiry was cyclical in nature.

Participant teachers were also asked to describe the similarities and differences between the engineering design and scientific inquiry. Before the intervention, pre-service science teachers mainly focused on the differences between the two processes. Most responses lacked detailed information to distinguish the scientific inquiry and the engineering design process. For example, Jackson said "Scientific inquiry is more focused on asking questions and then doing trials to see if you were asking the right question. Engineering design process is more about starting with a question and working to find the answer or solution.". After the intervention, pre-service teachers were explicit on the similarities and differences between scientific inquiry and engineering design process. Most teachers referenced specific steps as common between the two processes. For example, conducting background research, designing and/or implementing a test, and communicating results were the most mentioned common steps between the scientific inquiry and the Engineering design process. They also viewed both processes as cyclical and iterative. For example, Figure 3 shows Sharon's drawings of the engineering design and the scientific inquiry during the interviews.

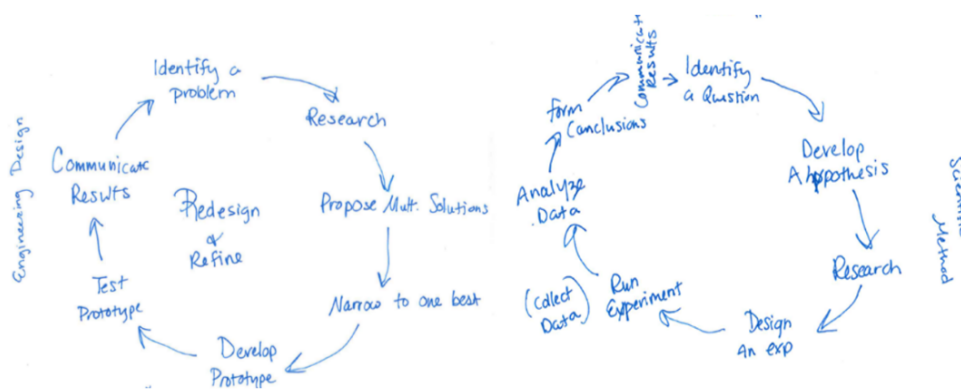


Figure 3: Post intervention Sharon's view of the engineering design and the scientific inquiry

When considering the differences between the two processes, pre-service science teachers cited the purpose of each process as a hallmark difference between them. Most preservice teachers viewed scientific inquiry as a process for answering questions or providing explanations and the EDP as focused on solving human problems. For example, Anita shared:

“Scientific inquiry attempts to answer a question while the engineering design process attempts to solve a problem. Scientific inquiry deals with the study of the natural world around us, while the Engineering Design process deals with the creation of an artificial world to solve real world problems”

Similarly, after the intervention, most pre-service science teachers stated that the scientific inquiry deals with the natural world, while the EDP addresses the artificial world. For example, Jim said “Scientific inquiry involves discovering the natural world by asking questions. Engineering design involves identifying a real world or human problem and developing a solution to fix the problem.”

### Discussion

Results show that after the intervention participant pre-service teachers developed understanding of science and engineering practices, engineering design process, and scientific inquiry. They also increased the use of engineering design-specific language when describing practices. These results are in keeping with those reported by Kilty and Burrows (2019). On the other hand, our findings are in contrast with those reported by other studies. For example, Boesdorfer (2017) reported that after the PD, many chemistry teachers still held low understanding of science and engineering practices. Similarly, in an exploratory study, Antink-Meyer and Meyer (2016) reported that teachers’ understanding of science and engineering practices were plagued by misconceptions. Kang et al. (2018) also found that most teachers reported lack of knowledge in the NGSS practices such as *Using mathematics and computational thinking* and *engaging in argument from evidence*. Yasar et al. (2006) and Hsu et al. (2011) posited that teachers indicated unfamiliarity with design, engineering and technology and they did not feel confident in teaching them.

Participant pre-service teachers’ understanding of the engineering design process is also in contrast with the results in previous studies. For example, Hynes (2012) reported that even after the intervention most middle school science teachers displayed inconsistent level of understanding of the engineering design process, as most of them demonstrated more knowledge for the “construct a prototype” and “redesign” than other steps. Researchers have attributed teachers’ misconceptions about the engineering design process to lack of exposure to engineering (e.g., Banilower et al., 2018; Haag and Megowan (2015). For example, Haag and Megowan (2015) reported that high school teachers lacked knowledge about engineering design because they never received instruction in engineering during teacher training. In our study, we provided training in engineering design to participant pre-service teachers through several EDIS activities designed to enhance teachers’ understanding of engineering design, and how to integrate engineering design in science teaching.

Another major finding in this study was the pre-service teachers’ understanding of the cyclical and iterative nature of both the engineering design process and scientific inquiry after the intervention. Participant pre-service teachers also acknowledged that there was more than one version of engineering design process, and scientific inquiry but they all serve the intended purposes in their disciplines. Similarly, Mesutoglu & Baran (2020) reported that after the

intervention, teachers developed understanding of the iterative nature of engineering design process. However, this finding is not in keeping with the results reported in earlier studies. For example, Hynes (2012) found that middle school teachers did not have a good understanding of the cyclical nature of the engineering design process. Similarly, Barnes and Angle (2015) reported that many science teachers said there was one exact or correct scientific inquiry that needed to be followed to collect accurate results. Antink-Meyer and Meyer (2016) also reported that teachers mainly considered scientific knowledge as the foundation of engineering and ignored the commonalities between the two disciplines. Our participant pre-service teachers understanding of the cyclical nature of engineering and scientific inquiry can be attributed to two reasons: First, throughout the intervention both scientific inquiry and engineering design process were taught as cyclical processes; and the pre-service teachers were involved in developing EDIS instructional materials to address both scientific inquiry and engineering design processes. Thus, we believe that through engaging in and developing EDIS units and activities, most pre-service teachers came to understand the cyclical and iterative nature of both engineering design and scientific inquiry. We also suggest that science teacher education programs should emphasize that teachers' understanding of the differences and similarities between engineering design and scientific inquiry is essential for effective EDIS instruction, and that focusing on only one of them misses the opportunity to provide a complete understanding of both processes among teachers and their students.

Overall, our study shows that the intervention positively impacted on the pre-service science teachers' understanding of science and engineering practices, engineering design and scientific inquiry. The following possible explanations for our results merit consideration. First, we believe the collaboration of two engineers, an engineering educator, and a science educator played a significant role in the success of the intervention. Engineers came into the intervention with practical experience in developing engineering education curriculum materials and working with in-service teachers. Some of the activities pre-service teachers did in the intervention were created by the two engineers and one engineer educator. The science education expert provided pedagogical strategies for integrating engineering in science teaching. This collaboration of engineers, engineering educator, and science educator in preparing pre-service teachers in engineering is rare. Many studies on engineering in teacher education have reported collaborations between science educators (Capobianco et al., 2020; French & Burrows, 2018) or between science and mathematics faculty members (e.g., Nesmith & Cooper, 2021). Second participants may have been motivated to learn more about engineering design because current science education reforms require them to incorporate it in science instruction. The presence of the three pre-service teachers who had degrees in engineering played a role in this intervention. During the activities we observed the three participants taking leading role in group engineering design activities and explaining design elements to other members of the group. We also observed preservice teachers who had scientific research experience explaining scientific inquiry process to their members of the group. Some of our pre-service teachers were career changers. They had worked as scientists or engineers in industries. As such, we believe these variables contributed to participant pre-service teachers understanding of practices, engineering design and scientific inquiry. Third, participant pre-service teachers were immersed in authentic EDIS activities that explicitly addressed the NGSS practices, engineering design process, and scientific inquiry. Therefore, it is possible to assume that pre-service teachers' experiences with such EDIS activities enabled them to learn more about the NGSS practices, engineering design process and scientific inquiry. Fourth, pre-service teachers were engaged in developing EDIS units and activities, and teacher guide manuals. They were

required to demonstrate how the appropriate NGSS dimensions (core ideas of science and engineering design, practices, and crosscutting concepts) were addressed in their units. In the teacher guide manuals, pre-service teachers were required to describe engineering design process and provide clear directions that other teachers can follow to develop their own EDIS instructional materials. Through these tasks, participant teachers were directly engaged in learning and applying the NGSS science and engineering practices, engineering design process, and scientific inquiry.

The growth demonstrated by pre-service teachers in their understanding of the NGSS practices, and engineering design, and their increased use of engineering specific language when describing the practices have implications for science teacher education. For example, preservice teachers' low conceptual knowledge of engineering design reported in our pre-intervention results and in previous studies should be a call to action in science teacher education. Science teacher education programs should refocus their science methods courses to explicitly address engineering design to ensure that pre-service science teachers are adequately prepared to teach science and engineering design as prescribed in the NGSS. We believe an implicit instructional approach to engineering design in science teacher education is likely to limit the opportunity for teachers to develop a deeper understanding of the engineering design process and how to integrate it in science instruction. Likewise, an implicit EDIS instructional approach is unlikely to have positive impact on students' understanding of engineering design and science core ideas outlined in the NGSS.

### **Recommendations for Future Research**

Although the findings in this study cannot be generalized due to a small number of participants, our findings suggest the evidence to support the need for professional development on engineering design for secondary pre-service science teachers to develop the understanding of engineering design process and how to integrate it in science instruction. We also suggest three areas for future research on engineering design in science teacher education: First, extend this study to a large sample of participant secondary pre-service science teachers. Second, investigate the relationship between teachers' understanding of engineering design integrated science teaching and their instructional practices in science classrooms. Third, examine the extent to which teachers' understanding of the NGSS practices and engineering design process impact their students' understanding of science concepts and engineering design process. These studies would provide evidence on whether teachers' understanding of engineering design is related to their EDIS instruction and students' achievement in science and engineering design.

### **Conclusions**

Our results show that participant pre-service teachers developed an understanding of the NGSS science and engineering practices, the engineering design process, and the scientific inquiry after the intervention. These results suggest that explicit instruction on engineering design process and scientific inquiry through intensive PD activities and EDIS instructional materials development can enhance pre-service science teachers' understanding of the NGSS practices, as well as their understanding of engineering design, scientific inquiry, and the cyclical and iterative nature of both processes.

### **References**

- Aminger, W., Hough, S., Roberts, S. A., Meier, V., Spina, A. D., Pajela, H. & Bianchini, J. A. (2021). Preservice secondary science teachers' implementation of an NGSS practice: Using mathematics and computational thinking. *Journal of Science Teacher Education*, 32(2), 188-209.
-

- Antink-Meyer, A., & Meyer, D. Z. (2016). Science teachers' misconceptions in science and engineering distinctions: Reflections on modern research examples. *Journal of Science Teacher Education*, 27(6), 625-647.
- Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). Report of the 2018 NSSME+. *Horizon Research, Inc.*
- Barnes, C., Angle, J., & Montgomery, D. (2015). Teachers describe epistemologies of science instruction through methodology. *School Science and Mathematics*, 115(3), 141-150.
- Boesdorfer, S. B. (2017, June). *High school chemistry teachers' views of engineering inclusion before and after a professional development program* (Center for Educational Transformation Research Brief No. 2). Retrieved from [https://cet.uni.edu/sites/default/files/boesdorfer\\_brief\\_0.pdf](https://cet.uni.edu/sites/default/files/boesdorfer_brief_0.pdf)
- Burghardt, M. D. & Hacker, M. (2004). Informed Design: A contemporary approach to design pedagogy as the core process in technology. *Technology Teacher*, 64, (1). 6.
- Bybee, R. W. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education*, 25(2), 211-221.
- Carr, R., & Strobel, J. (2011). Integrating engineering into secondary math and science curriculum: Preparing teachers. *1st Integrated STEM Education Conference*. Ewing, NJ: IEEE.
- Chiu, J. L., Hecht, D., Malcolm, P., DeJaegher, C., Pan, E. Bradley, M., & Burghardt, M. D. (2013). WISEngineering: Supporting Precollege Engineering Design and Mathematical Understanding. *Computers & Education*, 67, 142-155.
- Capobianco, B. M., Radloff, J., & Lehman, J. D. (2020). Elementary science teachers' sense-making with learning to implement engineering design and its impact on students' science achievement. *Journal of Science Teacher Education*, 32(1), 39-61.
- Cunningham, C. M., & Carlsen, W. S. (2014). Teaching Engineering Practices. *Journal of Science Teacher Education*, 25(2), 197-210.
- Custer, R. L. & Daugherty, J. L. (2009). Professional Development for Teachers of Engineering: Research and Related Activities. *The Bridge: Linking Engineering and Society*, 39(3), 18-24.
- Custer, R.L. & Daugherty, J.L. (2011) Teaching engineering concepts in high school project. *Journal of Technology Education*, 23(1), 2-4.
- Duncan, D., Diefes-dux, H., & Gentry, M. (2011). Professional development through engineering academies: An examination of elementary teachers' recognition and understanding of engineering. *Journal of Engineering Education*, 100(3), 520-539.
- Fantz, T. D., De Miranda, M. A., & Siller, T. J. (2011). Knowing what engineering and technology teachers need to know: an analysis of pre-service teachers engineering design problems. *International Journal of Technology and Design Education*, 21(3), 307-320.
- French, D. A., & Burrows, A. C. (2018). Evidence of science and engineering practices in preservice secondary science teachers' instructional planning. *Journal of Science Education and Technology*, 27(6), 536-549.
- Gauch, H. G. (2003). *Scientific inquiry in practice*. Cambridge University Press.
- Haag, S., & Megowan, C. (2015). Next generation science standards: A national Mixed-methods study on teacher readiness. *School Science and Mathematics*, 115(8), 416-426.
- Holder, T., Pottmeyer, L., & Mumba, F. (2019). Slime Mold Quarantine: An Engineering-Design-Integrated Biology Unit. *The American Biology Teacher*, 81(8), 570-576.

- Hsu, M. C., Purzer, S., & Cardella, M. E. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research*, 1(2), 5.
- Hynes, M. M. (2012). Middle-school teachers' understanding and teaching of the engineering design process: A look at subject matter and pedagogical content knowledge. *International Journal of Technology and Design Education*, 22(3), 345-360.
- Kang, E., Donovan, C., & McCarthy, M. (2018). Exploring Elementary Teachers' Pedagogical Content Knowledge and Confidence in Implementing the NGSS Science and Engineering Practices. *Journal of Science Teacher Education*, 29:1, 9-29.
- Kilty, T. J., & Burrows, A. C. (2019). Secondary science preservice teachers' perceptions of engineering: A learner analysis. *Education Sciences*, 9(1), 29.
- Kim, E., Oliver, J. S., & Kim, Y. A. (2019). Engineering design and the development of knowledge for teaching among preservice science teachers. *School Science and Mathematics*, 119(1), 24-34.
- Mesutoglu, C., & Baran, E. (2020). Examining the development of middle school science teachers' understanding of engineering design process. *International Journal of Science and Mathematics Education*, 18, 1509-1529.
- Mumba, F., & Ochs, L. (2018). A model for determining the nature and extent of integration in engineering design and science integrated activities. In *Proceedings of the Association of Science Teacher Education (ASTE) Conference*, Baltimore, MD, January 3–6, 2018.
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, D.C.: National Academies Press.
- Nesmith, S. M., & Cooper, S. (2021). Connecting engineering design and inquiry cycles: Impact on elementary preservice teachers' engineering efficacy and perspectives toward teaching engineering. *School Science and Mathematics*, 121(5), 251–262.
- NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.
- Rice, M., Mumba, F., & Pottmeyer, L. (2022). Learning about Osmosis through Engineering Design Process. *The American Biology Teacher*, 84(5), 297-307.
- Schnittka, C., & Richards, L. (2016). POWERED by the Sun. *The Science Teacher*, 83(3), 25.
- Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*, 27(2), 237-246.
- Windshittl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific inquiry: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, 92(5), 941-967.
- Yaşar, Ş., Baker, D., Robinson-Kurpius, S., Krause, S., & Roberts, C. (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. *Journal of Engineering education*, 95(3), 205-216.

### Authors

Frackson Mumba  
Associate Professor  
University of Virginia, Department of Curriculum, Instruction & Special Education  
Email: [fm4v@virginia.edu](mailto:fm4v@virginia.edu)

Alexis Rutt

---

Assistant Professor  
University of Mary Washington, College of Education  
Email: [arutt@umw.edu](mailto:arutt@umw.edu)

Paul Asunda  
Associate Professor  
Purdue University, Department of Curriculum and Instruction  
Email: [pasunda@purdue.edu](mailto:pasunda@purdue.edu)

Reid Bailey  
Professor  
University of Virginia, Department of Systems and Information Engineering  
Email: [rrb5b@virginia.edu](mailto:rrb5b@virginia.edu)

### **Appendix A -Pre-Post Questionnaire**

1. What is engineering?
2. Describe the engineering design process.
3. What is the difference between the scientific inquiry and the engineering design process?
4. What is a design challenge in engineering?
5. What is a design solution in engineering?
6. Explain what the following statements mean in science and engineering.
  - Asking questions (for science) and defining problems (for engineering)
  - Developing and using models
  - Planning and carrying out investigations
  - Analyzing and interpreting data
  - Using mathematics and computational thinking
  - Constructing explanations (for science) and designing solutions (for engineering)
  - Engaging in argument from evidence
  - Obtaining, evaluating, and communicating information

### **Appendix B: Semi-Structured Interview Protocol**

1. How do you describe engineering?
2. How do you describe engineering design?
3. Walk me through an engineering design process we discussed in class (*Ask them to draw a diagram*). [*Most important question*]
4. Walk me through the scientific inquiry process we discussed in class. (*Ask them to draw a diagram*). [*Most important question*]
5. What are the similarities between Engineering Design & Scientific Inquiry?
6. What are the differences between Engineering Design & Scientific Inquiry?
7. How do you describe the following?
  - a. Asking questions (for science) and defining problems (for engineering)
  - b. Developing and using models in engineering design?
  - c. Planning and carrying out investigations?
  - d. Analyzing and interpreting data?
  - e. Using mathematics and computational thinking in engineering design?
  - f. Designing engineering solutions?
  - g. Engaging in an argument from evidence?
  - h. Obtaining, evaluating, and communicating information in engineering design?
8. Any other information on engineering design you want to share with me?



## **Investigating an Instructional Model for Integrated STEM in Teacher Education**

Laurie O. Campbell  
*University of Central Florida*

Nicole Damico  
*University of Central Florida*

### **Abstract**

Active learning experiences that incorporate technology, design, and making combine to form an important and necessary pedagogical approach that supports the 21<sup>st</sup> century skills of collaboration, communication, creativity, digital literacies, and computational thinking as a problem-solving framework. Active learning experiences in teacher preparation serve as a model for future educators to follow, while building the educators' efficacy to conduct future implementations with their own students. In this study, a multidisciplinary Pop-Up Makerspaces activity was conducted as an active hands-on approach to interdisciplinary STEM education. The intersectionality of English language arts with integrated STEM through design and making included: (a) enriching language and integrated STEM literacy, (b) scaffolding and supporting pre- and inservice educators through well-designed active learning as these opportunities help to develop self-efficacy, and (c) exploring new models and frameworks for transdisciplinarity.

*Keywords:* STEM; Makerspace; Active Learning; Teacher education; mixed methods

National and international imperatives to solve complex and pervasive world concerns like disease, energy depletion, and natural disasters have heightened the call to prepare a workforce equipped to find solutions for global and interdisciplinary problems. In the United States, integrated science, technology, engineering, and mathematics (STEM) education has been identified as an educational priority for the purpose of cultivating a prepared workforce to face these global challenges (NAE & NRC, 2014). Integrated STEM includes multidisciplinary skills, content knowledge, and various approaches to problem solving and critical thinking. To support STEM integration, teacher educators and K-12 faculty have engaged in ongoing efforts to foster integrated STEM literacy in K-12 education (Brophy et al., 2008; Kelley & Knowles, 2016; National Research Council, 2011; Shanahan & Shanahan, 2008; Yore, 2011).

Fostering STEM literacy among students in K-12 education requires that educators are versed in integrated and interconnected STEM-based education pedagogies and approaches (Ring et al., 2017). Yet, Pre-K through 12<sup>th</sup> grade educators indicate that they lack the knowledge and self-efficacy to plan and implement interdisciplinary STEM activities that would foster STEM literacy and ways of thinking within their classes (Madden et al., 2016). Although in its infancy, professional development training and preservice education in interrelated STEM education has

proven to correlate to increased confidence and self-efficacy among teachers for incorporating integrated STEM (NAE & NRC, 2014; Cantrell et al., 2003). Calls for interdisciplinary STEM education research (Li et al., 2019) have prompted teacher educators and researchers from diverse disciplines to consider ways to train teachers in integrated STEM (English, 2016).

The goal of this explorative study, which was conducted within the context of an English Language Arts (ELA) teacher education course, was to answer the need for increased research collaborations in STEM education and investigate an instructional model for exploring integrated STEM and disciplinary content knowledge through design and making. Using a mixed-method approach, we attempted to answer the following questions:

- What are preservice and inservice teachers' perceptions of self-efficacy after completing a multidisciplinary active learning design and making learning experience with an integrated STEM focus?
- What are preservice and inservice teachers' perceptions of the intersectionalities of English Language Arts and integrated STEM?

### **Literature Review**

The term “integrated STEM” encompasses an interdisciplinary approach to the disciplines represented in STEM (e.g. science, engineering, technology, and mathematics) to a multidisciplinary perspective that includes combinations of stand-alone STEM disciplines with another non-STEM discipline (Li, 2014). In other words, disparate disciplines amalgamate towards new understandings. Integrated STEM is further characterized by authentic problem-based learning taught from an active learning approach. The following section provides an overview of integrated STEM in education.

#### **Integrated STEM Literacy and Training**

According to Zollman (2012), integrated STEM literacy encompasses three levels of understanding: (a) disciplinary content, (b) needs (societal, economic, and personal), and (c) cognitive, affective, and psychomotor learning domains. Further, integrated STEM literacy includes various ways of thinking including but not limited to: (a) design thinking, (b) computational thinking (Wing, 2006), (c) mathematical thinking, (d) critical thinking, and (e) scientific inquiry (Slavit et al., 2019). These three levels of understanding and ways of thinking coalesce to form integrated STEM literacy. While some factors of integrated STEM literacy have been identified, learner outcomes and perceptions related to integrated STEM learning experiences are understudied (English, 2016; NAE & NRC, 2014).

Developing educators' knowledge and efficacy for conducting integrated STEM learning experiences for PK-12 educators can and should occur through preservice education and professional development and practice. Yet, integrated STEM training in preservice education is limited (Shernoff et al., 2017) and professional development training is often localized. Likewise, teacher education standards to encourage training in integrated STEM are lacking (Rosengrant et al., 2019). The federal priority of the National Science and Technology Council (NSTC, 2018) of building strong foundations for STEM literacy recognizes the need for (a) building computational literacy and (b) engaging students where disciplines converge. The need for partnering with teacher educators to promote computational thinking and to contribute to STEM literacy is prevalent and necessitates that promising practices and lessons learned are investigated and disseminated.

Nadelson and Seifert (2017) asserted that teachers need to have appropriate skills, mindsets, and training to employ integrated STEM in teaching and learning. However, little research exists related to developing and accessing teachers in integrated STEM literacy. Nonetheless, research related to general disciplines can inform the instructional design of integrated STEM preparation. The design of preservice and professional development training for integrated STEM literacy should include: (a) teachers experiencing what their students would experience (Loucks-Horsley et al., 2009), (b) opportunities to explicitly identify multidisciplinary skills and ways of thinking (English, 2016; NAE & NRC, 2014), (c) ascertaining teachers' beliefs (Zollman, 2012), and (d) developing pedagogical approaches from research knowledge for classroom implementation.

### **Integrated STEM and Language Arts**

Prior integrated STEM and language arts integrations have been studied both at the school and classroom levels. With the contemporary focus on reading informational texts and writing argumentative and explanatory texts demands that literacy be seen as a school-wide endeavor. Research indicates that students who participated in school-wide integrated STEM programs inclusive of all core subjects, including language arts, felt more prepared for college than those who did not attend a school-wide integrated STEM program (Subotnik et al., 2013).

The connections between STEM and literacy and inspired iterations of the STEM acronym like STEAM (with an added A for Arts) and STREAM (with an added R for Reading). At the classroom level, English language arts and integrated STEM classroom studies have supported and enhanced content instruction while developing other STEM skills and thinking. For example, the STEM movement has inspired that teachers of literacy to consider STEM elements like data visualization and quantitative literary analysis as discrete skills that prepare students to communicate and interact with the modern world (Lynch 2015, Alvermann et al., 2019). Cross and colleagues (2013) studied an eighth-grade class of students that developed coding sequences to demonstrate their comprehension of poetry. Outcomes of this study demonstrated that students perceived a greater appreciation for poetry, along with increased technological literacy and an opportunity to practice computational thinking skills. School-wide programs of study benefit not only students but teachers as well, as teachers will support each other in an integrated culture of learning (Lesseig et al., 2016).

### **Makerspace for Design and Making**

Makerspaces foster hands-on opportunities to combine technology and design ideas to explore, develop, and build solutions to fictitious and real-world challenges and problems, while increasing participants' 21st-century interdisciplinary skills and extending content knowledge. The benefits of these learning experiences include interacting in an interdisciplinary learning space (Hlubinka et al., 2013), fostering inclusivity in STEM (Brady et al., 2014; Harvin, 2015), inspiring independence (Barron & Barron, 2016), and increasing motivation (Han et al., 2017). These physical spaces for designing, making, exploring, building, and problem-solving have become a part of the educational landscape and are known as Makerspaces, design labs, fab labs, and other physical spaces. Makerspaces afford a means for learners to use, modify, and create content (Lee et al., 2011).

While these exploratory spaces can provide active and meaningful learning opportunities as a curricular support or learning extension, limitations to incorporating a learning experience in these spaces include limited access to physical locations (if the school has one dedicated space), the cost of developing a space, allocating time to use the space, the purchase of high-tech tools, and limited implementation knowledge. As a result, schools and classrooms with limited resources may not

have the means to include these valued learning experiences. One solution to limited resources includes employing *Pop-Up Makerspaces*.

*Pop-Up Makerspaces* are flexible and overcome typical classroom constraints such as space, time, and resources. As a result, more teachers can incorporate design and making activities that can improve students' interdisciplinary skills and increase student accessibility (Campbell & Heller, 2019). In commerce, small pop-up shops appear for a short time to provide access to products. Like a pop-up shop, mobile design Makerspaces appear in a classroom for a limited time and aim to extend curriculum, to practice and develop curricular related ideas, and to foster interdisciplinary connections. These spaces do not include high-tech tools but do include simulated challenges and recyclable and or low-cost materials. The mobile *Pop-Up Makerspaces* discussed in this study, provide a model for preservice and inservice educators to consider in their own teaching.

### **Incorporating Computational Thinking**

Computational thinking, a concept derived from the field of computer science, provides a framework for “solving problems, designing systems, and understanding human behavior” (Wing, 2006, p. 33). Components of computational thinking include pattern recognition, decomposition, abstraction, and algorithmic design. While evidence of explicit instruction of computational thinking as a framework for problem-solving may not be realized, educators would benefit from developing their own efficacy in computational thinking in order to foster students' computational thinking (Jaipal-Jamani & Angeli, 2017; Yadav, et al., 2014).

### **Purpose and Research Questions**

The framework for STEM teaching and learning considered in this study was grounded in Merrill's (2009) definition that STEM teaching includes (a) authentic content and problems, and (b) using hands-on, technological tools, equipment, and procedures to solve human problems. To learn more about multidisciplinary integrated STEM in teacher education, the following exploratory study was conducted to investigate an active integrated STEM design and making learning experience with secondary language arts preservice and inservice teachers. Objectives of the study included: (a) demonstrating a low-cost model of an integrated STEM design and making activity, (b) fostering preservice and inservice teachers' self-efficacy towards integrated STEM literacy, (c) introducing integrated STEM pedagogical knowledge for transferability, and (d) promoting computational thinking awareness. Therefore, the following study investigated an activity to build integrated STEM literacy in preservice and inservice education.

The following research questions guided this study:

- What are preservice and inservice teachers' perceptions of self-efficacy after completing a multidisciplinary active learning design and making learning experience with an integrated STEM focus?
- What are preservice and inservice teachers' perceptions of the intersectionalities of English Language Arts and integrated STEM?

### **Methods**

A mixed method study was conducted to investigate STEM-based *Pop-Up Makerspace* in a literacy-based context. Both qualitative and quantitative data were collected simultaneously and

---

then combined to compare the perspectives of the participants. Both types of data were weighed equally.

### Participants

The study took place within the context of an English Language Arts education course taught by one of the researchers. The course enrolled a hybrid population of both undergraduate and graduate students, for a total of 22 participants (fourteen women and eight men ranging from 21-40 years old). The undergraduate students (n=15) enrolled in the course were secondary English Language Arts education majors and preservice teachers enrolled in required concurrent practicum experience in English language arts. The graduate students (n=7) were inservice educators teaching in English language arts public school classrooms taking the class for teacher certification, recertification, or to earn a graduate degree. The content of the course centered around methods of teaching English Language Arts, with a particular focus on teaching Young Adult (YA) Literature. During each class, students were expected to come prepared by having read a common YA text (e.g., *The Hate You Give*, *The Absolutely True Diary of a Part-Time Indian*, and *The Lord of the Flies*) and discuss pedagogical implications and practical approaches for teaching the focus text.

To set the stage for this study, two researchers from different disciplines (English language arts education and learning sciences, respectively) conceptualized a *Pop-Up Makerspace* seminar with an integrated STEM focus based on one of the course novels, *Lord of the Flies*. Researchers developed problem-based learning activities that incorporated themes from the YA text with STEM integrated tasks like interacting with informational texts and researching and cataloging using digital technologies. Participants arrived for the class session and were seated in groups of four and five peers. Researchers presented the participants with five problem-based activities related to the main themes and symbols of the *Lord of the Flies*. These activities included: Shelter Building, Digital Sketchnoting, Flag Design, Raft Building, and developing a Museum Artifact Box.

### Data Sources

**Pre and Post Surveys.** All participants took an entrance survey to ascertain what the teachers knew about computational thinking, the participants' level of confidence for teaching disciplinary science, and their level of confidence for teaching STEM-integrated concepts. A Likert-type scale of 1 (lowest) to 7 (highest) was utilized. At the end of the learning experience, participants completed a post survey. The exit survey asked which activities from the design and making learning experience they enjoyed the most and why, and to rate the overall experience on a scale of 1 to 5 (1 being "I had a terrible time" to 5 being "I had the time of my life"). Further, the exit survey asked the participants to identify factors of computational thinking and to identify the disciplinary context of each activity within the design and making learning experience.

**Lord of the Flies STEM Activities.** In a full class discussion led by researchers, participants reviewed and reflected on aspects of the novel that were important to its themes and discussed how these themes translated into modern day culture. They reviewed definitions for computational thinking and considered how it may be evidenced in a non-computer science setting. Reusable shopping bags full of supplies were placed on five different tables around the room. Groups seated at the table were instructed to find the problem-based learning challenge card inside the bag and use their supplies to solve the problem indicated on the challenge card. In cases where the challenge required access to an online program, participants either used a class-provided device or personal mobile device like a smartphone, tablet, or laptop. Each challenge took approximately

20-25 minutes to complete and was based on some aspect of the novel *Lord of the Flies*, inviting students to make inferences about what they read while employing computational thinking and design principles, in addition to STEM-integrated elements. Further, the activities and challenges in these integrated STEM-infused literacy themed Makerspaces were designed to encourage communication and collaboration while incorporating aspects of computational thinking for problem-solving. General supplies provided to the participants in the bag included paper, scissors, tape, glue, recycled cardboard, containers, markers, crayons, pens, and pencils. Some of the bags included more specialized items like fabric scraps, popsicle sticks, straws, pipe cleaners, duct tape, string or yarn, a glue gun and glue sticks, or decorative material. Most of the materials for the activities were leftovers recycled from other projects. Items like popsicle sticks and straws were purchased at a dollar store. After each activity, students completed activity reflections where they answered open-ended questions including: (a) What would you like to tell us that we did not ask?; and (b) Please indicate other ways that you could incorporate an activity like the one you participated in today.

**Other Data Sources.** The University systematically collects students' perceptions of instruction at the end of each semester. Students are able to provide comments related to instruction on that survey. At the end of the semester, some participants provided voluntary comments on their university overall course evaluations about the Makerspace enrichment learning experience. These comments were unsolicited and anonymous and were provided to the researchers eight weeks after the course was concluded. All comments related to the Makerspace learning experience included on the students' perceptions of instruction were included for analysis.

**Shelter Building.** The shelter building activity tasked the participants to role play that they were stranded on the island that appears in the *Lord of the Flies* novel. They were directed to use the recycled materials to build a shelter no taller than one foot that would withstand the known elements of destruction found on the island depicted in the *Lord of the Flies* novel. They were challenged to encounter and use STEM principles to problem solve constraints like size, materials, and building strength. They were provided digital images of several types of shelter such as a tent, yurt, log cabin, and a camper. During this activity, participants incorporated digital technologies as a documentation tool to take pictures with their smartphones and posted them to a class digital media curation website to document the building process. Further, they solicited feedback through social media outlets from their friends who may have not been at their table but were in the classroom working on another activity. It was anticipated that the problem-solving strategies evidenced through this activity would include decomposition, algorithmic design, and abstraction. Other activities included (a) raise your flag, (b) build a raft, (c) museum artifact box, (d) digital sketch noting, and (e) online corkboard. See Table 1 below for descriptions:

### Research Design and Data Analysis

The purpose of this mixed-method, convergent research study was to explore participants' perceptions after engaging in an active learning, literacy-focused, technology-infused *Pop-Up Makerspace* learning experience. The learning experience was designed to contribute to preservice and inservice educators' efficacy for integrating STEM ways of thinking in literacy. Both quantitative (closed questions) and qualitative data (open-ended questions) were gathered to provide a greater understanding of the participants' perceptions for future research and to inform present and future transdisciplinary frameworks for design and making activities. Data were collected through surveys, activity reflections, and end of course feedback.

Table 1

*Activities with Integrated STEM Components*

Activity	Description	Integrated STEM Components
Raise Your Flag	For the flag activity, the participants worked in teams and created a flag that represented each member of the team in some way.	The factor of computational thinking for problem-solving expected to be employed during this activity was pattern recognition.
Build a Raft	Participants were challenged to build a raft with only ten popsicle sticks.	The task required participants to employ algorithmic thinking and pattern recognition to effectively persist towards the solution.
Museum Artifact Box	Participants were challenged to create and annotate a museum-type artifact box include four compartments, display symbols (artifacts) that represented important details from the story.	Each of the artifacts were contained in a box with a lid. The participants were challenged to incorporate Math and Engineering skills in building their box to have equal partitions.
Digital Sketchnoting	Sketchnoting is a method for taking notes and heavily augmenting the notes through visuals to improve retention (Mayer, 2008). Using online whiteboards and mobile digital devices the participants created sketchnotes portraying aspects of living on the island.	In this ELA activity, participants documented their perceptions of island living by employing digital devices and conceptual visualization techniques.
Online Corkboard	The virtual corkboard served as a digital repository of the activities for both the researchers and the participants. The ease of use and the accessibility of the digital tool supported reflections as the participants only needed a link and not an account to contribute.	The online corkboard activity allowed participants to utilize various technologies that are helpful as an integrated STEM planning tool.

Quantitative data obtained from Likert-type questions were averaged based on single constructs. The qualitative data obtained from the open-ended responses to the survey, activity reflections, and end of course surveys were analyzed through content analysis. To determine the initial coding schema for the content analysis, outcomes from prior integrated STEM literature were considered through a constant comparison coding method (Glaser & Strauss, 1999). The coders read through a sample of three participants' comments and classified each response according to the predetermined categories. The coders met and discussed the resulting bracketing and determined there were three overarching themes. Themes included: (a) affective/social connections, (b) perceptions of experience, and (c) cognitive association. The coders then coded all of the responses. If there was a difference in coding, the coders discussed the difference for consensus.

## Results

To provide context about the participants' disciplinary knowledge, participants were asked about their confidence level for teaching disciplinary content and their knowledge of computational thinking. The participants' confidence levels were the strongest for language arts and minimal for other STEM subjects (see Table 2).

Table 2

*Students' Confidence Levels for Teaching or Integrating Ways of Thinking from Other Disciplines*

	Average (1-7 Likert Scale)	Male	Female
Science	2.6	3.4	2.2
Engineering	2.33	3.6	1.7
Language Arts	6.29	----	----

Note: Confidence levels for Language Arts were not broken down by gender as they were similar.

Next when asked to define the term computational thinking, only two participants, one male and one female, representing approximately 13% of the sample, indicated that they understood the term computational thinking. Both participants connected their understanding of the definition to computer coding and *Hour of Code*, as they had participated earlier in the school year at an *Hour of Code* coding awareness event. The results of the study are presented in the order of the research questions. First, the quantitative results are presented followed by the qualitative evidence.

### Research Question One

What were the participants' ratings of the activities and self-efficacy perceptions after completing a multidisciplinary active learning design and making learning experience? To determine the preservice and inservice teachers' perceptions after completing an active learning, literacy-focused, technology-infused Makerspace, the teachers were surveyed. Questions included both Likert-type questions and open-ended questions. The descriptive results for the question: "Rate your experience today from 1 to 5 (1 being "I had a terrible time" to 5 being "I had the time of my life.")" are provided. Sixteen responses were recorded with a mean score of 4.19, the mode was 4 and the range was 3-5. In general, all written comments about the *Pop-Up Makerspaces* experience were positive. Words used to describe their interactions included: fun, motivating, interactive, and promoted creativity. However, there was recognition that some participants were challenged by the activities. For instance, one preservice educator claimed, "some activities were infuriating to accomplish, but it was still fun." Another said, "I was so stuck on one task, but I finally got it. If it had not been for my classmates, I would have never finished."

Open-ended comments were coded utilizing the following themes: affective/social connections, cognitive associations, and perceptions of experience (see Table 3). Affective connections included the feelings felt or expressed and social connections included statements that indicated collaboration or isolation. Cognitive associations were "ah ha" moments, evidence of ideas that were crystallized, and beliefs that were confirmed or rejected. Perceptions of personal experience included statements that were indicative of the participants' experiences of the activities. The English language arts participants favored the urban planning/shelter building



activity. In this activity, the participants solved the challenge by making shelters for themselves that would survive weather challenges found on an island.

Table 3  
*Participant Response to the Learning Experiences by Activity*

Source	Response	Theme
Survey	“the shelter...allowed me to <b>work together</b> and be creative”	affective/ <b>social connections</b>
Survey	“...the urban planning activity included <b>collaboration</b> we were able to create an amazing space that could actually be lived in,”	affective/ <b>social connections</b>
Survey	“We loved the urban planning activity the most because of the <b>collaboration</b> . We had fun with it.”	affective/ <b>social connections</b> <u>perceptions of experience</u>
Activity Reflection	“We absolutely loved the urban planning activity as we used it to <b>collaborate and work together</b> to create a strong and effective house that was also glamorous.”	affective/ <b>social connections</b> <u>perceptions of experience</u>
Survey	“Doing the difficult task of building a raft got me in the <b><i>mindset of how it feels to be a frustrated student</i></b> , <i>how persistence pays off</i> and <b><i>how will I encourage</i></b> a student who gets frustrated and wants to just give up,”	affective connections <b><u>cognitive association</u></b>

Note: *affective coding (italics)*, social connections (**bold**), perceptions of experiences (underline), cognitive association (***bold, italics, and underline***)

Participants' self-efficacy related to conducting and designing an activity like this on their own were ascertained by the participants indicating their confidence level for integrating English/Language Arts with other subject areas as a teacher and a course designer (see Table 4).

In general, the participants indicated that they were less confident to design these types of experiences and more confident to be the instructor in a pre-designed hands-on integrated learning experience. Further, non-STEM subjects were more favored for integrated learning experiences over integrated STEM and individual STEM subjects.

### Research Question Two

First, the participants were asked to what degree they believed that they could identify the interdisciplinary aspects of the activities. On a five-point scale the average response was a 4.89 meaning that the participants were overwhelmingly confident that they could identify multiple learning objectives. Next, the participants were asked to identify what disciplinary content was evident in each challenge activity. In the top half of the table, participants indicated the disciplines that they perceived were necessary to complete the *Lord of the Flies* interdisciplinary challenges.

In the bottom half of the table, participants' average responses were tabulated by percent. More than one discipline could be selected by participants (see Table 5).

Table 4

*Instructor Confidence for Integrating STEM and English/Language Arts*

	Confidence to be the instructor	Confidence to design these types of experiences
ELA and Art (all types)	4.32	4.10
ELA and Social Science	4.40	4.07
ELA and STEM	4.12	3.54
ELA and Science*	4.28	3.80
ELA and Technology*	4.10	3.90
ELA and Engineering	3.04	2.22
ELA and mathematics*	3.37	2.03

Note: Science, mathematics, and Technology content were interpreted based on the participants' own determination (e.g. Biology, Physics, and Chemistry). Not everyone considered each subject collectively or holistically but rather based their understanding on one aspect of the subject (e.g. Algebra I or Computer Application).

Table 5

*Participants' Perceptions of Multidisciplinary Content*

Percentage*	Mathematics	Science	Engineering	Technology	Integrated STEM	Language Arts	Other
Flag	25%		62%	18%	43%		Art
Raft		62%	87%		93%	43%	Physics
Sketchnoting	43%			100%		100%	Art
Shelter Building	50%	37%	100%	37%	100%	31%	
Artifact Box	56%	43%	87%		100%	68%	Origami

Note \* The percentage of the respondents who indicated that discipline was needed to solve the problem-based challenges.

Next, the participants were asked to identify what factors of computational thinking were employed in the activities. While most did not indicate they knew what computational thinking was prior to the learning experience, they were able to recognize aspects of computational thinking in their problem-solving approach when provided a list of the factors (see Table 6). The activity

that most participants indicated included all factors of computational thinking was the shelter building activity. In the case of the flag project, 94% of the participants recognized that pattern recognition was involved to complete the project activity.

Table 6

*Participants' Identification of Factors of Computational Thinking by Activity*

Activity	Pattern Recognition	Decomposition	Abstraction	Algorithmic Design
Flag	94%	--	43%	62%
Raft	56%	--	--	88%
Sketchnoting	--	56%	75%	--
Shelter Building	56%	80%	43%	62%
Artifact Box	62%	--	--	94%

\* Participants could choose more than one factor for each activity.

For research question two, participants' written responses were analyzed. All of the inservice and most of the preservice participants recognized the versatility of *Pop-Up Makerspaces* to explore multiple content objectives, to promote 21<sup>st</sup> century skills, and to enrich traditional literacy instruction. Further, they identified the potential for *Pop-Up Makerspaces* to inspire and motivate learners to explore content in a new way. The same three themes from research question one were considered: affective/social connections, cognitive associations, and perceptions of experience (see Table 7).

In the final course evaluation, one teacher education student noted "learning in language arts is not all about reading and writing, as we traditionally think about them. We can offer our students VARIETY and CHOICES!" Another inservice teacher educator felt like the *Pop-Up Makerspace* activity afforded seamless integration of digital as well as physical tools in an ELA environment. One preservice teacher summed up their impressions of the course experience by stating, "the most memorable part that will stay within the recesses of my mind will be the makerspace lesson. I know a lot of students would like the hands-on approach, just as many would not appreciate this. It's interesting how the centers[activities] involved some sort of literacy and STEM, but even though they were hands-on, literacy did get lost."

Table 7  
 Perceptions related to the integrated of English Language Arts, Technology, and an Integrated Makerspaces

Source	Response	Theme
Activity Reflection	“ <u>Awesome experience! I was struggling with ways to incorporate Makerspaces in an ELA classroom with technology.</u> ”	<u>cognitive association</u> perceptions of experience
Activity Reflection	“I enjoyed making. More than that, I <u>enjoyed the connections that were drawn from the projects</u> to the text to technology,”	<u>cognitive association</u> perceptions of experience
Course Evaluations	“I valued <u>looking at literacy through a different lens</u> . The Makerspace was <i>my favorite activity</i> . I even <b>discussed the concept of this with other teachers I know</b> . We are going to try do one in the Fall.	<u>cognitive association</u> <b>affective/social connections</b>
Survey	“Makerspace <u>allowed text to translate into new ways</u> , especially engineering.”	<u>cognitive association</u>
Survey	“It works.” “ <u>Makerspaces can be incorporated into ELA curriculum.</u> ” “It <u>was possible to</u> actually do this in ELA not just STEM!!! <i>So excited now!</i> ”	<u>cognitive association</u> <i>affective connection</i>

Note: *affective coding (italics)*, **social connections (bold)**, perceptions of experiences (underline), cognitive association (***bold, italics, and underline***)

## Discussion

A multidisciplinary, problem-based, hands-on active learning activity to promote integrated-STEM literacy was conducted in a secondary English language arts course with preservice and inservice teachers. The objective of the study was to model to the current and future educators’ ways to incorporate making and design educational experiences by utilizing a hands-on design-based approach that was multidisciplinary and multifaceted. Integrative STEM literacy was introduced and practiced. The purpose of the research was to determine the participants’ perceptions of (a) the activities, (b) their ability to identify the multidisciplinary aspects of the experience, and (c) their self-efficacy to replicate the experience. Data were collected through a pre and post survey, observation, and reflection comments that included both qualitative and descriptive quantitative data.

All participants explored their perceptions of the Makerspace activity in relation to themselves and their teaching practices. They indicated that the experience itself was positive, and the activity promoted interdisciplinary learning objectives and pedagogical skills. Similarly, Stevenson and his colleagues (2019) noted that teachers increased confidence to conduct a Makerspace while building their capacity for technology and STEM-integrated ways of thinking. Complementary to

Sheffield and colleagues (2017), learners in this study practiced 21st century skills like collaboration, communication, critical thinking, and creativity while building computational thinking skills through a Makerspace.

Educators reported greater self-efficacy in facilitating an integrated STEM activity when they were included in the design process of the curricula. They attributed low levels of self-efficacy in STEM instruction to the following factors: (a) the time, creativity, energy, and collaboration with others that designing a multidisciplinary activity entails; and (b) the previous expectations of their role as merely facilitators of STEM activities without much input on the design of those activities. Research has indicated that there are improvements in the implementation of learning activities when educators re-design or co-design those learning experiences (Cviko, McKenney, & Voogt, 2014). In addition, educators who demonstrate greater self-efficacy are more confident in both facilitating and designing instruction, especially when prior knowledge and experience is activated (Holzberger et al., 2013).

A longitudinal analysis. *Journal of Educational Psychology*, 105(3), 774. The participants' recognition of computational thinking increased after the intervention. In part, this was attributed to the introduction to computational thinking before the design and making mention of computational thinking during the instructions. Moreover, the facilitators engaged in explicit conversation with the participants about computational thinking. Explaining the importance of computational thinking as a component of integrated STEM literacy heightened the preservice and inservice teachers' understanding which can lead to increased transferability to other contexts. Similarly, Soules et al. (2014) encouraged that more time should be spent explaining connections to improve instructional benefits.

Participants identified the disciplinary components that comprised the multidisciplinary problem-based challenges. By identifying the activity purposes, multidisciplinary awareness and explicit curricular connections occurred. The importance of this reflective activity may contribute to the degree teachers employ integrated STEM as knowledge of explicit connections are a key indicator of integration (Dare et al., 2018). The participants' responses indicated that the learners made positive affective/social and new cognitive connections related to conducting future multidisciplinary integrated STEM activities.

The perceptions of integrated English Language Arts and STEM through design and making included: (a) enriching language and integrated STEM literacy, (b) scaffolding and supporting pre- and inservice educators through well-designed active learning as these opportunities help to develop self-efficacy, and (c) exploring new models and frameworks for transdisciplinarity. For these reasons, continued efforts should be made to increase integrated STEM and non-STEM literacy-based design and making experiences in teacher education.

Implications for teacher educators to build capacity for integrated STEM literacy includes: (a) developing active learning multidisciplinary activities and practicing the activities with teacher educators, (b) designing implementation plans with teachers specific to their classroom situation, and (c) explicitly identifying connections and ways of thinking. Limitations of this exploratory mixed-methods study included: (a) the instrument used to collect the pre and post data, (b) varying understandings of the constructs being measured, and (c) the size of the sample. The instrument was not vetted for construct and content validity. The constructs did not have robust descriptors for the participants to have shared meaning. The instrument was used solely for the context of this study. While the study focused on the teachers and one Language Arts novel as the context, in

future studies, institutional factors such as resources to support the teachers, time for development, and school culture need to be addressed to ensure better cohesion to integrating STEM in multidisciplinary contexts (Loucks-Horsley et al., 2009). Likewise, other novels that focus on STEM based problems could be considered in future replications of this study.

### Conclusion

In this study, a multidisciplinary *Pop-Up Makerspaces* activity was conducted as an active hands-on approach to interdisciplinary STEM education. The potential of these hands-on active learning experiences included: (a) extending and supporting disciplinary content, (b) making interdisciplinary connections, (c) increasing the appropriate use of digital technologies, and (d) integrating multiple integrated STEM objectives beyond English language arts. Further, preservice and inservice educators benefit from these hands-on design experiences to build their own pedagogical knowledge and efficacy of how to increase design and making experiences and access. As preservice and inservice teachers observe making and design as a pedagogical affordance, they are more apt to include these needed learning experiences with their own participants.

### References

- Alvermann, D., McGrail, E., Young, C., Damico, N., Zucker, L. (2019). "Beliefs for Integrating Technology into the English Language Arts Classroom": Reflections from scholars in the field. *Contemporary Issues in Technology and Teacher Education*, English Education, 19(3).
- Barron, C. & Barron A. (2016). Seven surprising benefits of Maker Spaces. *School Library Journal*. Retrieved from <http://www.slj.com/2016/08/technology/seven-surprising-benefits-of-maker-spaces/>
- Brady, T., Salas, C., Nuriddin, A., Rodgers, W., & Subramaniam, M. (2014). MakeAbility: Creating accessible makerspace events in a public library. *Public Library Quarterly*, 33(4), 330-347. doi:10.1080/01616846.2014.970425
- Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in p-12 classrooms. *Journal of Engineering Education*, 97(3), 369-387. doi:10.1002/j.2168-9830.2008.tb00985.x
- Campbell, L. O. & Heller, S. (2019). Building computational thinking: Design and making in teacher education. In Leonard, J., Burrows, A. C., & Kitchen, R. (Eds.), *Recruiting, preparing, and retaining STEM teachers for a global generation* (pp. 163-189). Leiden, The Netherlands: Brill | Sense. [https://doi.org/10.1163/9789004399990\\_007](https://doi.org/10.1163/9789004399990_007)
- Cantrell, P., Young, S., & Moore, A. (2003). Factors affecting science teaching efficacy of preservice elementary teachers. *Journal of Science Teacher Education*, 14(3), 177-192. doi:10.1023/A:1025974417256
- Cross, J., Bartley, C., Hamner, E., & Nourbakhsh, I. (2013). A visual robot-programming environment for multidisciplinary education. In *Robotics and Automation (ICRA)*, 2013 IEEE International Conference on (pp. 445-452). Karlsruhe, Germany: IEEE. doi:10.1109/ICRA.2013.6630613
- Cviko, A., McKenney, S., & Voogt, J. (2014). Teacher roles in designing technology-rich learning activities for early literacy: A cross-case analysis. *Computers & Education*, 72, 68-79.
- Dare, E. A., Ellis, J. A., & Roehrig, G. H. (2018). Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study. *International Journal of STEM Education*, 5(1), 4. doi:10.1186/s40594-018-0101-z
- English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, 3(1), 3. doi:10.1186/s40594-016-0036-1

- Han, S., Yoo, J., Zo, H., & Ciganek, A. P. (2017). Understanding makerspace continuance: A self-determination perspective. *Telematics and Informatics*, 34(4), 184-195. doi:10.1016/j.tele.2017.02.003
- Harvin, A. (2015). Experiences of Students from Traditionally Underrepresented Groups in an Informal STEM Educational Setting and the Effect on Self-Efficacy, Task Value, and Academic Course Selection. In *Society for Information Technology & Teacher Education International Conference* (pp. 33-43). Association for the Advancement of Computing in Education (AACE).
- Hlubinka, M., Dougherty, D., Thomas, P., Chang, S., Hofer, S., Alexander, I., McGuire, D. & Vanderwerff, B. S. (2013). "Makerspace Playbook (School ed.)". Retrieved from <https://makered.org/wp-content/uploads/2014/09/Makerspace-Playbook-Feb-2013.pdf>
- Holzberger, D., Philipp, A., & Kunter, M. (2013). How teachers' self-efficacy is related to instructional quality: A longitudinal analysis. *Journal of Educational Psychology*, 105(3), 774.
- Jaipal-Jamani, K., & Angeli, C. (2017). Effect of robotics on elementary preservice teachers' self-efficacy, science learning, and computational thinking. *Journal of Science Education and Technology*, 26(2), 175-192. doi:10.1007/s10956-016-9663-z
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(11), 2-11. doi:10.1186/s40594-016-0046-z
- Lee, I., Martin, F., Denner, J., Coulter, B., Allan, W., Erickson, J., ... & Werner, L. (2011). Computational thinking for youth in practice. *ACM Inroads*, 2(1), 32-37. doi:10.1145/1929887.1929902
- Lesseig, K., Nelson, T. H., Slavitt, D., & Seidel, R. A. (2016). Supporting middle school teachers' implementation of STEM design challenges. *School Science and Math Semantics*, 116(4), 177-188. doi:10.1111/ssm.12172
- Li, Y. (2014). *International Journal of STEM Education - a platform to promote STEM education and research worldwide*. *IJ STEM Ed* 1(1). doi:10.1186/2196-7822-1-1
- Li, Y., Schoenfeld, A. H., Graesser, A. C., Benson, L. C., English, L. D., & Duschl, R. A. (2019). On thinking and STEM education. *Journal for STEM Education Research*, 2(1), 1-13. doi:10.1186/s40594-019-0197-9
- Lynch, T. L. (2015). Soft (a) ware in the english classroom: Spreadsheets and sinners: How and why english teachers can claim their rightful place in stem education. *The English Journal*, 104(5), 98-101. Liam-Lynch
- Loucks-Horsley, S., Stiles, K. E., Mundry, S., Love, N., & Hewson, P. W. (2009). *Designing professional development for teachers of science and math*. Corwin Press.
- Madden, L., Beyers, J., & O'Brien, S. (2016). The importance of STEM education in the elementary grades: Learning from preservice and novice teachers' perspectives. *Electronic Journal of Science Education*, 20(5), 1-18. Retrieved from <https://eric.ed.gov/?id=EJ1188311>
- Mayer, R. E. (2008). Applying the science of learning: Evidence-based principles for the design of multimedia instruction. *American Psychologist*, 63(8), 760-769. <https://doi.org/10.1037/0003-066x.63.8.760>
- Merrill, C. (2009). The future of TE masters degrees: STEM. *Presentation at the 70th Annual International Technology Education Association Conference*. Louisville, Kentucky: International Technology Education Association.
- Nadelson, L. S. & Seifert, A. L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research*, 110(3), 221-223. doi.org/10.1080/00220671.2017.1289775

- National Academy of Engineering and National Research Council. 2014. STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research. Washington, DC: The National Academies Press.
- National Research Council. (2011). Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and math. Washington, DC: National Academies Press.
- The National Science and Technology Council (NSTC) (2018). Charting a course for success: America's strategy for STEM education. *The Committee on STEM Education (CoSTEM)*. Retrieved from <https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf>
- Ring, E. A., Dare, E. A., Crotty, E. A., & Roehrig, G. H. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education*, 28(5), 444-467. doi:10.1080/1046560X.2017.1356671
- Rosengrant, D., Hensberry, K. K., Vernon-Jackson, S., & Gibson-Dee, K. (2019). Improving STEM education programs through the development of STEM education standards. *Journal of Math Education*, 12(1), 123-140. doi:10.26711/007577152790042
- Shanahan, T. & Shanahan, C. (2008) Teaching disciplinary literacy to adolescents: Rethinking content-area literacy, *Harvard Educational Review*, 78(1), 40-59. doi:10.17763/haer.78.1.v62444321p602101
- Sheffield, R., Koul, R., Blackley, S., & Maynard, N. (2017) Makerspace in STEM for girls: a physical space to develop twenty-first-century skills. *Educational Media International*, 54(2), 148-164. doi:10.1080/09523987.2017.1362812
- Shernoff, D. J., Sinha, S., Bressler, D. M., & Ginsburg, L. (2017). Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. *International Journal of STEM Education*, 4, 1-16.
- Soules, A., Nielson, S., LeDuc, D., Inouye, C., Singley, J., Wildly, E., & Seitz, J. (2014). Embedding multiple literacies into STEM curricula. *College Teaching*, 62(4), 121-128. doi:10.1080/87567555.2014.935699
- Slavit, D., Grace, E., & Lesseig, K. (2019). Stem ways of thinking. In S. Otten, A. G. Candela, Z. de Araujo, C. Haines, & C. Munter, (Eds.). *Proceedings of the Forty-first Annual Meeting of the North American Chapter of the International Group for the Psychology of Math Education* (pp. 793-801). St Louis, MO: University of Missouri.
- Subotnik, R. F., Tai, R. H., Almarode, J., & Crowe, E. (2013). What are the value-added contributions of selective secondary schools of math, science, and technology? Preliminary analyses from a U.S. national research study. *Talent Development & Excellence*, 5, 87-97. Retrieved from <https://d-nb.info/1045250104/34#page=91>
- Stevenson, M., Bower, M., Falloon, G., Forbes, A., & Hatzigianni, M. (2019). By design: Professional learning ecologies to develop primary school teachers' makerspaces pedagogical capabilities. *British Journal of Educational Technology*, 50(3), 1260-1274. doi:10.1111/bjet.12743
- Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33-35. doi:10.1145/1118178.1118215
- Yadav, A., Mayfield, C., Zhou, N., Hambrusch, S., & Korb, J. T. (2014). Computational thinking in elementary and secondary teacher education. *ACM Transactions on Computing Education (TOCE)*, 14(1), 1-16. doi:10.1145/2576872
- Yore, L. (2011) Foundations of scientific, mathematical, and technological Literacies—Common themes and theoretical frameworks. In L. D. Yore, E. van der Flier-Keller, D. W. Blades, T. W. Pelton & D.



B. Zandvliet (Eds.) *Pacific Crystal Centre for Science, Mathematics, and Technology Literacy: Lessons Learned* (pp. 23-46). Rotterdam, Netherlands: Sense Publishers.

Zollman, A. (2012). Learning for STEM literacy: STEM literacy for learning. *School Science and Mathematics, 112*(1), 12-19. doi:10.1111/j.1949-8594.2012.00101.x

### **Authors**

Laurie O. Campbell

Associate Professor

University of Central Florida, College of Community Innovation and Education

Email: [locampbell@ucf.edu](mailto:locampbell@ucf.edu)

Nicole Damico

Associate Professor

University of Central Florida, College of Community Innovation and Education

Email: [nicole.damico@ucf.edu](mailto:nicole.damico@ucf.edu)