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ABSTRACT

STEM education is a useful tool in promoting 21st-century competencies, such as cultural awareness, critical-thinking and problem-solving skills. Having these skills prepares students for a competitive, global marketplace. Teachers play a crucial role in providing quality STEM education, and teachers require high levels of self-efficacy and STEM pedagogical content knowledge to impart quality levels of instruction. We examined the relationship between self-efficacy and STEM pedagogical content knowledge. Results showed higher self-efficacy was related to higher STEM pedagogical content knowledge. Implications are discussed.

Keywords: stem education; preservice teachers; self-efficacy; stem pedagogical content knowledge.

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I. THE SELF-EFFICACY OF PRESERVICE TEACHERS IN STEM PEDAGOGICAL CONTENT KNOWLEDGE

The quality of STEM education is directly related to the knowledge, pedagogy and self-efficacy of the teachers who are responsible for driving instruction. Teachers who have a strong understanding of STEM concepts and pedagogy can effectively engage students in hands-on, inquiry-based learning experiences that promote critical thinking, problem-solving, and creativity. On the other hand, if teachers lack the necessary knowledge and skills, they may struggle to effectively teach STEM subjects, leading to disengagement and limited learning outcomes for their students.

Preservice teachers' content knowledge and self-efficacy are direct indicators of their performance in the future classroom (Cervone et al., 2020; Koutsianou & Emvalotis, 2019; McLean et al., 2019; Nasir et al., 2019). Studies also reveal that teachers spend more time teaching in the content areas where they feel most confident and may even neglect some content altogether due to discomfort (Bybee, 2010). If preservice teachers are not properly prepared to teach STEM as a cohesive unit of 21st-century skills, they may devote less time or omit STEM content altogether.

STEM is a widely used acronym developed for science, technology, engineering, and mathematics (Jong et al., 2021). It is a term utilized from preschool to postgraduate levels to describe related content, higher education majors, and occupations (Marrero et al., 2014). STEM education is critical for the United States to compete in a global marketplace (Dejarnette, 2016; Peterson et al., 2011). The rationale for STEM education is often focused on the need to prepare students to have the required 21st-century skills necessary for economic security, environmental impacts, and competitiveness in a global marketplace (Du Plessis, 2020; Koehler et al., 2013). STEM education prepares students to be "actively engaged citizens of society" in the future (Du Plessis, 2020, p.1466). Issues such as national security, disease, climate change, and energy efficiency need STEM competent citizens to innovate potential solutions (Du Plessis, 2020). In essence, students need strategies and skills to solve problems that may not currently even exist (Barrett-Zahn, 2019).

Teachers require STEM-related skills and knowledge to provide effective STEM instruction (Yildirim & Şahin-Topalcengiz, 2018, p.4). Quality STEM education and instruction prioritizes hands-on, real-world, and authentic experiences for genuine problem-solving opportunities for students (Siekmann, 2016). To engage students in STEM education, schools require programs that integrate engineering and technology into the curriculum of mathematics and science (Kennedy & Odell, 2014). Focusing on inquiry, design, and innovation utilizing technology is another example of quality STEM instruction (Kennedy & Odell, 2014). Teachers must also recognize and celebrate the accomplishments of their students in STEM (Yildirim & Şahin-Topalcengiz, 2018).

In order for teachers to be able to produce and deliver this type of curriculum, teacher preparation programs need to include a solid foundation of teaching STEM in the classroom (Dejarnette, 2016). There is a plethora of information regarding STEM careers, the lack of diversity in STEM fields (including college majors and occupations), and how/why STEM education is vital to remain competitive in a global economy (Hutton, 2019; Perna et al., 2010). Teachers' instructional practices play a crucial role in addressing these needs by helping students learn in STEM classes and develop their aspirations to pursue STEM careers (Guzey et al., 2014).

However, teachers commonly use the pedagogical methods they are most comfortable with, and these may not be aligned with best practice for teaching STEM. Further, teachers tend to spend less time teaching content that they do not feel they know well, which contributes to teachers spending less time teaching students STEM in the classroom (Sterling, 2006). A lack of knowledge in STEM content and best practices for teaching STEM adversely affects teachers' self-efficacy when providing STEM instruction (Epstein & Miller, 2011).

II. SELF-EFFICACY AND TEACHING

Preservice teachers must believe in their abilities to teach successfully in the classroom (Michael et al., 2020; Yildiz & Arici, 2021). Self-efficacy directly correlates to the learning environment they will provide their students (Koutsianou & Emvalotis, 2019; Pearman et al., 2021). Teachers with higher levels of self-efficacy have been shown to utilize more teaching strategies, display stronger classroom management skills and create opportunities for student-centered learning (Jamil et al., 2012; Kaygısız et al., 2020; Nasir & Iqbal, 2019). Teachers with high self-efficacy are more flexible in their instruction, open to new ideas and strategies, and display higher motivation levels (Chen et al., 2021; Masri et al., 2021; Michael et al., 2020; Pearman et al., 2021). Educators with higher self-efficacy are more likely to approach problems as challenges to conquer and new information to be attained (Salar, 2021).

As teacher self-efficacy increases, so does their beliefs in their students' abilities (Pearman et al., 2021). Yildiz and Arici (2021) acknowledge teachers' self-efficacy directly correlates to their student's self-efficacy. When teachers with high levels of self-efficacy believe in their students, student achievement and even student self-efficacy increases (Michael et al., 2020; Moawad & Corkett, 2021). Research has shown that a teacher's self-efficacy determines the amount of time spent teaching a subject, therefore, how much time a student is allotted to learn a topic (Chen et al., 2021). Students of teachers with high self-efficacy tend to have higher levels of motivation, engagement and display appropriate classroom behavior (McLean et al., 2019). Students with high self-efficacy teachers also benefit from lower anxiety levels and stronger problem-solving skills (Jamil et al., 2012).

In contrast, teachers with lower self-efficacy tend to teach with more teacher-centered strategies, such as reading from a textbook and having students fill in worksheets (Kaygısız et al., 2020).

In teacher-centered instruction students are passive while the teacher is active. Lectures, note taking, and students sitting quietly at their desks is much of a teacher-centered approach to education. The teacher is the authority figure, students are submissive, and there is no collaboration. Educators with lower self-efficacy may also experience more self-doubt and have a limited ability to persevere through challenges (Salar, 2021). McLean et al. (2019) found a relationship between teacher self-efficacy and teacher burnout that may impact teacher perception of student behavior.

III. SELF-EFFICACY IN STEM TEACHERS

Research on teachers regarding their beliefs, attitudes and efficacy around teaching STEM show that they find value in STEM education and are more likely to have interest in teaching STEM and to learn more about teaching STEM when they have high self-efficacy. In a study of K-12 engineering and technology teachers, Asunda and Walker (2018) found K-12 teachers had mixed reactions to STEM education but acknowledged its importance. Some teachers reported high levels of self-efficacy, while others reported difficulty assessing students in STEM education and problem-based learning. Teachers articulated they had limited knowledge on how to teach STEM effectively. Positive attitudes toward STEM is important as it is related to an increase in explicit instruction of the integrated STEM approach and participation in authentic STEM activities (Çetin, 2021).

Other research has demonstrated that when teachers have an interest in and experience with STEM activities they have greater self-efficacy (Çetin, 2021; Chen et. al, 2021; Salar, 2021). Teachers with higher self-efficacy also tend to be those who are interested in more training around STEM. Chen et al. (2021) showed that preservice preschool teachers' STEM self-efficacy was positively correlated to their pedagogical beliefs and desire for further STEM learning or professional development (PD). Engaging in PD around STEM may further increase teacher self-efficacy. For example, Nathan et al. (2011) found that after PD in integrated STEM education, teachers' self-efficacy for teaching STEM significantly increased.

PD is often focused on teaching both content and pedagogy. In STEM this is referred to as STEM pedagogical content knowledge (STEMPCK). Although the literature has shown that increased PD leads to higher teacher self-efficacy and this in turn is related to more interest in STEM, it is unclear if higher self-efficacy is related to STEMPCK. Feeling more confident in one's ability to teach STEM is certainly important, however if this confidence is without strong knowledge in both STEM content and pedagogy, it may have unintended detrimental effects such as not preparing students in the way that they need to be. This study examines the relationship between preservice teachers' self-efficacy and STEMPCK.

IV. METHODS

4.1 Participants

Preservice teachers enrolled in teacher preparation programs in the United States were the target population for this study. A total of N=64 preservice teachers participated. The survey participants were primarily between the ages of 18-24 (97%), female (92%) and most identified as White (84%). The participants reported being enrolled in a range of teacher preparation programs including Educational Studies, Middle Grades 4-8, Middle Grades 4-8 dual Pre-K-12 Special Education, Music Education K-12, Pre-K-4 Early Grades, Pre-K-4 Early Grades dual Pre-K-12 Special Education, and Pre-K-12 Special Education and Secondary Education. The majority (56%) were enrolled in a Pre-K-4 Early Grades teacher preparation program.

4.2 Instrumentation

The STEM Pedagogical Content Knowledge Scale (STEMPCK Scale; Yildirim & Şahin-Topalcengiz, 2018) was used to rate preservice teacher's knowledge of STEM content and pedagogy. The STEMPCK scale consists of 56 items that are rated on a 5-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree. The STEMPCK scale provides an overall score as well as six subscale scores: pedagogical knowledge (PK), science, technology, engineering, mathematics, and 21st-century skills. Acceptable reliability for the overall scale and subscales have been shown to range from α=.78 to α=.95 (Yildirim & Şahin-Topalcengiz, 2018).

Schwarzer & Jerusalem's (1995) Generalized Self-Efficacy Scale was used to measure preservice teachers' self-efficacy around teaching. The scale has 10 items rated on a 4-point Likert scale anchored at 1=Not at All to 4=Completely True. Data from participants in 23 countries has demonstrated that the scaled is unidimensional and reliability with Cronbach alpha ranging from α=.76 to α=.90 (Schwarzer & Jerusalem, 1995).

4.3 Procedures

All procedures were approved by the Institutional Review Board at the authors' university. Student were recruited from four universities in Southeastern Pennsylvania in the United States. One of the schools is a public university, while the other three are private, religiously affiliated higher education institutions. A faculty or staff member at each college and university distributed an email invitation to their students enrolled in teacher preparation programs. If interested, students used a link provided in the email to access both the consent form and the surveys used in this study. As such, all data was collected electronically and the identity of all participants was anonymous.

V. RESULTS

Table 1. shows preservice teachers' average scores on the STEMPCK scale. The overall score was *M*=3.76 showing general agreement across items on the scale. The subscale average scores were highest for pedagogical knowledge (PK, *M*=4.26) and 21st century skills (*M*=4.43). Preservice teachers also had average scores in the agreeable range for the mathematics subscale (*M*=3.73) and technology subscale (*M*=3.62). The average scores for science (*M*=2.93) and engineering (*M*=2.90) were both in the disagreeable range.

Table 1: Descriptive Statistics for STEMPCK scale and subscales

	Mean	SD	Minimum	Maximum
STEMPCK	3.76	0.43	2.84	4.57
PK	4.26	0.40	3.25	5.00
Science	2.93	0.78	1.22	4.44
Technology	3.62	0.75	1.71	5.00
Engineering	2.90	0.71	1.57	5.00
Mathematics	3.73	0.78	2.00	5.00
21st-Century	4.43	0.40	3.57	5.00

Preservice teachers had an average self-efficacy score of *M*=3.27(0.27) and this was significantly correlated with overall their scores on the STEMPCK scale. There was a moderate, positive, and statistically significant correlation, *r*=.46, *p*<.001. As STEM pedagogical content knowledge increased, self-efficacy also increased in this sample of preservice teachers.

Table 2 shows the correlations between self-efficacy and the six subscales of the STEMPCK Scale. Self-efficacy was strongly and significantly correlated with each subscale (*ps*<.05) except for engineering and mathematics (*p*=.18). The strongest correlations existed between self-efficacy and PK knowledge (*r*=.50) and 21st century skills (*r*=48). Moderate positive correlations existed between self-efficacy and science (*r*=.33) as well as self-efficacy and technology (*r*=.33). However, the correlations with self-efficacy were weaker for engineering (*r*=.16) and mathematics (*r*=.23).

Table 2: Research Question 3 – STEMPCK and Self-efficacy Correlation of Subscales

1. PK	Pearson's *r*	—						
	p-value	—						
2. Science	Pearson's *r*	0.45	—					
	p-value	< .001	—					
3. Technology	Pearson's *r*	0.34	0.35	—				
	p-value	0.006	0.004	—				
4. Engineering	Pearson's *r*	0.28	0.63	0.46	—			
	p-value	0.02	< .001	< .001	—			
5. Mathematics	Pearson's *r*	0.28	0.57	0.37	0.55	—		
	p-value	0.02	< .001	0.002	< .001	—		
6. 21st-Century	Pearson's *r*	0.59	0.32	0.35	0.31	0.28	—	
	p-value	< .001	0.008	0.004	0.01	0.02	—	
7. Self-Efficacy	Pearson's *r*	0.50	0.33	0.33	0.16	0.23	0.48	—
	p-value	< .001	0.006	0.008	0.18	0.06	< .001	—

Correlations between Self-Efficacy and STEMPCK Subscales (N=64)

VI. DISCUSSION

If students are to remain in the proverbial STEM pipeline and gain essential 21st-century skills, they must be properly prepared. Students require teachers with passion, drive, and high levels of self-efficacy. Teacher self-efficacy is a direct indicator of student achievement, and teachers' own experience with subjects like science and mathematics can determine the amount of time spent on that content (Thomson et al., 2018). Teachers with high levels of self-efficacy are more likely to try different instructional strategies and provide opportunities for authentic hands-on student-centered learning (Cheung et al., 2019). The need for professional development in schools demonstrates that teachers are not coming into the classroom prepared to integrate STEM as a tool to promote 21st-century competencies (Nowikowski, 2017).

Preservice teachers with high levels of self-efficacy are more successful in the classroom (Michael et al.,2020). Motivation, flexibility, and adaptability are also characteristics of teachers with high levels of self-efficacy (Chen et al., 2020; Masri et al., 2021). Pearman et al. (2021) found that as teachers' self-efficacy increases, so does their beliefs in their students' abilities, and, in turn, if teachers believe in their students' abilities, student achievement and student self-efficacy also increase (Moawad & Corkett, 2021).

Overall, the preservice teachers in this study reported high self-efficacy, which is encouraging given that higher self-efficacy is related to positive outcomes. The purpose of this study was to examine if self-efficacy was related to STEMPCK. The results showed this to be the case. As preservice teachers' STEMPCK knowledge increases, their self-efficacy also increases. Prior research has shown that teachers' with higher self-efficacy are more motivated to teach STEM, however there was a gap in understanding whether they were also prepared to teach STEM. The results of this study show that preservice teachers with higher self-efficacy were also well prepared to teach STEM as higher scores in self-efficacy were related to higher scores of pedagogical knowledge, science, technology and 21st century skills.

These findings are not without limitations. The data came from one geographical location, which limits generalizability. The study also did not include a measure of preservice teachers' motivation for teaching STEM. Future research could replicate this study in other locations and include measures of preservice teachers' motivation for teaching STEM. By including measures of motivation with a larger sample, analysis could examine the path of the relationships between all three variables.

VII. CONCLUSION

This study has found that the more STEM pedagogical content knowledge preservice teachers have, the higher their self-efficacy. These results are encouraging as preservice teachers will be preparing students to solve ongoing problems including the need for renewable energy, growing national security as technology advances, and continuing to combat disease in an increasing human population.

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