

RESEARCH ARTICLE

Spatial thinking in science, technology, engineering, and mathematics: Elementary teachers' beliefs, perceptions, and self-efficacy

Kristin Michod Gagnier¹  | Steven J. Holochwost² |
Kelly R. Fisher¹

¹Science of Learning Institute Johns Hopkins University, Baltimore, Maryland, USA

²Palmer Wolf and City University of New York, Bronx, New York, USA

Correspondence

Kristin Michod Gagnier, Science of Learning Institute Johns Hopkins University, 3400 N. Charles Street, Baltimore, MD 21218, USA.
Email: kristin.gagnier@jhu.edu

Funding information

Institute of Education Sciences, Grant/Award Number: R305A170411

Abstract

Fostering students' spatial thinking skills holds great promise for improving Science, Technology, Engineering, and Mathematics (STEM) education. Recent efforts have focused on the development of classroom interventions to build students' spatial skills, yet these interventions will be implemented by teachers, and their beliefs and perceptions about spatial thinking influence the effectiveness of such interventions. However, our understanding of elementary school teachers' beliefs and perceptions around spatial thinking and STEM is in its infancy. Thus, we created novel measures to survey elementary teachers' anxiety in solving spatial problems, beliefs in the importance of spatial thinking skills for students' academic success, and self-efficacy in cultivating students' spatial skills during science instruction. All measures exhibited high internal consistency and showed that elementary teachers experience low anxiety when solving spatial problems and feel strongly that their skills can improve with practice. Teachers were able to identify educational problems that rely on spatial problem-solving and believed that spatial skills are more important for older compared to younger students.

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

© 2021 The Authors. *Journal of Research in Science Teaching* published by Wiley Periodicals LLC on behalf of National Association for Research in Science Teaching.

Despite reporting high efficacy in their general teaching and science teaching, teachers reported significantly lower efficacy in their capacities to cultivate students' spatial skills during science instruction. Results were fairly consistent across teacher characteristics (e.g., years of experience and teaching role as generalist or specialist) with the exception that only years of teaching *science* was related to teachers' efficacy in cultivating students' spatial thinking skills during science instruction. Results are discussed within the broader context of teacher beliefs, self-efficacy, and implications for professional development research.

KEYWORDS

professional development, self-efficacy, spatial thinking, STEM education, teacher beliefs

1 | INTRODUCTION

Innovations in Science, Technology, Engineering, and Mathematics (STEM) are a cornerstone of the United States' economic prosperity, yet national and international assessments paint a poor picture of students' STEM competencies. For example, only 38% of 4th graders reach proficiency levels in science and this rate drops to 22% in 12th grade (National Assessment of Educational Progress, 2015). International assessments reflect the same patterns (OECD, 2018); just 9% of 15-year-old students in 2018 showcased high scientific literacy—the capacity to effectively analyze complex information, synthesize, and evaluate evidence, and reason from various sources (NCES, 2020, <https://nces.ed.gov/surveys/pisa/pisa2018/index.asp#/science/intlcompare>). Data such as these have motivated transformative approaches to improve STEM education including research-informed science and mathematics standards (e.g., The Next Generation Science Standards; National Research Council, 2012; and Common Core State Standards) and recommendations to maximize science and mathematics teachers' instructional effectiveness (NAS, 2015; Stigler & Hiebert, 2004).

One area that holds particular promise for improving STEM education is *spatial thinking* (Newcombe, 2010). Over 60 years of longitudinal research has suggested that spatial thinking skills are essential to success in STEM (Shea et al., 2001; Wai et al., 2009) and a growing body of intervention work has shown that improving students' spatial thinking skills improves STEM outcomes (Cheng & Mix, 2014; Gagnier et al., 2017; Lowrie et al., 2017; Miller & Halpern, 2013; Small & Morton, 1983; Sorby et al., 2013). These findings have led to efforts to infuse spatial thinking into classroom-based interventions (Burte et al., 2017; Davatzes et al., 2018; Gagnier & Fisher, 2020; Resnick et al., 2017; Taylor & Hutton, 2013). While such efforts focus on students' skills, teachers are the key drivers of intervention effectiveness, and their beliefs (e.g. self-efficacy) and feelings (e.g. anxiety) can influence intervention fidelity (Cantrell et al., 2013; Klimes-Dougan et al., 2009) and student motivation and achievement (Anderson et al., 1988; Beilock et al., 2010; Canning et al., 2019; Lumpe et al., 2012).

In order to develop effective classroom interventions to foster students' spatial skills, we must understand teachers' spatial thinking beliefs, perceptions, and feelings. In this article, we report the first attempt to probe elementary teachers' perceptions of their own spatial skills, beliefs about the importance of these skills for solving STEM problems and academic success, and self-efficacy in cultivating students' spatial skills during classroom instruction in science. This work will directly inform our understanding of teachers' beliefs and lead to actionable recommendations for teacher training to support the development, implementation, and evaluation of spatial interventions in the classroom. In the following sections we describe research linking spatial thinking to success in STEM fields, the promise of training spatial skills for improving STEM education, and the role that teachers' beliefs (e.g., self-efficacy), perceptions, and feelings (e.g. anxiety) play in the success of educational interventions, and why understanding teachers' spatial thinking beliefs, perceptions, and feelings are central to ensuring the effectiveness of interventions aimed at building students' spatial thinking skill.

1.1 | Spatial thinking is critical for STEM success

Spatial thinking encompasses a collection of cognitive skills that allow us to organize, reason about, and mentally manipulate spaces that are both real and imagined. These include reasoning about the shape, size, orientation, direction, and trajectory of objects, the relations among objects, mentally visualizing objects and/or these relations, and reasoning about the objects and their relations over space and time (NRC, 2006). Spatial thinking skills are critical in daily life as we search for specific locations (e.g., where is the movie theater in relation to the supermarket), use representation of space such as navigating with a map or assembling furniture from a diagram, or imagine what our living room furniture might look like in an alternative arrangement.

Spatial thinking skills are also essential for success in STEM. Longitudinal research over the last 60 years suggests that spatial skills predict students' entrance into, retention in, and success within STEM fields (Shea et al., 2001; Wai et al., 2009). A seminal study, Project Talent, measured the spatial thinking skills of a nationally representative sample of 400,000 high school students in the 1960s and followed them for 11 years postgraduation. Students' spatial skills were measured in tests that asked students to imagine folding a two-dimensional shape into a three-dimensional one, mentally rotate two-dimensional shapes in their head, and reason about mechanical gears (see Newcombe, 2010 for examples). Results showed that 11 years later, students who had performed well on these measures of spatial thinking were more likely to have selected STEM college majors, succeed in those majors, and pursued STEM careers, compared to their peers who had performed less well on these measures. This was true even after controlling for students' mathematical and verbal skills. Other longitudinal studies, in which students' spatial skills were assessed in middle school and followed for 20 years (Shea et al., 2001), or in preschool and followed through high school (Wolfgang et al., 2003), show similar findings; spatial skills are unique and independent predictors of success in STEM fields.

There is also ample experimental evidence that spatial thinking underlies students' comprehension of and reasoning about scientific phenomena (Gagnier et al., 2017; Jee et al., 2013; Kozhevnikov et al., 2007; Miller & Halpern, 2013; Mix, 2019; Rudmann, 2002; Sanchez, 2012; Shipley et al., 2013; Small & Morton, 1983; Sorby, 2001; Stieff, 2011; Verdine et al., 2017). In order for students to solve scientific problems, they must be able to understand and reason about the spatial properties of objects (e.g., location, size, and volume). They must also use visualizations (e.g., maps, graphs, and diagrams) to understand and reason about spatial relations

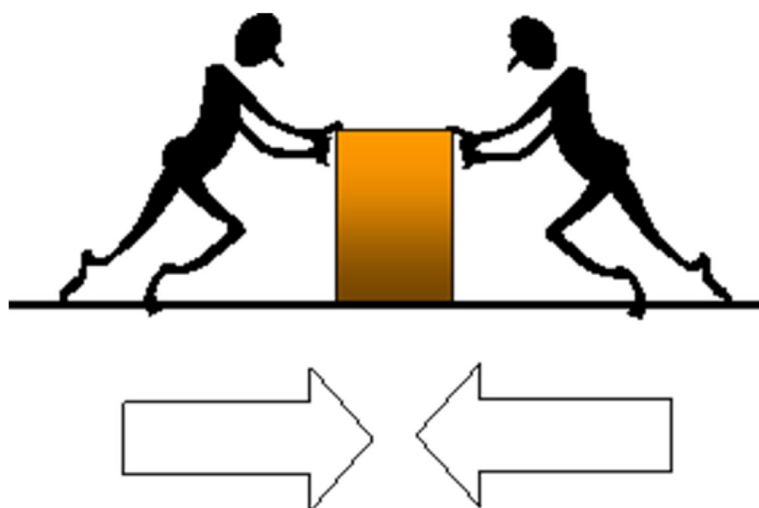


FIGURE 1 A diagram illustrating why a balanced force is an object at rest. The arrows' size and direction indicate the strength and direction of the force being applied to the box. Image credit: <https://quizizz.com/Balanced & Unbalanced Forces/Newton's Laws>

that are often unable to be directly observed (e.g., molecules, tectonic plates, and forces). For instance, the Next Generation Science Standards require students to use diagrams, such as Figure 1, to understand forces and predict how changes in forces can influence the motion of an object. To use the diagram in Figure 1, a student must (1) relate the lines in the diagram to 3D objects, (2) understand that the size and direction of the arrows indicate the force being applied to the object, (3) reason about how these elements interact with one another, and (4) visualize and predict how changes to the forces will affect the object's movement.

While often assumed to be innate, spatial skills are malleable. A recent meta-analysis showed that spatial thinking skills can be improved through training with long-lasting and generalizable benefits (Uttal et al., 2013). Spatial training improves performance in many populations including high achievers (Miller & Halpern, 2013) as well as across students of varying academic ability (Terlecki et al., 2008), and these benefits occur for men and women (see Uttal et al., 2013). A variety of experiences can improve skills including formal practice, coursework in spatially-rich disciplines such as engineering drafting, and playing spatially-intensive videogames. Critically, for those interested in advancing STEM education, an emerging body of research has shown that training spatial skills leads to improvements in STEM outcomes. Compared to control groups who receive nonspatial training, students who receive spatial training show significant improvements on pre- to post-test measures of knowledge and skills in chemistry (Small & Morton, 1983), engineering (Sorby, 2001, 2009), elementary and middle school math (Cheng & Mix, 2014; Lowrie et al., 2017), calculus (Sorby et al., 2013), physics (Miller & Halpern, 2013), and geoscience (Gagnier et al., 2017; Sanchez, 2012). For example, Cheng and Mix (2014) gave 6–8-year-olds a pre- and postmeasure of mathematical skill. In between, half of the students received training on crossword puzzles (nonspatial training) and the other half received training on mentally imagining rotating objects (spatial training). Only the students who received spatial training showed significant improvement in their mathematical skill post-test.

Together, these findings suggest that training spatial skills is a promising avenue to improve STEM learning and have led to calls to leverage spatial thinking research in the classroom

(e.g., Cognitive Research Principles and Implications Spatial is Special, Special Edition; Gagnier & Fisher, 2020; Hegarty, 2014; Newcombe, 2010, 2013, 2017; Newcombe & Frick, 2010; Uttal & Cohen, 2012; Uttal et al., 2013; Wai & Uttal, 2018). These recent efforts have focused on the development of classroom-based interventions aimed at improving STEM learning by building students' spatial skills (Burte et al., 2017; Lowrie et al., 2017; Taylor & Hutton, 2013). For example, Burte et al. (2017) trained teachers to lead a 6-week classroom intervention that included origami and pop-up paper engineering activities to build elementary students' spatial thinking and mathematical skills. Similarly, Lowrie et al. (2017) taught five middle school math teachers about spatial thinking research and asked them to design and implement 20 lesson plans to build students' spatial skills. Gagnier and Fisher (2020) outline a curriculum development project in which a team of cognitive and developmental scientists, science education experts, and curriculum developers are creating a spatially-enhanced curriculum for 3rd grade students, which will be implemented by 3rd grade teachers.

1.2 | Teacher beliefs, perceptions, and feelings influence their practices and student outcomes

As these previous examples illustrate, classroom-based interventions aimed at building students' spatial skills will be implemented by *teachers* (see also Gagnier & Fisher, 2020). Yet, the success of such interventions will be dependent on teachers' beliefs, perceptions, and feelings. Theoretical frameworks within educational, cognitive, and social psychology posit that teachers' knowledge, beliefs, and attitudes influence their classroom practices and professional activities, which in turn influence the classroom environment, and student interest and learning (see Fang, 1996; Kagan, 1992; Nespor, 1987; OECD, 2009). For example, it is well-recognized that teacher characteristics (e.g., years of experience; Wayne & Youngs, 2003) beliefs, perceptions, and feelings shape their classroom practices (Charlesworth et al., 1991; Hyson et al., 1990), fidelity of program implementation (Cantrell & Hughes, 2008; Cantrell et al., 2013; Durlak & DuPre, 2008; Klimes-Dougan et al., 2009), and student interest, motivation, self-confidence, and achievement (Beilock et al., 2010; Canning et al., 2019; Ertmer et al., 2012; Stipek et al., 2001; Upadyaya & Eccles, 2014).

One of the most well-studied teacher beliefs is teaching self-efficacy. Derived from Bandura's (1997) social cognitive theory, teacher self-efficacy, or teaching efficacy, is a teacher's belief in his or her capacity to promote students' learning (Hoy, 2000) and successfully cope with tasks, obligations, and challenges related to his/her professional role (Caprara et al., 2006). Self-efficacy has emerged as a critical mechanism influencing teachers' behaviors and student learning (Burley et al., 1991; Glickman & Tamashiro, 1982; Klassen et al., 2011; Klassen & Tze, 2014; Meijer & Foster, 1988; Soodak & Podell, 1993). Teaching efficacy is positively related to the classroom use of effective teaching strategies (Guskey, 1988; Ross, 1994; Woolfolk Hoy & Burke-Spero, 2005), openness to novel teaching methods (Berman et al., 1977; Guskey, 1988; Stein & Wang, 1988), effective classroom management (Tsoloupas et al., 2010), high levels of planning and organization (Allinder, 1994), and greater teacher well-being and job satisfaction (Betoret, 2006; Egyed & Short, 2006; Klassen et al., 2009; Skaalvik & Skaalvik, 2007; Smylie, 1988; Tschannen-Moran & Hoy, 2001). Teachers' self-efficacy is also related to student motivation, self-efficacy, and achievement (Anderson et al., 1988; Armor et al., 1976; Ashton & Webb, 1986; Caprara et al., 2006; Goddard et al., 2000; Kim & Seo, 2018; Klassen & Tze, 2014; Midgley et al., 1989; Mojavezi & Tamiz, 2012; Moore & Esselman, 1992; Ross, 1992; Tschannen-Moran & Barr, 2004).

Teacher efficacy is critical to the discussion of how teacher beliefs might impact the implementation of programs designed to develop students' spatial thinking, as teaching self-efficacy influences the degree to which an educational program is implemented as intended. For example, Cantrell and Hughes (2008) found that personal teaching efficacy was related to the implementation of content-focused literacy practices at the beginning of the year, suggesting that teachers with high efficacy implement programs with greater fidelity. Implementation fidelity is a critical component of developing and maintaining effective programs (Carroll, Patterson, Wood, Booth, Rick, & Balain, 2007; O'Donnell, 2008), as an intervention must be implemented with high fidelity to achieve optimal effectiveness. In a thorough review of factors that affect implementation fidelity of programs, Durlak and DuPre (2008) noted four characteristics (beliefs and skills) of program implementers that influenced their fidelity of implementation, and self-efficacy was chief among them. Program implementers who feel more confident in their capacity to do what is expected (i.e., have higher self-efficacy), are more likely to have greater implementation fidelity of programs. Other characteristics that supported greater implementation fidelity included those who recognize the importance of the intervention, those who believe the intervention will be successful, and those who have the required skills and knowledge to successfully implement the program.

Beyond self-efficacy, teachers' feelings and emotional states can also influence their behaviors and student achievement. For example, anxiety about a domain (e.g., math) can influence teacher practices and student achievement (Bates et al., 2011; Beilock et al., 2010). Beilock et al. (2010) found that the more math-anxious a female first and second grade teacher, the more likely her female students are to endorse math stereotypes and the lower their math achievement at the end of the year. Gunderson et al. (2013) extended this finding to the domain of spatial thinking; first and 2nd grade teachers with higher spatial anxiety¹ had students who performed less well on a measure of spatial thinking than low anxious teachers. The causal mechanism(s) that accounts for the effects of teacher anxiety on student achievement remains unknown; however, Gunderson et al. (2013) offer several possible hypotheses. They note that as spatial skill is not an academic content area (and thus, is not formally present in the curricula) teachers with high spatial anxiety may avoid introducing spatial activities in the classroom, thus limiting students' opportunities to engage in spatial thinking and subsequently decreasing spatial learning (see also Levine et al., 2012). Additionally, teachers with high spatial anxiety may select less effective spatial activities or implement them less effectively than teachers with low spatial anxiety. Finally, teachers with higher spatial anxiety may be less supportive of students who engage in spatial thinking (e.g., diagramming a math word problem to find the solution), which will again limit students' opportunities to practice spatial thinking in the classroom.

As these hypotheses illustrate, supporting students' spatial skills in the classroom likely relies on teachers' comfort with spatial thinking and self-efficacy in implementing effective spatial practices. Yet, we know virtually nothing about teachers' self-efficacy with regards to cultivating students' spatial skills in the classroom or their beliefs and perceptions about spatial thinking in STEM. Recent evidence, however, suggests a need to build elementary teachers' capacities. Using a nationally representative sample, Atit et al. (2018) examined the spatial skill of high school students who later became teachers. The results showed that high school students who went on to teach preschool and primary grades had below-average spatial skills compared to the college graduate population (by almost 0.6 standard deviations).

While this finding illustrates the opportunity to build elementary teachers' spatial skills, it does not provide an understanding of teachers' beliefs and perceptions regarding these skills. To our knowledge, only one study has examined teachers' beliefs about spatial thinking in a STEM

domain, and it focused on mathematics. Burte et al. (2020) surveyed kindergarten through 6th grade teachers' attitudes about mathematics and spatial thinking, anxiety about teaching mathematics, and their spatial anxiety.² They found that teachers with lower spatial anxiety were more likely to have lower anxiety about teaching math, greater efficacy in teaching math, and math beliefs that were aligned with research on how children learn math. This study revealed connections between elementary school teachers' beliefs about spatial thinking and mathematics and raises additional questions regarding whether these relations extend to other domains, such as science, and whether teachers believe that spatial thinking is important for STEM success and that their own skills can improve with training.

1.3 | The current study

In this article, we sought to further understand elementary teachers' feelings, beliefs, and perceptions about spatial thinking and STEM. Our specific research questions and selected measures to answer them were motivated by frameworks and findings that link teacher beliefs, perceptions, and feelings and with teacher practices and student outcomes. Drawing upon Bandura's social cognitive framework (Bandura, 1997), which posits that teachers are strongly influenced by their beliefs about whether they can impact student learning and that these beliefs directly relate to their persistence, effort, and practices in the classroom, we were specifically interested in understanding three questions:

1. *How anxious and confident are elementary school teachers when solving spatial problems and do they believe their spatial skills can improve with training?* Drawing upon the inverse relationship between teacher anxiety and student achievement (Bates et al., 2011; Beilock et al., 2010; Gunderson et al., 2013), we reasoned that if teachers are anxious about spatial problem-solving, this might influence their successful implementation of spatial programs and practices. However, previous work in this area (Gunderson et al., 2013) measured teachers' spatial anxiety in situations that were primarily navigation-focused and thus may not be directly tapping into the types of spatial skills that teachers will encounter and/or use when teaching science. Here, we focused on teachers' anxiety solving spatial problems that have been linked to performance in STEM (see Uttal & Cohen, 2012) and extended this work to examine the degree to which teachers feel their skills can improve with training. Understanding teachers' spatial anxiety has direct implications for teacher training programs regarding how to implement spatial thinking activities and programs in the classroom.
2. *How important do elementary school teachers believe spatial skills are for solving STEM problems and do they perceive spatial skills are equally important for students of all ages?* Durlak and DuPre (2008) reported that program implementation is influenced by the degree to which implementers feel the intervention is important, thus, we surveyed teachers' beliefs about how important spatial thinking is for academic problem-solving and a student's academic career at various ages. Understanding how important teachers feel these skills are for solving STEM and non-STEM problems at various ages will contribute to our understanding of teacher beliefs more broadly and has direct implications for training teachers in how to implement spatial thinking practices in their classroom.
3. *How well do elementary school teachers feel they can cultivate students' spatial skills during science instruction and how does this relate to their science teaching and general teaching self-efficacy?* This question was motivated by the extensive literature linking teaching efficacy to

teacher behaviors, implementation fidelity, and student outcomes. We focused on spatial thinking self-efficacy during *science* instruction because science is undervalued in elementary school. For example, science instruction often receives less attention in elementary school than instruction in mathematics and literacy (McCutcheon, 1980; Spillane et al., 2001; Stake et al., 1978). Additionally, elementary school teachers often report less positive experiences with science and low confidence teaching it (Czerniak & Chiarelott, 1990; Gustafson & Rowell, 1995). If teachers feel less capable in developing students' spatial skills during science instruction, this suggests targeted professional development opportunities are necessary to support teachers' use of spatial practices in their classroom.

There are, however, no extant measures to probe our three research questions. Therefore, the work presented here had three goals. First, we sought to develop such measures and examine their psychometric properties. Second, we aimed to describe teachers' feelings, beliefs, and perceptions related to spatial thinking in STEM and self-efficacy in cultivating students' spatial skills during science instruction. Third, we examined similarities and differences in beliefs, feelings, and perceptions based on teacher characteristics (such as years of experience teaching and discipline taught (e.g., a generalist teaching all subjects or a specialist teaching math and science). Finally, we explored the relations between general and science teaching self-efficacy, and teachers' self-efficacy in cultivating students' spatial thinking skills during science instruction. These questions will further our understanding of elementary teachers' beliefs and perceptions and yield novel insights to guide the development of targeted teacher training programs and interventions to leverage spatial thinking to support STEM learning.

2 | METHODS

2.1 | Participants

One hundred and four 2nd, 4th, and 5th grade teachers participated. Teachers were drawn from a large, urban district outside of Washington, DC, and were recruited through emails from school principals. Most teachers identified as female (84.6%) and the plurality identified as African American/Black (44.2%), though a substantial portion identified as White (32.7%). The largest proportion of teachers were between 30 and 39 years old (28.8%), with substantial proportions between 20 and 29 (24.0%) or 40 and 49 (22.5%). See Table 1 for additional information

TABLE 1 Demographic composition of the sample

Race/ethnicity	Frequency	Percent	Age	Frequency	Percent
African American/Black	46	44.2%	Under 25 years	2	1.9%
Hispanic/Latinx	4	3.8%	Between 25 and 29	25	24.0%
White	34	32.7%	Between 30 and 39	30	28.8%
Asian/Pacific Islander	10	9.6%	Between 40 and 49	23	22.1%
Multiracial	5	4.8%	Between 50 and 59	17	16.3%
Other	2	1.9%	Over 60	5	4.8%
Did not Report	3	2.9%	Did not report	2	1.9%

about the sample's demographic composition; 25.3% of our sample taught 2nd grade, 34.1% taught 4th grade, and 40.7% taught 5th grade.³ Over half of teachers (57.7%) reported that their highest degree in the field of education was a master's degree, and on average teachers had 11.8 years of experience ($SD = 8.53$ years), though the amount of experience ranged widely from 1 to 34 years. Experience in teaching science also varied widely (from 0 to 33 years), with teachers reporting 8.06 years' experience on average ($SD = 6.91$). Approximately half of teachers (53.8%) reported that they worked in a Title I school (meaning that at least 40% of children come from low-income families), and more than half (56.7%) indicated that there were specialists, rather than generalists. Of the specialists, 44.1% taught math and 94.9% taught science.

2.2 | Procedure and measures

All 2nd, 4th, and 5th grade teachers in the district were recruited for and eligible to participate in the study. They received an email with a link to participate. All surveys were completed online using SurveyMonkey and the survey in total took approximately an hour to complete. When participants logged into the platform, they first completed a consent form which informed them of the purpose of the study, procedures, risks and discomforts, benefits of the study, that their participation was voluntary and they may stop at any time, that all documents and materials will be kept confidential, and the compensation they would receive for their participation. Participants who completed all surveys received a 40-dollar gift card.

Following the consent form, participants read a paragraph informing them that the surveys contained a series of questions that probed their beliefs and opinions about teaching, their students, their problem-solving skills, and their classroom. They were assured there were no right or wrong answers and that we were interested in their beliefs, perceptions, and feelings. Participants then proceeded to complete the survey, which consisted of the following six surveys. Each survey had its own set of instructions which informed the participant of the specific details, instructions, and rating scale used. All participants completed the following surveys in the following order:

Teachers' Sense of Efficacy Scale Short Form (TSES; Tschannen-Moran & Hoy, 2001): This reliable and valid 12-item survey probes teachers' efficacy in three domains: (1) student engagement (4 questions; e.g., How much can you do to motivate students who show low interest in schoolwork?), (2) instructional strategies (4 questions; To what extent can you craft good questions for your students?), and (3) classroom management (4 questions; How much can you do to control disruptive behavior in the classroom?). The instructions informed participants that a number of statements about organizations, people, and teaching would be presented and that the purpose of this survey is to gather information regarding the actual attitudes of educators concerning these statements. Respondents then rated how much they feel they can do for each question on a 9-point rating scale from "none at all" to a "great deal." Consistent with the findings reported by Tschannen-Moran and Hoy (2001), each of the three sub-domains exhibited high internal consistency in our sample: student engagement ($\alpha = 0.81$), instructional strategies ($\alpha = 0.89$), and classroom management ($\alpha = 0.89$). We included this measure to probe teachers' efficacy regarding teaching in general. This serves as a baseline to which we can compare specific forms of efficacy (e.g., efficacy teaching science and cultivating spatial thinking skills).

Science Teaching Efficacy Belief Instrument (STEBI; Riggs & Enochs, 1990): This 25-item survey is a reliable and valid measure of teachers' beliefs about science teaching. The measure includes two subscales: (1) Personal Science Teaching Efficacy Belief scale which probes teachers' beliefs about their own skills and capacities in teaching science (13 questions;

e.g., Even when I try very hard, I do not teach science as well as I do most subjects) and (2) the Science Teaching Outcome Expectancy scale which probes what teachers result or outcome teachers expect from science teaching (12 questions, e.g., effectiveness in science teaching has little influence on the achievement of students with low motivation). Participants were informed that they would be asked a series of questions designed to help us get a better sense of their confidence in teaching practices related to the science curriculum and that there were no right or wrong answers. The survey instructions specified that when the questions referred to “helping your students” this meant that the teacher was not providing the answer or offering direct instruction on a concept, but rather, letting students discover. Statements are rated on a 5-pt scale from “strongly disagree” to “strongly agree.” Although this measure included two sub-scales, we only included the Personal Science Teaching Efficacy Belief scale in our analyses ($\alpha = 0.91$) because internal consistency for the Science Teaching Outcome Expectancy scale exhibited marginal internal consistency ($\alpha = 0.69$). This scale probed teachers' efficacy in teaching science. The inclusion of this measure allowed us to understand the relations between teachers' general efficacy, efficacy teaching science, and efficacy in cultivating spatial thinking skills during science instruction.

Spatial Thinking Confidence and Anxiety Instrument: This 11-item instrument was developed for this study to gauge teachers' sense of anxiety and confidence in solving spatial problems. Participants were informed that the next questions were related to their thoughts about spatial thinking and the following definition of spatial thinking was provided, “Spatial thinking concerns the locations of objects, their shapes, their relations to each other, and the paths they take as they move. All of us think spatially in many everyday situations: when we consider rearranging the furniture in a room, when we assemble a bookcase using a diagram, or when we relate a map to the road ahead of us.” Participants then proceeded with the survey. Questions 1–10 were each comprised of four parts (an example is shown in Figure 2). In part 1, teachers solved a spatial problem. For example, as shown in Figure 2, they were asked to pick, which of four answer choices best represents the cross-section resulting from the pictured cut. In parts 2–4, teachers rated how anxious they felt when asked to solve the problem, how confident they were that they solved the problem correctly, and how confident they were that they could get better at this type of problem with practice. Our intention was not to test teachers' skills, but to allow them to experience spatial problem-solving and thus more accurately judge their own anxiety and confidence.

Current measures of spatial anxiety (e.g., Lawton, 1994; Lyons, Ramirez, Maloney, Rendina, Levine, & Beilock, 2018) ask participants to rate their feelings of anxiety in a variety of imagined spatial tasks that include mental manipulation (e.g., asked to imagine and mentally rotate a three-dimensional figure), navigation (e.g., finding your way back to your hotel after becoming lost in a new city), or using imagery (e.g., asked to give a detailed description of a person's face whom you have only met once). To more accurately gauge teachers' anxiety while solving spatial problems, we felt it was critical to ask teachers to actually problem-solve rather than imagine doing so.

We selected 10 spatial problems that have been linked to performance in STEM (Uttal & Cohen, 2012). The spatial problems were selected from a variety of measures of spatial thinking including the Johns Hopkins Center for Talent Youth's Spatial Test Battery (Stumpf et al., 2013), the Geologic Block Cross-Sectioning Test (Ormand et al., 2014), the Mental Rotation Test-A (Peters et al., 1995). Questions were selected to represent a range of spatial thinking tasks including mental rotation, perspective taking, visualizing cross-sections, paper-folding, disembedding, surface development, and understanding of isometric projection. In Question 11,

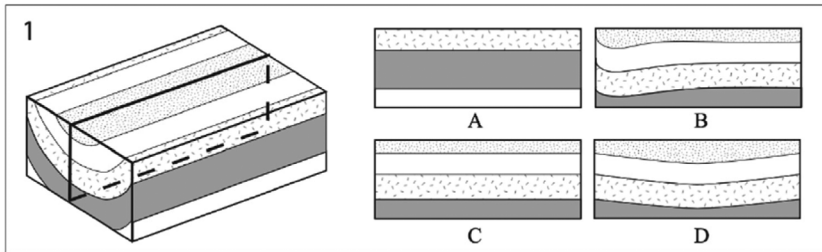
Question 3:

1. This task is designed to assess your ability to mentally slide through a three-dimensional geologic structure expressed in the diagram.

Step 1: Study the geologic structure that is displayed in the 3D block diagram.

Step 2: Determine what the cross-section of that geologic structure would look like on the surface of the vertical plane intersecting the block.

Step 3: Choose the multiple choice answer that best represents how the structure would appear along that plane.



2. How anxious did you feel when asked to solve this problem?

Not At All Slightly Moderately Very Extremely

3. How confident are you that you solved the problem correctly?

4. How confident are you that you would get better at this type of problem with practice?

FIGURE 2 An illustration of spatial thinking confidence and anxiety instrument. (1) Teachers read the directions and solved each problem; and then rated their (2) anxiety during problem-solving; (3) confidence in their answer, and (4) confidence that they could improve with practice

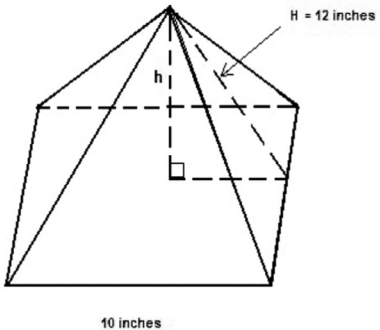
teachers were asked to reflect on all of the problems they just solved and rate their general level of anxiety solving these types of problems and confidence completing the questions correctly and confidence that they could improve on these general types of problems with practice. This question was intended as a global measure of anxiety and confidence in spatial problem-solving. All questions were rated on a five-point scale ranging from “Not at all” (coded 0) to “Extremely” (coded 4).

Beliefs about the Importance of Spatial Thinking for Solving Problems: Drawing upon the previously described work Durlak and DuPre (2008) and the literature linking spatial thinking to STEM (Uttal & Cohen, 2012), we developed this 18-item measure to assess teachers' perceptions of the importance of spatial skills in solving problems. Teachers read 17 educational scenarios depicting a problem a student must solve (e.g., a 10th grade geometry student solving the area of the base of a pyramid; See Figure 3). Teachers read each scenario and rated how important spatial skills are to solve each problem on a 5-pt scale from not important (coded 0) to extremely important (coded 4). Again, the instructions concerned that they were not being asked to solve the problems, but simply to share their opinions and beliefs regarding the

2. Juliette is a 10th grade geometry student working on the following problem: Each side of the square pyramid shown below is 10 inches. The slant height, H , of this pyramid measures 12 inches. What is the area, in square inches, of the base of the pyramid?

How important are spatial thinking skills to solve this problem?

Not Important	Slightly Important	Moderately Important	Very Important	Extremely Important
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



10 inches

$H = 12$ inches

Photo Credit: analyzemath.com

FIGURE 3 An illustration of the beliefs about the importance of spatial thinking for solving problems measure. Teachers read the scenario and rated how important spatial thinking skills are to solve the problem. This scenario was rated by experts and teachers as a “high-importance” problem

importance of spatial thinking skills for solving each problem. Scenarios spanned educational content for elementary (e.g., phases of the moon), middle (model of the solar system), high-school (mitochondrial cell functioning), and college-level (e.g., engineering drafting) content and always included a visual diagram. Thirteen scenarios included STEM content (geometry, astronomy, engineering drafting, algebra, weather, biology, chemistry) and four included non-STEM content (literature, history, photography, and English).

During measurement development, we engaged four spatial thinking experts (with over 10 years of experience in spatial thinking and STEM education research) to rate how important spatial thinking was to solve each problem. We used their ratings to classify educational scenarios as *high-importance* problems (i.e., spatial thinking was judged as very important to solving the problem), *medium-importance* problems (i.e., spatial thinking was judged as moderately important to solving the problem), or *low-importance* problems (i.e., spatial thinking was judged as not important to solving the problem). Of the STEM scenarios, five scenarios were rated by experts as high-importance, four scenarios were rated as medium importance, and four scenarios were rated as low-importance. In our sample, teachers' ratings justified calculating a sub-scale score for the high-importance problems ($\alpha = 0.74$), medium-importance problems ($\alpha = 0.87$), low-importance STEM problems ($\alpha = 0.87$), and the low-importance, non-STEM problems ($\alpha = 0.85$). These scores were calculated as the mean rating of the problems that comprised each sub-scale.

Question 18 of this measure gauged teachers' sense of the importance of spatial thinking skills for students across grades. Teachers were asked to rate how important spatial thinking was in general for five groups of students: those in kindergarten through second grade, those in grades 3–5, those in grades 6–8, those in grades 9–12, and those in college.

Spatial Thinking in Science Self-Efficacy: We developed this 24-item scale to probe teachers' self-efficacy in cultivating and assessing students' spatial thinking skills during various aspects of science instruction. Drawing upon existing measures of general teaching self-efficacy (Hoy & Woolfolk, 1993; Tschannen-Moran & Hoy, 2001) and theories of job-embedded practice that identify activities that teachers engage in during daily teaching (Croft et al., 2010), we probed efficacy across five teacher practice dimensions:

1. Four questions probed efficacy in cultivating students' spatial thinking skills when observing students in the classroom ($\alpha = 0.88$). For example, "Imagine you are observing students while currently teaching a science lesson. How well can you tell that a student is struggling with a particular lesson because she or he does not have the spatial skills to solve the problem?"
2. Six questions probed efficacy during lesson planning ($\alpha = 0.87$). For example, "Imagine you are revising an existing science lesson plan. How well can you create class activities that promote a student's spatial thinking skills?"
3. Five questions related to efficacy in differentiating instruction ($\alpha = 0.95$). For example, "Imagine you are revising an existing science lesson plan to meet the needs of individual students. How well can you tailor a lesson plan to meet a student's spatial thinking skill level?"
4. Five questions probed efficacy in designing assessments ($\alpha = 0.96$). For example, "Imagine you are designing an assessment for a science lesson. How well can you identify whether a science assessment relies on a student's spatial thinking skills?"
5. Four questions probed efficacy when reviewing science standards ($\alpha = 0.92$). For example, "Imagine your school is about to adopt new science standards and you have been asked to review the standards. How well can you distinguish between science standards that rely heavily on spatial thinking skills versus those that do not?"

Participants were informed that these questions were designed to help us better understand what they feel they can do in the classroom and that there were no right or wrong answers, we were simply interested in their opinions and feelings. All items were scored on a 5-pt scale ranging from not at all well (coded 0) to extremely well (coded 4). A subscale score was calculated as the mean of the items corresponding to each dimension, and an overall score was calculated as the mean of all items on the measure ($\alpha = 0.97$).

Demographic Questionnaire: Following the completion of the previously described measures, teachers completed a demographic questionnaire which probed characteristics such as gender, ethnicity, age, educational experiences (e.g., years of experience teaching, highest degree, types of educational certifications), school type (e.g., Title 1), and whether they were a generalist (a teacher who taught all subjects) or a specialist (e.g., taught only math and science).

3 | RESULTS

In the following section, we present the results for our three main research questions. For each, we describe overall findings and then discuss results based on teacher characteristics such as years of experience and subjects taught.

3.1 | How anxious and confident are teachers when solving spatial problems?

Teachers reported a low level of anxiety about answering the questions ($M = 1.25$, $SD = 0.88$), a modest level of confidence that they answered them correctly ($M = 2.08$, $SD = 0.86$), and high confidence that they could improve with training ($M = 2.94$, $SD = 1.06$). While this measure was not an index of spatial skill, we did examine performance. On average, teachers answered

half of the questions correctly ($M = 49.7\%$ correct, $SD = 24.2\%$) and this did not differ across specialists ($M = 52.8\%$ correct) and generalists ($M = 45.9\%$ correct, $t [89] = 1.34$, $p = 0.185$).

Table 2 displays the percentage of correct responses, which varied by question. Teachers' anxiety and confidence also varied by question, and these variations generally followed the questions' difficulty (as indexed by the percent of teachers responding to a particular question correctly). For example, for question 8, which was answered correctly by 83.7% of respondents, teachers reported the lowest level of anxiety ($M = 0.64$) and the highest level of confidence that they solved the question correctly ($M = 2.76$). The proportion of correct responses was negatively correlated with teachers' anxiety ($r [10] = -0.86$, $p = 0.001$), and positively correlated with confidence that they answered the question correctly ($r [10] = 0.90$, $p < 0.001$) and that they could improve with training ($r [10] = 0.78$, $p = 0.007$). Teachers who answered a question correctly reported lower anxiety and higher confidence than teachers who answered that question incorrectly, although these differences only achieved significance in a small number of cases (see Table 2).

Teachers' anxiety was not related to how long they had been teaching science ($p = 0.374$). There were trend-level associations between years teaching science and confidence that they answered the questions correctly ($r [100] = 0.17$, $p = 0.098$) and that they could improve with training ($r [100] = 0.16$, $p = 0.109$). Specialists reported lower levels of overall anxiety ($M = 1.10$, $SD = 0.87$), than their generalist peers ($M = 1.45$, $SD = 0.87$) at a rate that was very nearly significant ($t [101] = -1.99$, $p = 0.050$). Parallel differences between specialists and generalists were not observed with respect to confidence in their answer ($p = 0.377$) or that they could improve with training ($p = 0.460$).

3.2 | How important do teachers believe spatial thinking is for solving problems?

Importance by Scenario Type. As reported in the measures section above, the three subscales of this measure exhibited internal consistency (α) ranging from 0.74 to 0.87. Table 3a shows the mean importance ratings teachers assigned for each of our three scenario types (high-importance, medium-importance, and low-importance). Teachers' ratings generally followed those made by the experts. That is teachers assigned a higher level of importance to scenarios that experts had also assigned a high-level of importance. After correcting for multiple comparisons via the Bonferroni method ($\alpha/6 = 0.008$), the mean score for "high-importance" scenarios was significantly higher than those assigned for "medium-importance" ($M_{\text{diff}} = 1.22$, $SD_{\text{diff}} = 1.10$, $t [102] = 11.26$, $p < 0.001$) or "low-importance" scenarios, regardless of whether low-importance questions presented STEM content ($M_{\text{diff}} = 1.56$, $SD_{\text{diff}} = 1.14$, $t [102] = 11.89$, $p < 0.001$) or not ($M_{\text{diff}} = 1.27$, $SD_{\text{diff}} = 1.14$, $t [102] = 11.32$, $p < 0.001$). A similar pattern was observed between "medium-importance" and STEM-related low-importance questions ($M_{\text{diff}} = 0.34$, $SD_{\text{diff}} = 0.75$, $t [102] = 4.64$, $p < 0.001$). There was, however, no difference in ratings for the "medium importance" and "low-importance" non-STEM scenarios ($p = 0.546$). Teachers rated spatial thinking as more important for the non-STEM scenarios than the STEM scenarios identified by experts as "low-importance" ($M_{\text{diff}} = 0.28$, $SD_{\text{diff}} = 0.08$, $t [102] = -3.47$, $p = 0.001$). A possible explanation for this is discussed in Section 4. These patterns are shown in Figure 4a.

On average, teachers who were generalists (teaching all subjects), assigned higher ratings to the "medium-importance" scenarios than did specialist teachers at the trend level

TABLE 2 Percentage of correct responses by spatial problem

Question	Spatial skill	% correct	Anxiety			Confidence solved correctly			Confidence could improve		
			Overall	Correct	Incorrect	Overall	Correct	Incorrect	Overall	Correct	Incorrect
1	Mental rotation	47.1%	1.27	1.06	1.46*	2.28	2.57	2.02*	3.25	3.37	3.15
2	Perspective taking	71.2%	0.89	0.82	1.07	2.63	2.82	2.14**	3.21	3.30	3.00
3	Cross-sectioning	29.8%	1.42	1.42	1.42	1.85	2.13	1.73	2.92	2.90	2.93
4	Paper-folding	65.4%	1.33	1.25	1.49	2.06	2.37	1.44**	2.99	3.10	2.77
5	Disembedding	60.6%	1.35	1.35	1.35	2.07	2.24	1.80	2.91	3.03	2.73
6	Surface development	11.5%	1.85	1.93	1.25	1.33	2.25	1.20**	2.55	3.42	2.44*
7	Isometric projection	29.8%	1.62	1.13	1.84*	1.49	2.10	1.21**	2.62	3.23	2.36**
8	Mental rotation	83.7%	0.64	0.66	0.57	2.76	2.84	2.29	3.17	3.22	2.86
9	Perspective taking	59.6%	0.84	0.74	1.00	2.57	2.79	2.23*	3.02	3.18	2.77
10	Mental rotation	38.5%	1.20	0.88	1.41*	1.83	2.15	1.62*	2.74	3.08	2.52*

Note: Difference in anxiety or confidence between teachers providing correct and incorrect responses is statistically significant at * $p < 0.05$ or ** $p < 0.01$.

TABLE 3 Importance of spatial thinking

(a) Perceived importance of spatial thinking for solving problems by scenario type										
Type of educational scenario	Overall (<i>N</i> = 103)		Role				Specialty			
			Generalist (<i>N</i> = 45)		Specialist (<i>N</i> = 58)		Science only (<i>N</i> = 30)		Science and math (<i>N</i> = 25)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
High importance, STEM	2.94	0.68	2.95	0.67	2.93	0.69	2.98	0.63	2.98	0.68
Medium importance, STEM	1.72	1.13	1.92	1.16	1.56	1.09	1.47	1.00	1.66	1.25
Low importance, STEM	1.38	1.04	1.51	0.99	1.27	1.07	1.66	1.25	1.21	0.93
Non-STEM	1.66	1.08	1.84	1.05	1.53	1.08	1.53	0.99	1.56	1.25
(b) Perceived importance of spatial thinking by school grade										
Grade level	Overall (<i>N</i> = 103)		Role				Specialty			
			Generalist (<i>N</i> = 45)		Specialist (<i>N</i> = 58)		Science only (<i>N</i> = 30)		Science and math (<i>N</i> = 25)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Kindergarten–2	2.54	1.17	2.51	1.16	2.57	1.19	2.83	1.15	2.28	1.21
3–5	2.90	0.86	2.84	0.88	2.95	0.85	2.93	0.91	3.04	0.74
6–8	3.20	0.75	3.16	0.80	3.24	0.71	3.17	0.79	3.40	0.58
9–12	3.40	0.71	3.33	0.77	3.45	0.65	3.33	0.76	3.64	0.49
College	3.30	0.81	3.20	0.89	3.39	0.73	3.40	0.77	3.42	0.72

Note: Average ratings for how important teachers felt spatial thinking was to solve various types of educational problems by scenarios type (top) and grade in school (bottom).

($t [101] = 1.62, p = 0.109$). No other differences were observed between scores assigned by generalists and specialists and there were no differences in ratings between teachers who reported that their specialty was science and those specialized in was science and math. Together these findings indicate that teachers are able to distinguish educational problems that rely on spatial thinking skills and there is little evidence that this differs across teachers who specialize in math and science compared to those teachers who teach all subjects.

Importance by School Grade. Table 3b shows teachers' ratings of the importance of spatial thinking by grade. After accounting for multiple comparisons (Bonferonni correction: $\alpha/10 = 0.005$), teachers rated spatial thinking skills as significantly less important for students in kindergarten through second grade than for students in grades 3–5 ($M_{\text{diff}} = -0.36, SD_{\text{diff}} = 0.70, t [102] = -5.22, p < 0.001$), 6–8 ($M_{\text{diff}} = -0.66, SD_{\text{diff}} = 1.01, t [102] = -6.66, p < 0.001$), 9–12 ($M_{\text{diff}} = -0.85, SD_{\text{diff}} = 1.17, t [102] = -7.43, p < 0.001$), and college ($M_{\text{diff}} = -0.76, SD_{\text{diff}} = 1.21, t [102] = -6.28, p < 0.001$). Similarly, these skills were rated as significantly less important for students in grades 3–5 than those in grades 6–8 ($M_{\text{diff}} = -0.30, SD_{\text{diff}} = 0.54, t [102] = -5.66, p < 0.001$), 9–12 ($M_{\text{diff}} = -0.50, SD_{\text{diff}} = 0.71, t [102] = -7.06, p < 0.001$), and college ($M_{\text{diff}} = -0.39, SD_{\text{diff}} = 0.82,$

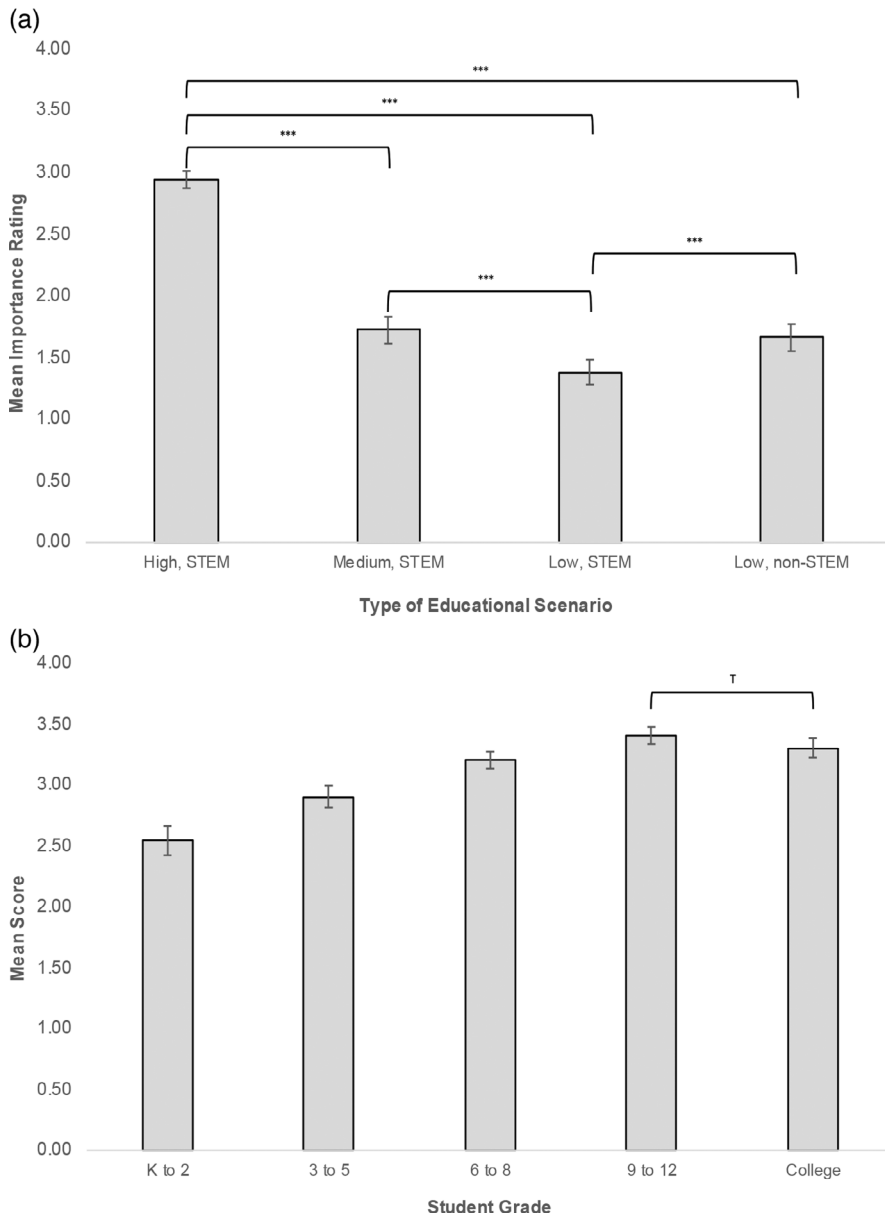


FIGURE 4 (a) Teachers' perceptions of the importance of spatial thinking skills for problem-solving. Average ratings for how important teachers felt spatial thinking was to solve various types of educational scenarios. Problems presented STEM and non-STEM content and were categorized as high, medium, and low based on experts' ratings regarding which problems spatial thinking was extremely important (high), moderately important (medium), and not import (low). *** indicates that the comparison under the bracket is statistically significant at $p < 0.001$. (b) Teachers' perceptions of the importance of spatial thinking skills across grades. All grade comparisons are statistically significant at $p < 0.001$ except for that under the bracket labeled †

$t [102] = -4.82, p < 0.001$). Spatial thinking skills were rated as significantly less important for students in grades 6–8 than those in grades 9 to 12 ($M_{\text{diff}} = -0.19, SD_{\text{diff}} = 0.40, t$

[102] = -4.96 , $p < 0.001$), and no such difference was observed in ratings for students in grades 9 to 12 and those in college ($p = 0.049$). These patterns are shown in Figure 4b.

Comparisons across teacher characteristics revealed modest, positive associations between years of experience teaching and beliefs in the importance of spatial skills for students in kindergarten through second grade ($r [89] = 0.27$, $p = 0.012$) and 3rd–5th ($r [89] = 0.25$, $p = 0.020$), as well as the remaining grade brackets at the trend level ($r [89] = [0.18, 0.20]$, $p = [0.059, 0.089]$). This indicates that teachers who have taught longer were more likely to rate spatial thinking as important at all ages, and in particular, more important for the younger grades. There was no association between importance ratings and teachers' role as a generalist or specialist ($p = [0.394, 0.854]$) or subject taught (e.g., science only or math and science; $p = [0.251, 0.886]$).

3.3 | How well do teachers feel they can cultivate students' spatial skills during science instruction and how does this relate to general and science teaching efficacy?

General and Science Teaching Efficacy: Ratings on our measure of general teaching self-efficacy (TSES) and efficacy teaching science (STEBI Personal Science Teaching Efficacy Belief scale), suggest a highly efficacious sample of teachers. Scores on the three sub-scales of the TSES are shown in Table 4a. As can be seen in the table, scores were highly inter-correlated ($r (104) = [0.75, 0.83]$, $p < 0.001$). Average scores were high, ranging from 7.28 to 7.76 on a scale from 3 to 9 (or 71.3–79.3% of the possible maximum score). The average score on the STEBI was also high ($M = 3.59$ out of 4, $SD = 0.66$, or 64.8% of the possible maximum), and this score was moderately correlated with the three subscales of the TSES ($r (104) = [0.36, 0.50]$, $p < 0.001$).

Spatial Thinking in Science Efficacy: Table 4a displays the mean score and Table 4b displays the descriptives for the five dimensions of the Spatial Thinking in Science Self-Efficacy scale. As can be seen in the table, all five dimensions exhibited high internal consistency (α) ranging from 0.87 to 0.96. The mean score for all five teaching practice dimensions centered around 2, indicating that, on average, teachers felt “moderately” capable of cultivating students' spatial skills during science instruction. To understand how spatial thinking in science self-efficacy compares to self-efficacy in general (TSES) and in teaching science (STEBI), we compared overall mean scores when scores were expressed as a percentage of the maximum score. The mean score for the Spatial Thinking in Science Self-Efficacy measure ($M = 2.12$ out of 4, $SD = 0.78$) was significantly lower than that for STEBI ($M_{\text{diff}} = -11.75\%$, $SD_{\text{diff}} = 22.99\%$, $t [102] = -5.19$, $p < 0.001$) and the TSES (Student Engagement scale, $M_{\text{diff}} = -18.46\%$, $SD_{\text{diff}} = 25.31\%$, $t (102) = -7.40$, $p < 0.0001$; Instructional Strategies scale, $M_{\text{diff}} = -24.06\%$, $SD_{\text{diff}} = 23.89\%$, $t (102) = -10.22$, $p < 0.0001$; Classroom Management scale, $M_{\text{diff}} = -26.38\%$, $SD_{\text{diff}} = 26.66\%$, $t (102) = -10.04$, $p < 0.0001$).

Table 4a illustrates the correlations between Spatial Thinking in Science Self-Efficacy and the TSES and the STEBI. As shown in the table, the overall Spatial Thinking in Science Self-Efficacy score was modestly correlated with the student engagement ($r [103] = 0.24$, $p = 0.013$) and instructional strategy ($r [103] = 0.28$, $p = 0.004$) subscales of the TSES, as well as STEBI ($r [103] = 0.20$, $p = 0.043$). These findings suggest that these scales are related but

TABLE 4 Teachers' self-efficacy

(a) Descriptives for and intercorrelations among different measures of self-efficacy						
	1	2	3	4	5	
1. TSES: Student engagement (Tschannen-Moran & Woolfolk Hoy; scale = [3, 9])	—	0.75 ^{***}	0.83 ^{***}	0.36 ^{***}	0.24 [*]	
2. TSES: Instructional strategy (Tschannen-Moran & Woolfolk Hoy; scale = [3, 9])	—	—	0.78 ^{***}	0.50 ^{***}	0.28 ^{**}	
3. TSES: Classroom management (Tschannen-Moran & Woolfolk Hoy; scale = [3, 9])	—	—	—	0.43 ^{***}	0.11	
4. STEBI (Riggs & Enochs; scale = [1, 5])	—	—	—	—	0.20 [*]	
5. Spatial thinking in science self-efficacy: overall (scale = [0, 4])	—	—	—	—	—	
<i>N</i>	104	104	104	104	103	
<i>M</i>	7.28	7.63	7.76	3.59	2.12	
<i>SD</i>	1.29	1.21	1.21	0.66	0.78	
<i>M</i> _{Pmax}	71.3%	77.2%	79.3%	64.8%	53.0%	
(b) Spatial thinking in science efficacy						
Dimension	α	<i>N</i>	<i>M</i>	<i>SD</i>	Minimum	Maximum
Observing students	0.88	102	2.21	0.85	0.25	4.00
Lesson planning	0.87	103	2.18	0.74	0.40	4.00
Differentiating instruction	0.95	103	2.04	0.89	0	4.00
Designing assessments	0.96	103	2.11	0.93	0	4.00
Reviewing science standards	0.92	103	2.08	0.85	0	4.00
Overall	0.97	103	2.12	0.78	0.17	4.00

Note: *N* for pairwise correlations = [103, 104]. STEBI reverse-scored to match valence of other measures (such that higher scores indicate higher levels of self-efficacy). Mean percent maximum scores (*M*_{Pmax}) were calculated as a percentage of the maximum possible score for each scale by subtracting the mean score from the minimum value of the scale (e.g., 3, for the TSES) and then dividing the result by the number of increments above that minimum (6, in the case of the TSES).

^{*}*p* < 0.05.

^{**}*p* < 0.01.

^{***}*p* < 0.001.

that self-efficacy in cultivating spatial skills during science is distinct from these other measures of self-efficacy in teaching in general and in teaching science.

To illustrate the differences in teachers' self-efficacy with respect to science teaching (both their science teaching self-efficacy and their self-efficacy in cultivating spatial thinking during science instruction), Figure 5 displays the frequency of teachers' who scored at various percentages of the maximum score for both the STEBI and the Spatial Thinking in Science Self-Efficacy measure. As can be seen in the figure, the STEBI has a right-ward shifted distribution indicating that more of our sample felt efficacious about their efficacy in teaching science. However, the Spatial Thinking in Science Self-Efficacy scale has a normal distribution with scores fairly distributed from low to high on percent of maximum score. Together, these distributions illustrate

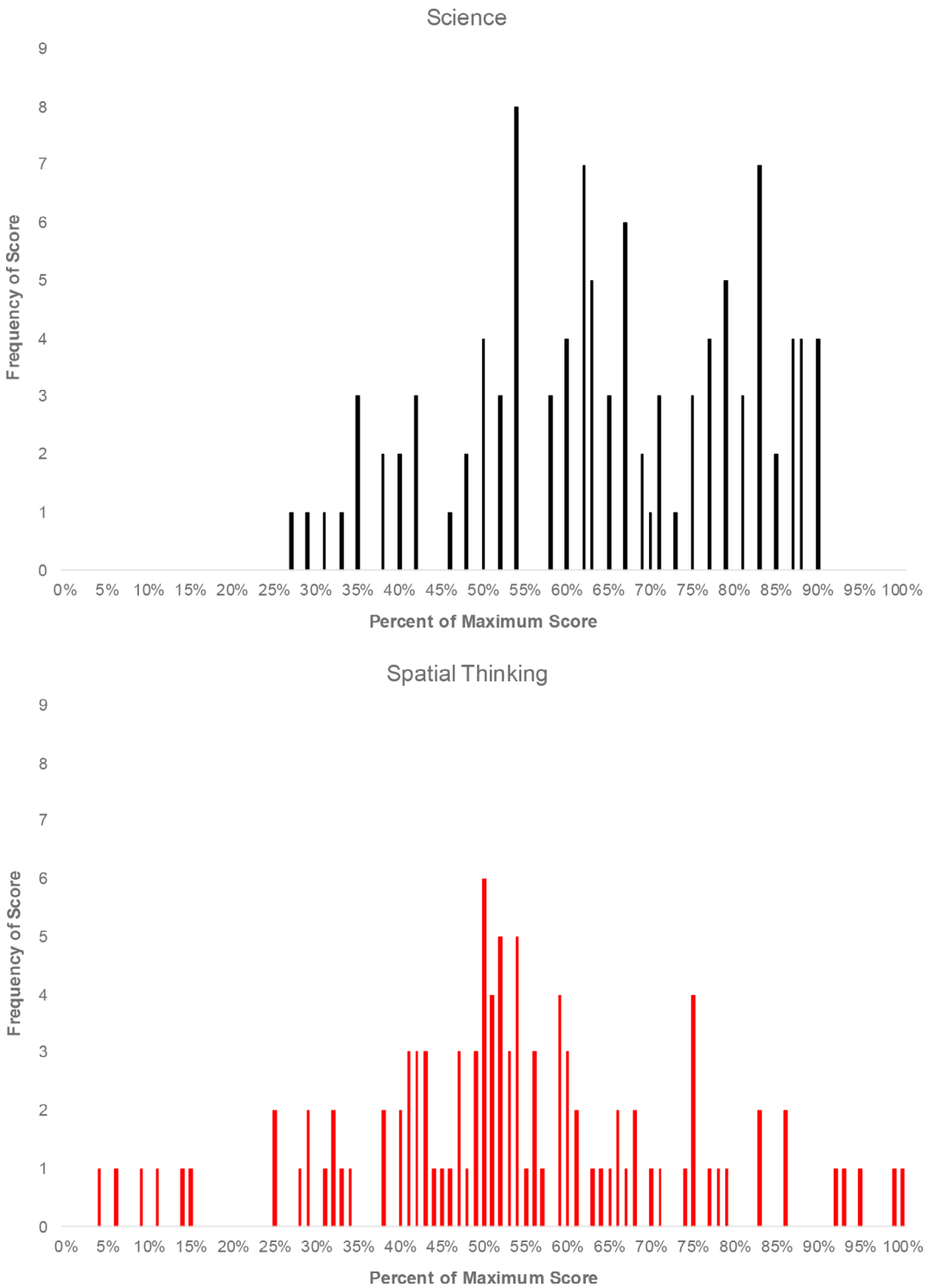


FIGURE 5 Distribution of scores on the STEBI (top) and spatial thinking in science self-efficacy scale (bottom). Figure displays the percentage of teachers who scored at various increments of the maximum score on each scale. For example, looking at the bottom figure, it can be seen that one teacher scored 5% of the maximum score on the Spatial Thinking in Science Self-Efficacy scale

TABLE 5 Self-efficacy by teacher characteristics

Measure	Correlation with teaching experience		Role				Specialty			
			Generalist (N = 45)		Specialist (N = 59)		Science only (N = 31)		Science and Math (N = 25)	
	Total (N = 103)	Science (N = 101)	M	SD	M	SD	M	SD	M	SD
General: Student engagement	0.14	0.10	7.19	1.51	7.35	1.10	7.38	1.02	7.29	1.22
General: Instructional strategies	0.23*	0.19	7.38	1.46	7.82	0.94	7.65	1.00	7.93	0.86
General: Classroom management	0.20*	0.15	7.59	1.51	7.89	0.91	7.90	0.89	7.79	0.95
Science teaching self-efficacy	0.26**	0.45***	3.38	0.64	3.76	0.64	3.87	0.59	3.60	0.70
Spatial thinking in science self-efficacy	0.15	0.23*	2.19	0.72	2.07	0.83	1.98	0.81	2.12	0.86

* $p < 0.05$.** $p < 0.01$.*** $p < 0.001$.

that our sample of teachers felt significantly less efficacious in their spatial thinking in science self-efficacy compared to their general science teaching self-efficacy.

Relations between teacher characteristics and all three measures of self-efficacy are shown in Table 5. As can be seen, years of experience, regardless of subject taught, was modestly correlated with general self-efficacy in instructional strategies ($r [103] = 0.23$, $p = 0.018$), classroom management ($r [103] = 0.20$, $p = 0.043$), and their self-efficacy teaching science ($r [103] = 0.26$, $p = 0.009$). Years of experience teaching, however, was not related to teachers' spatial thinking in science self-efficacy ($p = 0.139$). In contrast, years of experience *teaching science* was associated both with spatial thinking in science self-efficacy ($r [101] = 0.23$, $p = 0.021$) and science teaching self-efficacy ($r [101] = 0.45$, $p < 0.001$). As noted above, 94% of specialist teachers taught science. Specialists reported significantly higher levels of science teaching self-efficacy ($t (102) = 2.98$, $p = 0.004$), but no other differences in self-efficacy as a function of teachers' characteristics were observed, as shown in Table 5.

4 | GENERAL DISCUSSION

This is the first exploration into elementary school teachers' feelings of anxiety and confidence when solving spatial problems, confidence that their own spatial skills can improve, beliefs

about the importance of spatial skills for student problem-solving and academic success, and self-efficacy in cultivating students' spatial skills during science instruction. We developed novel measures to assess these beliefs, perceptions, and feelings. Analyses suggest that all measures performed well and exhibited high internal consistency. Our results indicate that elementary school teachers feel low anxiety when solving spatial problems and strongly believe their spatial skills can improve with practice. They are capable of distinguishing which kinds of educational problems spatial skills are of high importance for solving compared to those for which spatial thinking is of medium or low importance. Teachers believed that spatial skills are more important for older students than younger ones, although teachers who have been in the profession longer, tended to see the importance of these skills in the early grades. Despite being able to recognize where spatial thinking is critical and feeling efficacious about general and science teaching, teachers reported significantly lower efficacy in cultivating students' spatial skills during science instruction. A wealth of research has indicated that teachers' knowledge, beliefs, and attitudes influence their classroom practices and professional activities, which in turn shape the classroom environment and student learning and outcomes (see Fang, 1996; Kagan, 1992; Nespor, 2006; OECD, 2009). Drawing upon these frameworks, our results have broader implications for our understanding of teacher beliefs (self-efficacy in particular), perceptions, and feelings, and professional development research.

4.1 | Relation to broader literature on beliefs and perceptions

Anxiety and Confidence: There is evidence that elementary school teachers have lower spatial skills compared to secondary teachers and the general, college-educated population (Atit et al., 2018). Yet this finding does not inform our understanding of why these differences might exist and what affective factors may contribute to these differences. This question involves understanding teachers' spatial thinking beliefs and perceptions. Our findings, that elementary school teachers express low anxiety when solving spatial problems, replicate those of Brute et al. (2020), and Gunderson et al. (2013) using a measure that was not focused solely on navigation. Teachers reported low levels of anxiety following solving a spatial problem that has been linked to performance in STEM (Uttal & Cohen, 2012).

While we did not intend this measure to serve as a measure of spatial skill (rather as a realistic way to induce true feelings regarding spatial problem-solving), we did examine the relationship between performance, anxiety, and confidence. Anxiety was inversely related to solving the problem correctly and confidence in one's skill, replicating a well-established relationship between anxiety, confidence, and performance seen in other domains such as sports and tests of academic or cognitive performance (see Compte & Postlewaite, 2004; Woodman & Hardy, 2003 for reviews). Importantly, teachers' ratings suggest they feel strongly that their skills in solving these types of spatial problems could improve with practice, indicating that elementary teachers perceive spatial thinking as a skill that can be developed through practice, rather than an ability that is set in stone.

The trend in lower anxiety in teachers' who teach math and science compared to those who teach all subjects, is ripe for future exploration as anxiety can impact confidence in teaching and use of instructional strategies in the classroom (e.g., Bursal & Paznokas, 2006; Ramirez et al., 2018). For example, Bursal and Paznokas (2006) reported that low math anxious preservice teachers were more confident in teaching elementary mathematics and science than their high anxious peers. More recently, Ramirez et al. (2018) found that anxiety about math was related to teachers using

less process-oriented (practices that empathize effort, reasoning, and sense-making) teaching practices than teachers who are not math-anxious. In the spatial domain, Gunderson et al. (2013) showed that teachers' spatial anxiety predicts their students end of the year spatial performance, and thus it may be that teachers who are less confident and more anxious with spatial thinking are less likely to provide opportunities to build students' spatial skills or less confident utilizing strategies that build students' spatial skill such as sketching or gesture (Gagnier & Fisher, 2020).

Belief in the Importance of Spatial Thinking: To our knowledge, this is the first study to examine elementary teachers' beliefs regarding how important spatial skills are for solving STEM and non-STEM problems. Elementary school teachers' perceptions of the importance of these skills tended to follow those made by spatial experts. This illustrates that following a very brief introduction to spatial thinking (in the form of solving spatial problems), elementary teachers can discern elements of problems for which spatial thinking is highly important, compared to those which rely less on spatial skills (medium/low-importance scenarios). Curiously, teachers tended to rate spatial thinking as more important for non-STEM problems than for the "low importance" STEM problems. The rationale for this remains unclear. It is possible that compared to the high-importance problems, the low-importance problems felt much less likely to rely on spatial thinking. It is also possible that teachers saw spatial elements in the non-STEM problems. Our future work aims to distinguish between these possibilities by conducting interviews with teachers to elucidate their thought processes in identifying spatial elements of academic problems.

Teachers tended to believe that spatial thinking is more important for older students (i.e., in high school and college), yet there were differences based on years of experience. Teachers who had been teaching longer were more likely to believe spatial thinking is important at all ages, particularly the younger grades. Spatial thinking is important for all ages. For example, spatial skill at age 3 is related to mathematical skill at age 3 (Verdine et al., 2014). Scholars have suggested that spatial skills can act as a "gatekeeper," allowing students to acquire domain-specific knowledge (Hambrick et al., 2012). Thus, building spatial skills early may influence whether students seek out additional STEM courses and learning opportunities throughout their school careers.

Making teachers aware of this relationship has the potential to improve implementation fidelity of educational programs aimed at building students' spatial thinking skills in the classroom. Durlak and DuPre (2008) reported that the degree to which program implementers feel the intervention is important will greatly influence the fidelity with which they implement the program. Our findings illustrate that teachers can identify problems for which experts believe spatial thinking skills are very important, which suggests teachers believe spatial thinking skills are important. However, building their knowledge of the importance of spatial thinking at all ages may support greater implementation fidelity of educational programs aimed at building elementary students' spatial thinking skills.

Self-Efficacy as a Differentiated Construct: Our work adds to the growing literature suggesting that teaching self-efficacy is a multidimensional construct (Gibson & Dembo, 1984; Skaalvik & Skaalvik, 2007; Tschannen-Moran & Hoy, 2001). Historically research on teacher efficacy beliefs has offered two distinct theoretical positions which have highlighted beliefs regarding personal efficacy (e.g., what I can do) versus external factors that affect students (e.g., the role the students' home environment plays in their success). Indeed, the first measure of self-efficacy (see Armor et al., 1976) distinguished between personal self-efficacy (e.g., "If I really try hard, I can get through to even the most difficult and unmotivated students) and external factors (e.g., When it comes right down to it, a teacher really cannot do much because

most of a student's motivation and performance depend on his or her home environment). Subsequent research has shown these two types of questions measure different constructs (Gibson & Dembo, 1984). Indeed, the Teachers' Sense of Efficacy Scale (Tschannen-Moran & Hoy, 2001) is divided into three subdimensions: efficacy in instructional strategies, student engagement, and classroom management. Yet some have argued that three dimensions are not sufficient to capture the complexities of teaching. For example, in an analysis of 224 elementary and middle school teachers, Skaalvik and Skaalvik (2007) provided support for 6 separate, but correlated dimensions of teacher self-efficacy in instruction, adapting education to meet student needs, motivating students, maintaining discipline and order, cooperating with colleagues, and coping with challenges.

Our data add to the growing literature highlighting that teachers hold differentiated views of their capacities in many aspects of teaching. The correlations between our three measures of self-efficacy suggest related yet not overlapping self-perceptions. The Skaalvik and Skaalvik (2007) six-dimension scale was derived from an analysis of central tasks in teachers' daily work based on the Norwegian curriculum. Here, our Spatial Thinking in Science self-efficacy measure was derived from the literature on job-embedded practice that identifies activities teachers engage in daily (Croft et al., 2010) combined with research linking spatial thinking skills to success in STEM education and problem-solving (see Newcombe, 2010; Newcombe, 2013 for review). The high reliability exhibited by this measure suggests that task analyses that combine theories of job-embedded practice with literature on how students master discipline-specific content (in our case spatial thinking as a conduit for mastering science content), is a useful method for understanding self-efficacy within specific academic domains.

Our sample was highly efficacious in general and science teaching self-efficacy, yet not on spatial thinking in science self-efficacy. There are at least two potential explanations for this finding. First, few teacher training programs address spatial thinking. Thus, teachers may not have been aware of these skills prior to this study and thus rated themselves lower based on lack of experience with these skills. Second, the Spatial Thinking in Science Self-efficacy measure offered teachers a more fine-grained level of self-reflection. For example, the STEBI asked, "When a student has difficulty understanding a science concept, I am usually at a loss as to how to help the student understand it better." This is compared to the Spatial Thinking in Science Self-Efficacy scale which probed "How well can you create class activities that promote a student's spatial thinking skills?" This level of task-specificity might have made teachers feel they were less capable. A limitation of this study is a lack of a scale with the same level of granularity that is unrelated to spatial skills.

Beliefs and Perceptions by Teacher Characteristics: By in large we found little differences in teachers' beliefs and perceptions based on their characteristics such as years of experience teaching or teaching role (generalist vs. specialist). This was true with the following exceptions. First, there was a trend toward less spatial anxiety for specialists compared to generalists. Second, we found that the more a teacher has taught *science* (not years of teaching in general), the more capable they feel in cultivating spatial skills during instruction. Future work should explore why. At least three possibilities emerge from a review of the literature. First, recent evidence suggests that teachers who specialize in science tend to be more effective teachers in general (Bastian & Fortner, 2020). Second, it is possible that science concepts inherently offer teachers opportunities to utilize spatial activities more so than other domains such as math or reading (Gagnier & Fisher, 2020; Kastens & Ishikawa, 2006; Uttal et al., 2013). A third possibility is that teachers who teach science, may have higher spatial thinking skill (Atit et al., 2018) which may lead them to incorporate more spatial language, spatial activities, or other

pedagogical strategies which incorporate the use of spatial strategies in the classroom and thus teachers' feel more capable in cultivating students' spatial thinking skills during science instruction. These possibilities need to be investigated in future research. Understanding the relation between self-efficacy in cultivating spatial skills and teachers' effectiveness, instructional practices teaching science, and use research-informed spatial strategies (e.g., sketching and gesture, Gagnier & Fisher, 2020) will advance teacher training to maximize effectiveness.

These issues relate to a broad discussion regarding teacher specialization in elementary school and the role of teacher knowledge in student achievement. This practice is becoming a more common elementary practice, yet data regarding the effectiveness of specialization is limited. A recent large-scale survey (Bastian & Fortner, 2020) called into question the effectiveness of specialists, showing that in the case of math and reading (but not science), specialists are less effective than they were as generalists. The cause of this is not known. Perhaps when teachers were moved to a specialist, they do not gain adequate domain-specific knowledge. Another possibility is that in the elementary domains, it is essential to have a holistic picture of a child's skills and competencies and when a teacher specializes, they lose that. For example, a teacher who only teaches science may not be aware that a student is struggling in reading or might not be able to draw links between different academic content the student is learning. While our work does not speak to effectiveness, we do contribute to the broader literature on specialists' and generalists' beliefs, perceptions, and feelings. As specialists become more common in elementary education, we suggest it is important for researchers to explore their beliefs and perceptions.

4.2 | Implications for professional development research

Drawing on decades of research on effective learning environments and professional development (e.g., Supovitz & Turner, 2000) Desimone, Darling-Hammond, and colleagues (Darling-Hammond et al., 2017; Desimone & Pak, 2017; Desimone, 2009; Garet et al., 2001) have identified seven features of effective professional development. Motivated by this framework, our data suggest three recommendations for in-service and preservice professional development. This is an emerging area of inquiry and thus research is needed to examine the impact of all three recommendations collectively on teachers' spatial and instructional capacities in the classroom.

First, professional development programs can help elementary school teachers understand that spatial skills are critical for academic success at all ages and thus should be cultivated throughout a child's academic career. Spatial thinking may be cultivated through informal experiences such as play with spatial toys including puzzles and building sets (Jirout & Newcombe, 2015). Teachers may also implement research-informed pedagogical activities such as using spatial language, gesture, and sketching to illustrate spatial properties of scientific phenomenon (e.g., the size and shape of tools used to measure the weather) and scientific visualizations (e.g., describing how to interpret the heights of bars in a bar graph or explaining how to interpret diagrams which show cross-sections of the earth). Such practices have been shown in laboratory-based research to improve student comprehension of diagrams and are now at the point of being translated into curricular activities and evaluated for effectiveness in the classroom (see Gagnier & Fisher, 2020 for details).

Second, our data indicate the need to develop and evaluate training programs for elementary teachers in how to cultivate students' spatial skills during science instruction. Frameworks of teacher beliefs (Fang, 1996; Kagan, 1992; Nespor, 2006; OECD, 2009; Ross, 1998; Tschannen-

Moran et al., 1998) suggest that bolstering teachers' sense of efficacy in cultivating students' spatial skills during science instruction will support their implementation of spatial activities in their classroom. Regardless of their own current spatial skill level, all teachers can utilize spatial techniques during science instruction to highlight spatial features of scientific phenomenon and encourage students' use of spatial problem-solving and strategies when thinking about scientific content (Gagnier & Fisher, 2020). For example, consider a third-grade science lesson that aims to build students' understanding of how weather tools are used to provide data on various types of weather (e.g., a rain gauge provides data on the amount of precipitation in a region). Teachers' may emphasize the spatial properties of how the rain gauge collects precipitation data by using gestures and spatial language to describe the shape of the rain gauge (e.g., a hollow tube), demonstrate how it collects rain using spatial language and gesture (e.g., rain falls from the sky into the tube), and how the water level in the tube increases over time as it continues to rain (see Gagnier & Fisher, 2020, Figure 3). Research is needed to understand the most effective professional development approach and classroom practices to help teachers build and assess students' spatial thinking skills during classroom instruction.

Third, professional development programs can develop elementary school teachers' spatial skills and confidence in solving spatial problems. We find that teachers believe their skills can improve with training and thus professional development programs can capitalize on these beliefs. Gunderson et al. (2013) hypothesized that teachers who have higher spatial anxiety may be less likely to utilize spatial activities in their classrooms. Developing teachers' spatial skills and confidence with spatial problem-solving may facilitate their use of spatial supports in the classroom, especially if paired with training on how to cultivate students' skills through instruction. Teacher confidence and skills are critical factors affecting behavior. For example, Durlak and DuPre (2008) found that program implementers' confidence, knowledge, and skills are key factors affecting their implementation of programs with high fidelity. Confidence regarding both their own skill and that they can use techniques to accomplish teaching goals appears to be a critical factor. For example, Wozney et al. (2006) found that teachers' confidence that they could successfully use technology to accomplish their learning goals predicted their use of technology in the classroom. The authors interpreted these data to mean that professional development should aim to increase teachers' confidence using technology to achieve student learning objectives.

Drawing upon the previous work of Durlak and DuPre (2008), Wozney et al. (2006), and the professional development frameworks of Desimone and Darling-Hammond, research should examine if professional development programs that aim to build (1) teachers' spatial skills, (2) confidence in spatial problem-solving, and (3) skills at implementing spatial strategies in their classroom as a way to build students' scientific knowledge, lead to improvements in teacher classroom practices and student outcomes. Future work is needed to develop and evaluate such programs to further advance our understanding of the most effective mechanisms to translate research on spatial thinking into teacher professional learning and classroom practice.

5 | CONCLUSION

Drawing upon decades of research linking spatial thinking skills to entrance into and success within STEM fields, recent efforts have focused on classroom-based interventions aimed at building students' spatial thinking skills. Yet, teachers are the implementation drivers of these

interventions and thus the intervention effectiveness will be dependent on teachers' spatial thinking beliefs and perceptions. Our aim in this article was to elucidate elementary teachers' beliefs, perceptions, and feelings about their own spatial thinking skills, their perceptions of the importance of spatial thinking skills for students' problem-solving and academic success, and their sense of efficacy in cultivating students' spatial thinking skills during science instruction. Our findings indicate elementary school teachers believe these skills are important and malleable with practice and suggest some targeted professional learning opportunities for cultivating teachers' capacity to develop students' skills through classroom-based instruction.

ORCID

Kristin Michod Gagnier  <https://orcid.org/0000-0002-5072-5750>

ENDNOTES

- ¹ Measured by a survey that probed anxiety during a variety of situations involving navigation (e.g., finding your way around an unfamiliar mall)."
- ² Here, their measure of spatial anxiety included anxiety during navigation situations (e.g., Gunderson et al., 2013) and non-navigational tasks such as assembling Ikea furniture.
- ³ This project was conceived of as part of a larger project to create a spatially-enhanced 3rd grade science curriculum in the district (see, Gagnier & Fisher, 2020). Thus, 3rd grade teachers were not recruited for this study to avoid overlap with that project.

REFERENCES

- Allinder, R. M. (1994). The relationship between efficacy and the instructional practices of special education teachers and consultants. *Teacher Education and Special Education, 17*(2), 86–95.
- Anderson, R. N., Greene, M. L., & Loewen, P. S. (1988). Relationships among teachers' and students' thinking skills, sense of efficacy, and student achievement. *Alberta Journal of Educational Research, 34*(2), 148–165.
- Armor, D. J., Conry-Oseguera, P., Cox, M., King, N. J., McDonnell, L. M., Pascal, A. H. & Zellman, G. L. (1976). Analysis of the school preferred reading program in selected Los Angeles Minority Schools, REPORT NO. R-2007-LAUSD. Santa Monica, CA: Rand Corporation (ERIC Document Reproduction Service No. 130 243).
- Ashton, P. T., & Webb, R. B. (1986). *Making a difference: Teachers' sense of efficacy and student achievement*. Longman Publishing Group.
- Atit, K., Miller, D. I., Newcombe, N. S., & Uttal, D. H. (2018). Teachers' spatial skills across disciplines and education levels: Exploring nationally representative data. *Archives of Scientific Psychology, 6*(1), 130–137.
- Bandura, A. (1997). *Self-efficacy: The exercise of control*. Freeman.
- Bastian, K. C., & Fortner, C. K. (2020). Is less more? Subject-area specialization and outcomes in elementary schools. *Education Finance and Policy, 15*(2), 357–382.
- Bates, A. B., Latham, N., & Kim, J. A. (2011). Linking preservice teachers' mathematics self-efficacy and mathematics teaching efficacy to their mathematical performance. *School Science and Mathematics, 111*(7), 325–333.
- Beilock, S. L., Gunderson, E. A., Ramirez, G., & Levine, S. C. (2010). Female teachers' math anxiety affects girls' math achievement. *Proceedings of the National Academy of Sciences, 107*(5), 1860–1863.
- Berman, P., McLaughlin, M., Bass, G., Pauly, E., & Zellman, G. (1977). Federal programs supporting educational change. In *Factors affecting implementation and continuation* (Vol. VII). The Rand Corp. Calif.: The Rand Corporation ERIC Document Reproduction Service No. 140432.
- Betoret, F. D. (2006). Stressors, self-efficacy, coping resources, and burnout among secondary school teachers in Spain. *Educational Psychology, 26*(4), 519–539.
- Burley, W. W., Hall, B. W., Villeme, M. G., & Brockmeier, L. L. (1991, April). A path analysis of the mediating role of efficacy in first-year teachers' experiences, reactions, and plans. In *Annual Meeting of the American Educational Research Association*, Chicago.

- Bursal, M., & Paznokas, L. (2006). Mathematics anxiety and preservice elementary teachers' confidence to teach mathematics and science. *School Science and Mathematics, 106*(4), 173–180.
- Burte, H., Gardony, A. L., Hutton, A., & Taylor, H. A. (2017). Think3d!: Improving mathematics learning through embodied spatial training. *Cognitive Research: Principles and Implications, 2*(1), 13.
- Burte, H., Gardony, A. L., Hutton, A., & Taylor, H. A. (2020). Elementary teachers' attitudes and beliefs about spatial thinking and mathematics. *Cognitive Research: Principles and Implications, 5*, 1–18.
- Canning, E. A., Muenks, K., Green, D. J., & Murphy, M. C. (2019). STEM faculty who believe ability is fixed have larger racial achievement gaps and inspire less student motivation in their classes. *Science Advances, 5*(2), eaau4734.
- Cantrell, S. C., Almasi, J. F., Carter, J. C., & Rintamaa, M. (2013). Reading intervention in middle and high schools: Implementation fidelity, teacher efficacy, and student achievement. *Reading Psychology, 34*(1), 26–58.
- Cantrell, S. C., & Hughes, H. K. (2008). Teacher efficacy and content literacy implementation: An exploration of the effects of extended professional development with coaching. *Journal of literacy research, 40* (1), 95–127.
- Caprara, G. V., Barbaranelli, C., Steca, P., & Malone, P. S. (2006). Teachers' self-efficacy beliefs as determinants of job satisfaction and students' academic achievement: A study at the school level. *Journal of School Psychology, 44*(6), 473–490.
- Carroll, C., Patterson, M., Wood, S., Booth, A., Rick, J., & Balain, S. (2007). A conceptual framework for implementation fidelity. *Implementation science, 2*(1), 1–9.
- Charlesworth, R., Hart, C. H., Burts, D. C., & Hernandez, S. (1991). Kindergarten teachers beliefs and practices. *Early Child Development and Care, 70*(1), 17–35.
- Cheng, Y. L., & Mix, K. S. (2014). Spatial training improves children's mathematics ability. *Journal of Cognition and Development, 15*(1), 2–11.
- Compte, O., & Postlewaite, A. (2004). Confidence-enhanced performance. *American Economic Review, 94*(5), 1536–1557.
- Croft, A., Cogshall, J. G., Dolan, M., & Powers, E. (2010). *Job-embedded professional development: what it is, who is responsible, and how to get it done well*. (Issue Brief). National Comprehensive Center for Teacher Quality.
- Czerniak, C., & Chiarelott, L. (1990). Teacher education for effective science instruction—A social cognitive perspective. *Journal of Teacher Education, 41*(1), 49–58.
- Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). *Effective teacher professional development*. Learning Policy Institute Report.
- Davatzes, A., Gagnier, K., Resnick, I., & Shipley, T. (2018). Learning to form accurate mental models. *Eos, 99*. <https://par.nsf.gov/servlets/purl/10054887>.
- Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*(3), 181–199.
- Desimone, L. M., & Pak, K. (2017). Instructional coaching as high-quality professional development. *Theory Into Practice, 56*(1), 3–12.
- Durlak, J. A., & DuPre, E. P. (2008). Implementation matters: A review of research on the influence of implementation on program outcomes and the factors affecting implementation. *American journal of community psychology, 41*(3–4), 327–350.
- Egyed, C. J., & Short, R. J. (2006). Teacher self-efficacy, burnout, experience and decision to refer a disruptive student. *School Psychology International, 27*(4), 462–474.
- Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., & Sendurur, P. (2012). Teacher beliefs and technology integration practices: A critical relationship. *Computers & Education, 59*(2), 423–435.
- Fang, Z. (1996). A review of research on teacher beliefs and practices. *Educational Research, 38*(1), 47–65.
- Gagnier, K. M., Atit, K., Ormand, C. J., & Shipley, T. F. (2017). Comprehending 3D diagrams: Sketching to support spatial reasoning. *Topics in cognitive science, 9*(4), 883–901.
- Gagnier, K. M., & Fisher, K. R. (2020). Unpacking the black box of translation: A framework for infusing spatial thinking into curricula. *Cognitive Research: Principles and Implications, 5*(1), 1–19.
- Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American educational research journal, 38*(4), 915–945.

- Gibson, S., & Dembo, M. H. (1984). Teacher efficacy: A construct validation. *Journal of Educational Psychology, 76*(4), 569–582.
- Glickman, C. D., & Tamashiro, R. T. (1982). A comparison of first-year, fifth-year, and former teachers on efficacy, ego development, and problem solving. *Psychology in the Schools, 19*(4), 558–562.
- Goddard, R. D., Hoy, W. K., & Hoy, A. W. (2000). Collective teacher efficacy: Its meaning, measure, and impact on student achievement. *American Educational Research Journal, 37*(2), 479–507.
- Gunderson, E. A., Ramirez, G., Beilock, S. L., & Levine, S. C. (2013). Teachers' spatial anxiety relates to 1st- and 2nd-graders' spatial learning. *Mind, Brain, and Education, 7*(3), 196–199.
- Guskey, T. R. (1988). Teacher efficacy, self-concept, and attitudes toward the implementation of instructional innovation. *Teaching and Teacher Education, 4*(1), 63–69.
- Gustafson, B. J., & Rowell, P. M. (1995). Elementary preservice teachers: Constructing conceptions about learning science, teaching science and the nature of science. *International Journal of Science Education, 17*(5), 589–605.
- Hambrick, D. Z., Libarkin, J. C., Petcovic, H. L., Baker, K. M., Elkins, J., Callahan, C. N., Turner, S. P., Rench, T. A., & LaDue, N. D. (2012). A test of the circumvention-of-limits hypothesis in scientific problem solving: The case of geological bedrock mapping. *Journal of Experimental Psychology: General, 141*(3), 397–403.
- Hegarty, M. (2014). Spatial thinking in undergraduate science education. *Spatial Cognition & Computation, 14*(2), 142–167.
- Highlights of U.S. PISA 2018 Results Web Report (NCES 2020-166 and 2020-072) (2020). U.S. Department of Education. Institute of Education Sciences, National Center for Education Statistics. <https://nces.ed.gov/surveys/pisa/pisa2018/index.asp#/science/intlcompare>.
- Hoy, A. W. (2000, April). Changes in teacher efficacy during the early years of teaching. *Annual meeting of the American Educational Research Association*, New Orleans, LA.
- Hyson, M. C., Hirsh-Pasek, K., & Rescorla, L. (1990). The classroom practices inventory: An observation instrument based on NAEYC's guidelines for developmentally appropriate practices for 4- and 5-year-old children. *Early Childhood Research Quarterly, 5*(4), 475–494.
- Jee, B. D., Uttal, D. H., Gentner, D., Manduca, C., Shipley, T. F., & Sageman, B. (2013). Finding faults: Analogical comparison supports spatial concept learning in geoscience. *Cognitive Processing, 14*(2), 175–187.
- Jirout, J. J., & Newcombe, N. S. (2015). Building blocks for developing spatial skills: Evidence from a large, representative US sample. *Psychological Science, 26*(3), 302–310.
- Kagan, D. M. (1992). Implication of research on teacher belief. *Educational psychologist, 27*(1), 65–90.
- Kastens, K. A., & Ishikawa, T. (2006). Spatial thinking in the geosciences and cognitive sciences: A cross-disciplinary look at the intersection of the two fields. *Special Papers-Geological Society of America*.
- Kim, K. R., & Seo, E. H. (2018). The relationship between teacher efficacy and students' academic achievement: A meta-analysis. *Social Behavior and Personality, 46*(4), 529–540.
- Klassen, R. M., Bong, M., Usher, E. L., Chong, W. H., Huan, V. S., Wong, I. Y., & Georgiou, T. (2009). Exploring the validity of a teachers' self-efficacy scale in five countries. *Contemporary educational psychology, 34*(1), 67–76.
- Klassen, R. M., & Tze, V. M. (2014). Teachers' self-efficacy, personality, and teaching effectiveness: A meta-analysis. *Educational Research Review, 12*, 59–76.
- Klassen, R. M., Tze, V. M., Betts, S. M., & Gordon, K. A. (2011). Teacher efficacy research 1998–2009: Signs of progress or unfulfilled promise? *Educational Psychology Review, 23*(1), 21–43.
- Klimes-Dougan, B., August, G. J., Lee, C. Y. S., Realmuto, G. M., Bloomquist, M. L., Horowitz, J. L., & Eisenberg, T. L. (2009). Practitioner and site characteristics that relate to fidelity of implementation: The early risers prevention program in a going-to-scale intervention trial. *Professional Psychology: Research and Practice, 40*(5), 467–475.
- Kozhevnikov, M., Motes, M. A., & Hegarty, M. (2007). Spatial visualization in physics problem solving. *Cognitive Science, 31*(4), 549–579.
- Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex roles, 30*(11), 765–779.
- Levine, S. C., Ratliff, K. R., Huttenlocher, J., & Cannon, J. (2012). Early puzzle play: A predictor of preschoolers' spatial transformation skill. *Developmental Psychology, 48*(2), 530–542.

- Lowrie, T., Logan, T., & Ramful, A. (2017). Visuospatial training improves elementary students' mathematics performance. *British Journal of Educational Psychology*, *87*(2), 170–186.
- Lumpe, A., Czerniak, C., Haney, J., & Beltyukova, S. (2012). Beliefs about teaching science: The relationship between elementary teachers' participation in professional development and student achievement. *International Journal of Science Education*, *34*(2), 153–166.
- Lyons, I. M., Ramirez, G., Maloney, E. A., Rendina, D. N., Levine, S. C., & Beilock, S. L. (2018). Spatial Anxiety: A novel questionnaire with subscales for measuring three aspects of spatial anxiety. *Journal of Numerical Cognition*, *4*(3), 526–553.
- McCutcheon, G. (1980). How do elementary school teachers plan? The nature of planning and influences on it. *The Elementary School Journal*, *81*(1), 4–23.
- Meijer, C. J. W., & Foster, S. F. (1988). The effect of teacher self-efficacy on referral chance. *The Journal of Special Education*, *22*(3), 378–385.
- Midgley, C., Feldlaufer, H., & Eccles, J. S. (1989). Change in teacher efficacy and student self-and task-related beliefs in mathematics during the transition to junior high school. *Journal of educational Psychology*, *81*(2), 247.
- Miller, D. I., & Halpern, D. F. (2013). Can spatial training improve long-term outcomes for gifted STEM undergraduates? *Learning and Individual Differences*, *26*, 141–152.
- Mix, K. S. (2019). Why are spatial skill and mathematics related? *Child Development Perspectives*, *13*(2), 121–126.
- Mojavezi, A., & Tamiz, M. P. (2012). The impact of teacher self-efficacy on the students' motivation and achievement. *Theory & Practice in Language Studies*, *2*(3). <http://www.academypublication.com/issues/past/tpls/vol02/03/08.pdf>.
- Moore, W. P., & Esselman, M. E. (1992). Teacher efficacy, empowerment, and a focused instructional climate: Does student achievement benefit?.
- National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. The National Academies Press. <https://doi.org/10.17226/21836>
- National Assessment of Educational Progress (2015). Science assessment. Available from https://www.nationsreportcard.gov/science_2015/#scores?grade=4
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.
- National Research Council (US), Committee on Support for Thinking Spatially, The Incorporation of Geographic Information Science Across the K-12 Curriculum, Committee on Geography, & National Research Council. (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. National Academy Press.
- Nespor, J. (1987). The role of beliefs in the practice of teaching. *Journal of curriculum studies*, *19*(4), 317–328.
- Newcombe, N. (2017). *Harnessing spatial thinking to support STEM learning*. (OECD Education Working Papers, No. 161). OECD Publishing.
- Newcombe, N. S. (2010). Picture this: Increasing math and science learning by improving spatial thinking. *American Educator*, *34*(2), 29.
- Newcombe, N. S. (2013). Seeing relationships: Using spatial thinking to teach science, mathematics, and social studies. *American Educator*, *37*(1), 26.
- Newcombe, N. S., & Frick, A. (2010). Early education for spatial intelligence: Why, what, and how. *Mind, Brain, and Education*, *4*(3), 102–111.
- O'Donnell, C. L. (2008). Defining, conceptualizing, and measuring fidelity of implementation and its relationship to outcomes in K–12 curriculum intervention research. *Review of educational research*, *78*(1), 33–84.
- OECD. (2009). Education at a Glance 2009. *OECD INDICATORS*, <https://www.oecd.org/education/skills-beyond-school/43636332.pdf>
- OECD. (2018). *Education at a glance 2018: OECD indicators*. OECD Publishing. <https://doi.org/10.1787/eag-2018-en>
- Ormand, C. J., Manduca, C., Shipley, T. F., Tikoff, B., Harwood, C. L., Atit, K., & Boone, A. P. (2014). Evaluating geoscience students' spatial thinking skills in a multi-institutional classroom study. *Journal of Geoscience Education*, *62*(1), 146–154.
- Peters, M., Chisholm, P., & Laeng, B. (1995). Spatial ability, student gender, and academic performance. *Journal of Engineering Education*, *84*(1), 69–73.

- Ramirez, G., Hooper, S. Y., Kersting, N. B., Ferguson, R., & Yeager, D. (2018). Teacher math anxiety relates to adolescent students' math achievement. *AERA Open*, 4(1), 1–3.
- Resnick, I., Davatzes, A., Newcombe, N. S., & Shipley, T. F. (2017). Using relational reasoning to learn about scientific phenomena at unfamiliar scales. *Educational Psychology Review*, 29(1), 11–25.
- Riggs, I., & Enochs, L. (1990). Toward the development of an elementary teacher's science teaching efficacy belief instrument. *Science Education*, 74, 625–638.
- Ross, J. A. (1992). Teacher efficacy and the effects of coaching on student achievement. *Canadian Journal of Education/Revue canadienne de l'éducation*, 17(1), 51–65.
- Ross, J. A. (1994). The impact of an inservice to promote cooperative learning on the stability of teacher efficacy. *Teaching and Teacher Education*, 10(4), 381–394.
- Ross, J. A. (1998). The antecedents and consequences of teacher efficacy. *Advances in Research on Teaching*, 7, 49–74.
- Rudmann, D. S. (2002). Solving astronomy problems can be limited by intuited knowledge, spatial ability, or both.
- Sanchez, C. A. (2012). Enhancing visuospatial performance through video game training to increase learning in visuospatial science domains. *Psychonomic Bulletin & Review*, 19(1), 58–65.
- Shea, D. L., Lubinski, D., & Benbow, C. P. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of Educational Psychology*, 93(3), 604–614.
- Skaalvik, E. M., & Skaalvik, S. (2007). Dimensions of teacher self-efficacy and relations with strain factors, perceived collective teacher efficacy, and teacher burnout. *Journal of educational psychology*, 99(3), 611–625.
- Small, M. Y., & Morton, M. E. (1983). Research in college science teaching: Spatial visualization training improves performance in organic chemistry. *Journal of College Science Teaching*, 13(1), 41–43.
- Smylie, M. A. (1988). The enhancement function of staff development: Organizational and psychological antecedents to individual teacher change. *American Educational Research Journal*, 25(1), 1–30.
- Soodak, L. C., & Podell, D. M. (1993). Teacher efficacy and student problem as factors in special education referral. *The Journal of Special Education*, 27(1), 66–81.
- Sorby, S., Casey, B., Veurink, N., & Dulaney, A. (2013). The role of spatial training in improving spatial and calculus performance in engineering students. *Learning and Individual Differences*, 26, 20–29.
- Sorby, S. A. (2001). A course in spatial visualization and its impact on the retention of female engineering students. *Journal of Women and Minorities in Science and Engineering*, 7(2), 20.
- Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education*, 31(3), 459–480.
- Spillane, J. P., Diamond, J. B., Walker, L. J., Halverson, R., & Jita, L. (2001). Urban school leadership for elementary science instruction: Identifying and activating resources in an undervalued school subject. *Journal of Research in Science Teaching*, 38(8), 918–940.
- Stake, R. E., Easley, J. A., & Anastasiou, C. J. (1978). *Case studies in science education* (Vol. 1). Center for Instructional Research and Curriculum Evaluation, University of Illinois at Urbana-Champaign.
- Stein, M. K., & Wang, M. C. (1988). Teacher development and school improvement: The process of teacher change. *Teaching and Teacher Education*, 4(2), 171–187.
- Stieff, M. (2011). Improving representational competence using molecular simulations embedded in inquiry activities. *Journal of Research in Science Teaching*, 48(10), 1137–1158.
- Stigler, J. W., & Hiebert, J. (2004). Improving mathematics teaching. *Educational Leadership*, 61(5), 12–17.
- Stipek, D. J., Givvin, K. B., Salmon, J. M., & MacGyvers, V. L. (2001). Teachers' beliefs and practices related to mathematics instruction. *Teaching and Teacher Education*, 17(2), 213–226.
- Stumpf, H., Mills, C. J., Brody, L. E., & Baxley, P. G. (2013). Expanding talent search procedures by including measures of spatial ability: CTY's spatial test battery. *Roeper Review*, 35(4), 254–264.
- Taylor, H. A., & Hutton, A. (2013). Think3d!: Training spatial thinking fundamental to STEM education. *Cognition and Instruction*, 31(4), 434–455.
- Terlecki, M. S., Newcombe, N. S., & Little, M. (2008). Durable and generalized effects of spatial experience on mental rotation: Gender differences in growth patterns. *Applied cognitive psychology*, 22(7), 996–1013.
- Tschannen-Moran, M., Hoy, A. W., & Hoy, W. K. (1998). Teacher efficacy: Its meaning and measure. *Review of educational research*, 68(2), 202–248.
- Tschannen-Moran, M., & Hoy, A. W. (2001). Teacher efficacy: Capturing an elusive construct. *Teaching and Teacher Education*, 17(7), 783–805.

- Tschannen-Moran, M., & Barr, M. (2004). Fostering student learning: The relationship of collective teacher efficacy and student achievement. *Leadership and Policy in Schools, 3*(3), 189–209.
- Tsoulopas, C. N., Carson, R. L., Matthews, R., Grawitch, M. J., & Barber, L. K. (2010). Exploring the association between teachers' perceived student misbehaviour and emotional exhaustion: The importance of teacher efficacy beliefs and emotion regulation. *Educational Psychology, 30*(2), 173–189.
- Upadaya, K., & Eccles, J. S. (2014). How do teachers' beliefs predict children's interest in math from kindergarten to sixth grade? *Merrill-Palmer Quarterly (1982), 60*(4), 403–430.
- Uttal, D. H., & Cohen, C. A. (2012). Spatial thinking and STEM education: When, why, and how? In *Psychology of Learning and Motivation* (Vol. 57, pp. 147–181). Academic Press.
- Uttal, D. H., Miller, D. I., & Newcombe, N. S. (2013). Exploring and enhancing spatial thinking: Links to achievement in science, technology, engineering, and mathematics? *Current Directions in Psychological Science, 22* (5), 367–373.
- Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., & Newcombe, N. S. (2017). I. Spatial skills, their development, and their links to mathematics. *Monographs of the Society for Research in Child Development, 82*(1), 7–30.
- Verdine, B. N., Golinkoff, R. M., Hirsh-Pasek, K., Newcombe, N. S., Filipowicz, A. T., & Chang, A. (2014). Deconstructing building blocks: Preschoolers' spatial assembly performance relates to early mathematical skills. *Child Development, 85*(3), 1062–1076.
- Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101*(4), 817–835.
- Wai, J., & Uttal, D. H. (2018). *Why spatial reasoning matters for education policy*. American Enterprise Institute.
- Wayne, A. J., & Youngs, P. (2003). Teacher characteristics and student achievement gains: A review. *Review of Educational Research, 73*(1), 89–122.
- Wolfgang, C., Stannard, L., & Jones, I. (2003). Advanced constructional play with LEGOs among preschoolers as a predictor of later school achievement in mathematics. *Early Child Development and Care, 173*(5), 467–475.
- Woodman, T. I. M., & Hardy, L. E. W. (2003). The relative impact of cognitive anxiety and self-confidence upon sport performance: A meta-analysis. *Journal of Sports Sciences, 21*(6), 443–457.
- Woolfolk Hoy, A. E., & Burke-Spero, R. (2005). What predicts student teacher self-efficacy. *Academic Exchange Quarterly, 9*(4), 123–127.
- Wozney, L., Venkatesh, V., & Abrami, P. (2006). Implementing computer technologies: Teachers' perceptions and practices. *Journal of Technology and Teacher Education, 14*(1), 173–207.

How to cite this article: Gagnier, K. M., Holochwost, S. J., & Fisher, K. R. (2021). Spatial thinking in science, technology, engineering, and mathematics: Elementary teachers' beliefs, perceptions, and self-efficacy. *Journal of Research in Science Teaching, 1*–32. <https://doi.org/10.1002/tea.21722>