PROSPECTIVE ELEMENTARY SCHOOL TEACHERS' PERCEPTIONS OF STEM THINKING AND THEIR ORIENTATIONS FOR STEM THINKING

Marta T. Magiera
Marquette University
marta.magiera@marquette.edu

Mohammad S. Al-younes
Marquette University
mohammad.al-younes@marquette.edu

Drawing on a concept-map methodology, we investigated how 18 prospective elementary teachers (PSTs) conceptualize STEM thinking as habits of mind shared across STEM domains in the context of problem-solving prior to explicit classroom discussions about STEM thinking. A 28-question, 5-point Likert-scale survey was used to explore PSTs' orientations for STEM thinking in elementary school mathematics classrooms. Our results show that PSTs come to teacher education with many general ideas about STEM thinking in problem-solving contexts but do not necessarily see STEM ways of thinking as common habits of mind supporting problem-solving across STEM domains. Our data also reveals that PSTs come with positive overall STEM thinking orientations, but they tend to be hesitant to think about themselves as future teachers who foster STEM thinking in their elementary school classrooms. We discuss implications for teacher preparation.

Keywords: Integrated STEM / STEAM, Preservice Teacher Education, Problem Solving, Teacher Beliefs

Background

The importance of STEM education, which refers to teaching and learning science, technology, engineering, and mathematics, has been established for many years. STEM education contributes to developing a STEM-literate society (Bybee, 2013). Early on, STEM education was interpreted through the lens of improving student learning in isolated STEM disciplines, primarily science, and mathematics (Breiner et al., 2012; Sanders, 2009; Wang et al., 2011). Over the years, the meaning of the acronym STEM has shifted from thinking about STEM as a collection of isolated disciplines—S, T, E, and M to thinking about STEM as an interdisciplinary domain centered around authentic problems that allow for integrating two or all of the STEM content (Tytler et al., 2019). Recently, some STEM education researchers advocated for expanding thinking about STEM education from content integration to focusing on common habits of mind that link STEM disciplines (Bennett & Ruchti, 2014; Kelley & Knowles, 2016; Maiorca & Roberts, 2022; Roberts et al., 2022; Williams & Roth, 2019). Kelley and Knowles (2016), for example, proposed interpreting STEM integration through the lens of problem-solving practices shared across the STEM disciplines. Bennett and Ruchti (2014) argued for interpreting STEM integration through the lens of reasoning skills foundational to all STEM disciplines. Roberts et al. (2022) viewed integrated STEM as problem-solving practices and ways of thinking that support problem-solving across the STEM domains.

Advocates of more integrated approaches to STEM education argue that teaching STEM in a more connected manner in the context of solving real-world problems helps students understand the characteristics and features of STEM disciplines as forms of human knowledge and inquiry and generates student awareness of how STEM fields shape human environments (Roberts et al., 2022; National Research Council, [NRC], 2014).

There is an increased trend to prepare STEM-focused teachers. However, despite the emphasis on STEM integration in K-12 education and calls for providing elementary students with early experiences with STEM, limited research addresses prospective elementary school teachers (PSTs') preparation for STEM integration. Our research explores perceptions about habits of mind across STEM problem-solving that elementary PSTs hold prior to engaging them in discussions about STEM thinking in a teacher education program. This research was guided by the following research questions: (1) What is elementary PSTs' initial understanding of habits of mind shared across STEM domains in the context of problem-solving before explicit instruction about STEM thinking? and (2) What is PSTs' initial orientation for STEM thinking in elementary school mathematics classrooms?

Conceptual Foundations

We drew on phenomenography as our research methodology to investigate PSTs' perceptions of STEM thinking (Marton, 1986; 1988). Our goal was to construct an initial framework that describes our PSTs' perceptions of STEM thinking in the context of problem-solving and track changes in our PSTs' understandings of STEM thinking. A central focus of phenomenography studies is the examination of *learners' conceptions* of a phenomenon of interest. However, we find it useful to briefly discuss how STEM thinking is conceptualized in the existing research literature.

Like other researchers (e.g., Bennett & Ruchti, 2014; Denick et al., 2013, Kelley & Knowles, 2016; Williams & Roth, 2019), we view STEM thinking as a way of STEM integration through the lens of problem-solving practices shared across the STEM disciplines. Consistent with NRC (2014) descriptions, we conceptualize STEM thinking as purposeful thinking in problem-solving situations that incorporates concepts, methods, attitudes, and practices from science, technology, engineering, and mathematics. We operationalize STEM thinking as the use of disciplinary practices related to problem-solving that transcend across STEM disciplines. Examples of these practices include asking questions, evaluating information, defining and interpreting problems, planning, carrying out investigations, developing and using solution models, analyzing and interpreting information, testing ideas, constructing and justifying arguments, constructing explanations, or communicating information.

Given the intricacies of STEM thinking and practices, we drew on concept mapping to allow PSTs to externalize their interpretations of STEM thinking. Concept maps are visual displays that show how individuals represent their knowledge by organizing their thoughts and experiences about a phenomenon of interest. The existing literature on concept mapping in teacher education provides evidence that concept maps can serve as useful and valid assessment tools for gaining insights into student knowledge (Brinkmann, 2003; Kinchin et al., 2000; Schmittau, 2009). Past researchers also documented that concept maps provide valid and reliable research tools (Miller et al., 2009).

Our conceptualization of prospective teachers' orientation for fostering STEM thinking in their future practice was grounded in the Theory of Planned Behavior (Ajzen, 1991). The Theory of Planned Behavior describes behavioral intentions as the predictive variables of one's behavior. We also drew on the existing research that provides evidence that beliefs, understandings, and intentions form a predictive platform on which prospective teachers build their orientations for fostering STEM subjects in their future classrooms (e.g., Kurup et al., 2019; Wu et al., 2022). For our study, we selected four behavioral domains as a platform for describing PSTs' orientations for STEM thinking: prospective teachers' (a) emotional readiness for STEM thinking practices in problem-solving contexts, (b) visions of the importance of STEM thinking, (c) perceptions of classroom implementation of STEM thinking, and (d) self-efficacy beliefs about their ability to engage in STEM thinking and foster STEM thinking in elementary classrooms.

Method

Participants and study context. The study was conducted in the context of a larger project that produced curricular materials designed to support teacher candidates' learning about STEM thinking in elementary mathematics classrooms. Participants were 18 PSTs enrolled in *Problem Solving and Reasoning for Teachers* course. The vast majority were in their first year at the university (12 PSTs), and the remaining participants were either in their second year (3 PSTs) or in their third year (3 PSTs). For all PSTs, the course that provided the context for the study was their first mathematics course in a 3-course mathematics sequence for elementary education majors. The 75 minutes long class sessions met twice a week for 14 weeks. This paper reports data collected during the first week of the course, during which PSTs engaged in a problem-solving activity from the first module. The initial class activity asked PSTs to build the tallest freestanding tower, given 20 pieces of uncooked spaghetti, clear tape, one yard of string, scissors, and a measuring tape. By working in groups of three, PSTs had 18 minutes to accomplish their task. Following the activity, the instructor introduced Polya's (2004) problem-solving framework as a general guide for organizing problem-solving activities and invited PSTs to reflect on their problem-solving approaches, strategies, and thinking in the *Spaghetti Tower* problem context. Individual students and groups shared how they made sense of the problem, planned solution approaches, evaluated and tested their ideas and strategies, what knowledge they drew upon, how they decided which materials to use, etc.

Data and Data Analysis. As part of their homework, following the *Spaghetti Tower* activity, PSTs were asked to construct and explain a concept map that illustrates their interpretation of ways of thinking that support solving problems across STEM disciplines (STEM thinking). We analyzed concept maps and reflections on STEM thinking (n = 18) to answer RQ #1.

At the beginning of the semester, PSTs were also asked to respond to 28 (5-point) Likert-scale survey questions designed to gain insights into their initial orientations for STEM thinking (n = 18). Consistent with our conceptual framework, the survey questions addressed each of the four predictive behavior categories described earlier. The survey questions were adapted from the existing literature (e.g., Kurup et al., 2019; Wu et al., 2022) and included seven questions per category. Included in Figure 1 are sample survey questions from each question category.

Emotional readiness questions (ER): Q3*: I enjoy thinking about becoming a teacher who takes on a STEM thinking approach in my lessons.* Q6: *I feel it is important for a teacher to be able to foster STEM thinking in the elementary school mathematics classroom.*	Visions of importance questions (VI) Q9*: I think the focus on STEM thinking in elementary mathematics classrooms can improve students' employment competitiveness.* Q10. *I think the focus on STEM thinking in elementary mathematics classrooms helps to cultivate students' ability to solve real-life problems.*
Perceptions of implementation questions (PI)	Self-efficacy questions (SE)

Q16: *I do not think implementing STEM thinking in my elementary school classroom will make me feel stressed and anxious.* Q 19: *If I have an option, I would like to teach in a place where STEM thinking and STEM integration are valued.*	Q23: *I feel confident that I will be able to motivate students who have a low interest in activities that facilitate STEM thinking.* Q 28: *I feel confident in my ability to understand and apply concepts and methods from STEM subjects in different problem situations.*

Figure 1: Examples of survey questions from each behavioral category

Analysis of PSTs' reflections and concept maps. We first utilized qualitative content analysis methods and open coding (Saldaña, 2016) to identify PSTs' initial views about thinking strategies that transcend STEM problem-solving. This data analysis stage comprised multiple passes through the data, during which each response was carefully annotated and scored. The identified concepts were then organized into broader categories that emerged from patterns in the data set. While revising our coding, we kept track of concepts that did not fit the initial list of the broader categories and further expanded our initial list of categories using patterns from the analysis. Ultimately, concepts that PSTs connected to STEM problem-solving were organized into five broader categories: (1) Analyzing, (2) Planning, (3) Executing, (4) Evaluating, and (5) Other. The *Other* category included more general concepts identified across the data that did not fit the first four categories. We then tabulated code frequencies to provide a collective summary of concepts that our group of PSTs connected to STEM thinking in problem-solving.

We also applied a concept map scoring rubric adapted from (Watson et al., 2016) to provide the overall picture of each PST's views of STEM thinking. Each map was scored on (a) the overall breadth of ideas related to STEM thinking in problem-solving included in the map, (b) the level of interconnectedness of ideas, and (c) the overall map design. Each aspect was scored on a 4-point scale (max. 12). The overall map score for each PST was computed as the average across concept map score categories. The overall map score provided a measure of the strength of each PSTs' vision of STEM thinking in problem-solving. We then computed the average concept map score for our PSTs cohort.

Analysis of survey responses. We first constructed survey scale sub-scores by combining PSTs' responses to questions from each group. For each PST, the survey sub-scores were defined as a sum of the PST's responses to all questions from a respective category (Sullivan & Artino, 2013; Norman, 2010). The sub-scores provided a measure of variables associated with each category: ER, emotional readiness for STEM thinking; VI, visions of the importance of STEM thinking; PI, perceptions on classroom implementation of STEM thinking; and SE, self-efficacy with STEM thinking (scale 7-35). We then conducted a non-parametric Friedman test to examine the distribution of median sub-scores and explore the extent to which each sub-score contributed to our PSTs' STEM thinking orientation. We conducted a Wilcoxon post hoc test with a Bonferroni adjustment for multiple comparisons to identify possible differences between sub-score pairs. For each PST, we also examined the percentage of survey questions for which the PST responded with a "strongly agree" score of 5 or "agree" (score of 4) to provide the overall summary of STEM thinking orientation for PSTs in our cohort.

Results

RQ1. *How do elementary PSTs understand habits of mind shared across STEM domains in the context of problem-solving before explicit instruction about STEM thinking?*

Included in Table 1 is a summary of ideas identified across the analyzed concept maps and accompanying explanations that our PSTs associated with STEM thinking.

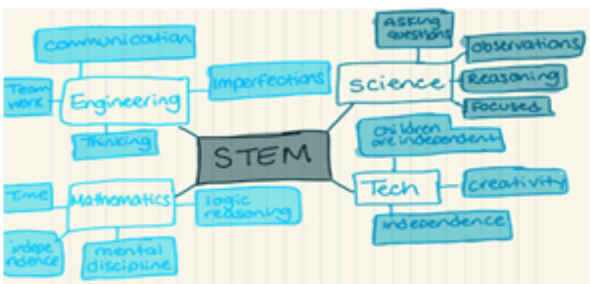
Table 1 shows that, as a group, collectively, PSTs associated with STEM thinking a broad range of habits of mind. About 60% of our PSTs considered some aspect of thinking related to analyzing problem information as a common thinking habit across STEM problem-solving. Over 70% of our PSTs considered some aspect of thinking related to solution planning as common habits across STEM problem-solving. As summarized in Table 1, half of our PSTs also thought about STEM problem-solving in terms of creativity. Less often, PSTs in our cohort associated STEM thinking in problem-solving with ways of thinking focused on executing or evaluating problem-solving activity. While, as a group, our PSTs associated a broad range of concepts with STEM thinking, the visions of STEM thinking shared by individual PSTs were more limited. PSTs' maps included between 1-12 concepts. The average map score for the group was 1.85, and the distribution of individual overall map scores was as follows: 5 PSTs (scores between 3-4); 4 PSTs (scores between 2-3); 9 PSTs (scores between 1-2). Most of the analyzed concept maps had limited breadths (number of concepts included) and minimal or no connections illustrating how the included concepts support thinking across STEM problem-solving.

Table 1: PSTs' collective views of STEM habits of mind in problem-solving

Category	Included Concepts	#PSTs (%)
Analyzing	•Thinking about problem information, what is known, interpreting problem situation, thinking about the knowledge needed to generate problem solution, making a mental picture of the problem and what is needed to address/solve, organizing information	11 (61%)
	•Generating and asking questions, wondering about	6 (33%)
	•Thinking about similarities and differences in problems and solutions, considering patterns,	5 (27%)
	•Making observations	3 (16%)
Planning	•Anticipating how a solution could look like, brainstorming, thinking about/considering options, having an open mind to possibilities, experimenting with ideas	14 (77%)
	•Thinking out of the box, thinking creatively/flexibly, being open to risk-taking, thinking in innovative ways	9 (50%)
	•Thinking about different tools	7 (39%)
Executing	•Testing options and strategies, creating new strategies/prototypes/models	7 (39%)
	•Engaging with others in a team, communicating/explaining solutions	7 (39%)
Evaluating	•Reflecting on understanding, reflecting on what works and what does not, thinking about progress, thinking about better worse ideas/solutions	5 (28%)

Other	•Using logic and reasoning, thinking in systematic ways	6 (33%)

Figure 2 shows an example of a concept map drawn by Alice (pseudonym). Alice's map and her explanation (Figure 1) illustrate that she might not perceive STEM thinking in terms of habits of mind that *connect* the STEM disciplines in problem-solving. Like many other PSTs, Alice considered a limited number of concepts overall and associated those concepts with isolated disciplines. Her star-like map design and the explanation she provided for her map show that she might think about STEM as a collection of isolated disciplines and not see the STEM habits of mind as overarching ways of thinking applicable to problem-solving situations across the STEM disciplines.



…Science allows to experiment and explore outside world. Observe things around, ask questions and wonder. Being pushed to find reasoning. Technology allows to be creative and independent when figuring out on the computer. Engineering allows for communication and team work. Mathematics brings mental discipline. …

Figure 2: An example of a concept map and an excerpt from the accompanying explanation (Alice)

RQ 2. *What is PSTs' initial orientation for STEM thinking in elementary school mathematics classrooms prior to the instruction about STEM thinking?*

The analysis of survey responses revealed that, overall, our PSTs had positive STEM thinking orientations. Eleven of the PSTs (61%) responded "strongly agree" or "agree" to more than 50% of survey questions. The analysis of survey responses, disaggregated by question group, showed that PSTs' STEM orientations differed along the four behavioral domains of interest.

Figure 3 summarizes distributions of PSTs' survey responses disaggregated by each of the four behavioral domains of interest: Emotional readiness for STEM thinking. ER; Visions of the importance of STEM thinking, VI; Perceptions of classroom implementation of STEM thinking, PI; and Self-efficacy beliefs about one's ability to engage in STEM thinking and foster STEM thinking in elementary classrooms, SE.

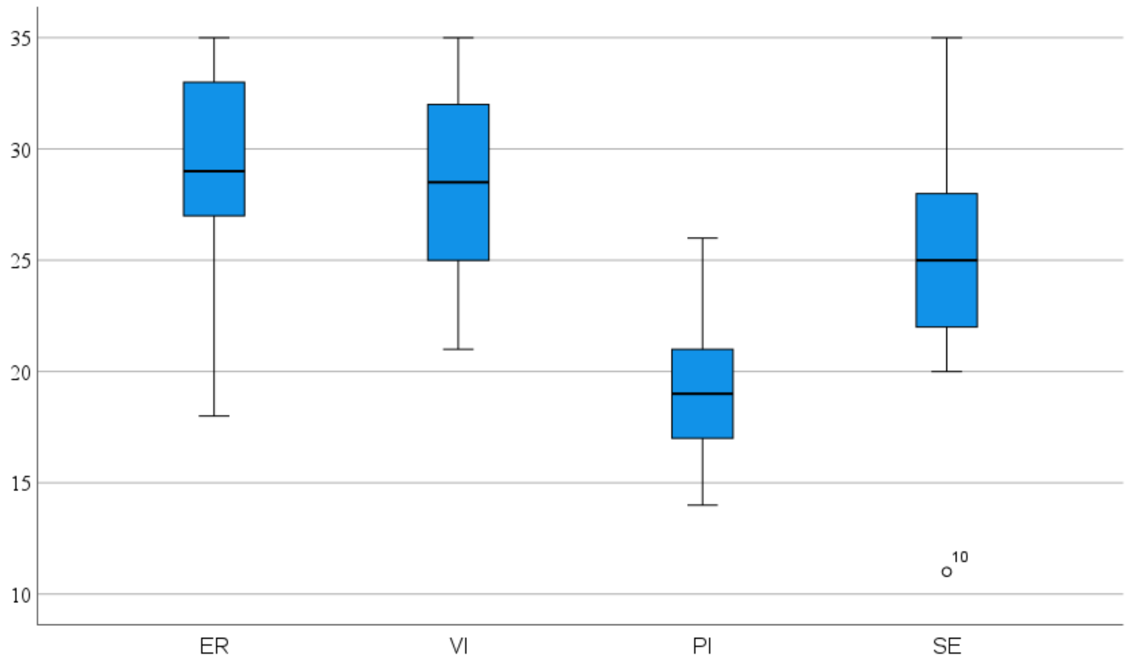


Figure 3: Distribution of median survey sub-scores

PST's orientations for STEM thinking differed across the four behavioral domains: ER (median = 29, range 18-35); VI (median = 28.5, range 21 - 35); PI (median = 19, range 14 - 26), and SE (median = 25, range 11-35). Friedman's test revealed statistically significant differences across PSTs' responses to these four groups of survey questions: $\chi 2(3, N = 18) = 33.16$, $p = 0.01$. Kendal's coefficient of concordance of 0.614 indicated that the observed differences in PSTs' orientations for STEM thinking were fairly large across the four domains.

We conducted follow-up comparisons using a Wilcoxon test and controlling for Type I error across these comparisons at the 0.05 level using the LSD procedure. The median for perceptions of implementation (PI) was significantly lower than the median for emotional readiness (ER), $p < 0.01$, the median for visions of importance (VI), $p < 0.01$, and the median for self-efficacy (SE), $p < 0.01$. The median for self-efficacy (SE) was significantly lower when compared to the median for emotional readiness (ER), $p = 0.02$, and the median for visions of importance (VI), $p = 0.006$.

Discussion

There is an increased focus on providing elementary school students with STEM experiences and engaging them in STEM problem-solving practices and ways of thinking (Estapa & Tank, 2017). At the same time, little is known about ideas about STEM thinking that prospective elementary school teachers bring to their preparation programs and what initial orientations for STEM thinking they have. Below, we discuss the implications of our research for teacher educators and future studies.

The analysis of concept maps our PSTs generated following the first class activity suggests that PSTs come with some ideas about STEM ways of thinking in problem-solving contexts. When considered as a group, our PSTs included many concepts and ideas about STEM thinking that were consistent with the existing literature (e.g., Bennett & Ruchti, 2014; Denick et al., 2013, Kelley & Knowles, 2016; Roberts et al., 2022; Williams & Roth, 2019). For example, thinking about structural similarities or differences across problems and solutions, anticipating how a problem solution could look like, asking questions, and wondering. But when considered individually, our PSTs shared more limited perspectives about STEM thinking in problem-solving contexts. Their maps were not well developed and generally included a limited number of concepts. In addition, the overall designs of their maps suggested that many of our PSTs might not think about STEM thinking as a form of STEM integration. To prepare PSTs for meeting the challenges of teaching mathematics in a way that supports STEM integration, teacher educators need to engage PSTs in explicit discussions about shared ways of thinking and practices that support STEM problem-solving. A possible entry point for supporting PSTs in developing views of habits of mind that connect STEM disciplines in problem-solving contexts could be explicit discussions about ways of thinking that contribute to problem analysis, planning, and execution across STEM problem-solving situations.

Our study shows that elementary PSTs come to their preparation programs with many positive orientations toward STEM thinking overall. About two-thirds of our participants documented positive emotional readiness for STEM thinking, viewed STEM thinking as important for students to develop, and many of the PSTs had positive self-efficacy beliefs about their ability to engage in STEM thinking in problem-solving contexts.

Our analysis of survey responses also revealed that our PSTs were most concerned about classroom implementation of STEM thinking. Their responses suggested that they appear to be hesitant to think of themselves as future teachers who can foster STEM thinking in their elementary school classrooms. This finding deserves special attention from teacher educators. Our results show that even though PSTs might think highly about the importance of engaging students in STEM thinking, they might not facilitate this engagement in their future classroom practice without proper support.

In future research, we are interested in seeking more information about ways in which prospective elementary school teachers make sense of STEM thinking in problem-solving contexts as a way of integrating STEM domains. We are also interested in exploring how to best support the development of PSTs' knowledge about STEM thinking as a way of STEM integration in problem-solving contexts and their dispositions for STEM thinking.

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References

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Making*, *50*(2), 17-211. https://www.sciencedirect.com/science/article/abs/pii/074959789190020T?via%3Dihub

Bennett, C. A., & Ruchti, W. (2014) Bridging STEM with mathematical practices*, Journal of STEM Teacher Education*, *49*(1), 17-28. DOI: doi.org/10.30707/JSTE49.1

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

Brinkmann, A. (2003). Graphical knowledge display - mind mapping and concept mapping as efficient tools in mathematics education. *Mathematics Education Review*, *16*, 35-48.
Bybee, R. W. (2013). *The Case for STEM Education: Challenges and Opportunities.* National Science Teachers Association, NSTA Press, Arlington, Virginia.
Denick, D., Dringenberg, E., Fayyaz, F., Nelson, L., Pitterson, N., Yatchmeneff, M., & Cardella, M. (2013). STEM thinking in informal environments: Integration and recommendations for formal settings. *In Proceedings of the 2013 ASEE IL-IN Section Conference*, Angola, IN.
Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education, *International Journal of STEM Education*, *3*(11), 1-11. https://doi.org/10.1186/s40594-016-0046-z
Kinchin, I. M., Hay, D. B., & Adams, A. (2000). How a qualitative approach to concept map analysis can be used to aid learning by illustrating patterns of conceptual development. *Educational Research*, *42*(1), 43-57
Korup, P., Li, X., Powell, G., & Brown, M. (2019). Building future primary teachers' capacity in STEM: based on a platform of beliefs, understandings and intentions. *International Journal of STEM education,* 6:10, https://doi.org/10.1186/s40594-019-0164-5
Marton, F. (1986). Phenomenography: A research approach to investigating different understandings of reality. *Journal of Thought*, *21*(3), 28–49.
Marton, F. (1988). Phenomenography: Exploring different conceptions of reality. In D. M. Fetterman (Ed.), *Qualitative approaches to evaluation in education: the silent scientific revolution* (pp. 176–205). New York: Praeger.
Maiorca, C., & Roberts, T. (2022). Problem-solving by design: The integrated STEM practices. *The Elementary School Journal*, 20-21.
Miller, K., Koury, K., Fitzgerald, G. E., Hollingsead, C., Mitchem, K., Tsai, H., & Park, M. (2009). Concept mapping as a research tool to evaluate conceptual change related to instructional methods. *Teacher Education and Special Education*, *32*(4), 365-378.
National Research Council (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: The National Academies Press. https://doi.org/10.17226/18612
Norman, G. (2010). Likert scales, levels of measurement and the "laws" of statistics. *Advances in Health Science Education*, *15*, 625-632.
Pólya, G. (2004). How to solve it: A new aspect of mathematical method (No. 246). Princeton University Press.
Roberts, T., Maiorca, C., Jackson, C., Mohr-Schroeder, M. (2022). Integrated STEM as problem-solving practice. *Investigations in Mathematics Learning*, *14*(1), 1-13.
Saldaña, J. (2016). *The coding manual for qualitative researchers*, Thousand Oaks, CA: Sage Publications Inc.
Sanders, M. (2009). STEM, STEM education, STEMmania. The Technology Teacher, 68(4), 20–26.
Schmittau, J. (2009). Concept mapping as a means to develop and assess conceptual understanding in secondary mathematics teacher education. In K. Afamasaga-Fuata'I (Ed.). *Concept mapping in mathematics: Research into practice,* (pp. 137-147). Springer Science+Business Media, New York, NY.
Sullivan, G., M., & Artino, A. R. (2013). Analyzing and interpreting data from Likert-type scales. *Journal of Graduate Medical Education*, *5*(3), 541-542.
Tytler, R., Williams, G., Hobbs, L., & Anderson, J. (2019). Challenges and opportunities for STEM interdisciplinary agenda. In B. Doing, J. Williams, D. Swanson, R. Borromeo Ferri, P. Drake (Eds.). Interdisciplinary mathematics education. The state of the art and beyond. (pp. 51-84). Cham, Switzerland: Springer.
Wang, H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, *1*(2), 1–13.
Watson, M. K., Pelkey, J., Noyes, C., Rodgers, M. (2016). Assessing conceptual knowledge using three concept maps scoring methods. *Journal of Engineering Education*, *105*(1), 118-146.
Williams, J., & Roth, W. M. (2019). Theoretical perspective on interdisciplinary mathematics. In B. Doing, J. Williams, D. Swanson, R. Borromeo Ferri, & P. Drake (Eds.). *Interdisciplinary mathematics education. The state of the art and beyond*, (pp. 13-34). Cham, Switzerland: Springer.
Wu, P., Yang, L., Hu, X., Li., B., Liu, Q., Wang., Y., & Huang, J. (2022). How K-12 teachers' readiness influences their intentions to implement STEM education: Exploratory study based on the decomposed theory of planned behavior, *Applied Science*, *12*, 11989. https://doi.org/10.3390/app122311989