Are You a STEM Teacher?: Exploring PK-12 Teachers' Conceptions of STEM Education

Nancy Holincheck
George Mason University

Terrie M. Galanti
University of North Florida

Abstract

This study explores teachers' conceptions of STEM education at the beginning of an online graduate course for practicing PK-12 teachers (n=20). A grounded theory approach was used to analyze open-ended survey data and concept maps. Teachers in the study interpreted STEM teaching from either a disciplinary or an integrated perspective. Their conceptions of STEM education within their concept maps fell into one or more of six categories: (1) utilitarian; (2) acquisition of disciplinary knowledge; (3) activities and resources; (4) access to meaningful problem-solving experiences; (5) advocacy for systemic change; and (6) buzzwords. This study reveals the complexity of teachers' conceptions of STEM education as they prepare to integrate STEM in their classrooms. The use of concept maps as a formative assessment can better position teacher educators and professional developers to move teachers toward a more sustainable integrated perspective of STEM teaching.

Are you a STEM teacher?: Exploring PK-12 Teachers' Conceptions of STEM Education

Researchers and policy makers have long advocated for a strategic approach to integrated STEM learning (e.g., National Academies of Engineering [NAE] & National Research Council [NRC], 2014), yet there remains a persistent lack of consensus on the conceptualization of STEM integration in PK-12 contexts (English, 2016; Moore et al., 2020). Disjointed perspectives of STEM subjects (Wang et al., 2011) extend from teachers to students (Kelley & Knowles, 2016). With more recent calls to increase the relevance of STEM as creative and real-world problem solving (Committee on STEM Education, 2018), PK-12 teachers need a robust sense of the possibilities of STEM integration beyond traditional subject-based instruction. This robustness is widely described by scholars as shared disciplinary practices in the context of collaborative, authentic, and complex real-world problem solving (Li & Schoenfeld, 2019; Moore et al., 2020).

As STEM teacher educators from two universities with a mutual interest in constructing a transdisciplinary conceptualization of STEM (Vasquez, 2015) with our graduate students, we collaboratively designed curriculum for online graduate courses for practicing PK-12 teachers in Summer 2021. We chose a transdisciplinary approach to STEM integration because it encourages teachers to build bridges between STEM disciplines and real-world challenges (Vasquez et al., 2013). Our instructional goal was the development of a robust vision of integrated STEM in curriculum, instruction, and assessment with an explicit focus on creating a more equitable world (Bryan & Guzey, 2020).

Teachers have a variety of STEM experiences, so it was important to capture what they thought about STEM and how they saw themselves as STEM educators at the beginning of our courses. We used concept maps as formative assessments to help us understand the perspectives that they brought to their graduate studies. This paper offers a qualitative thematic analysis of teachers' initial conceptions of STEM education with implications for fostering sustainable integrated STEM teaching practices in professional development contexts.

Literature Review

School divisions and policymakers across the United States have responded to calls to prioritize STEM (Bybee, 2010), yet there is a persistent lack of consensus on the conceptualization of the integrated STEM in PK-12 education (Akerson et al., 2018; English, 2016; Moore et al., 2020; NAE and NRC, 2014). This lack of consensus is driven by contextual barriers to the blending of traditional STEM disciplines in our current PK-12 education systems. These barriers may include pedagogical challenges, structural challenges, curriculum constraints, student readiness, and administrator support (Ejiwale, 2013, García-Carrillo et al., 2021; Margot & Keller, 2019; So et al., 2021). Furthermore, STEM integration is dependent upon elementary teacher STEM knowledge and professional beliefs about ambiguity and open-endedness (Baker & Galanti, 2017; Nadelson & Seifert, 2017). A productive conception of STEM education must acknowledge contextual barriers to integration but also communicate the potential to engage students in relevant problem-solving experiences.

In our work with practicing PK-12 teachers, we draw upon Nadelson and Seifert's (2017) definition of integrated STEM as requiring "the application of knowledge and practices from multiple STEM disciplines to learn about or solve transdisciplinary problems" (p. 221). We elaborate on these conditions as student-centered, collaborative class structures with an explicit focus on the engineering design process (Jolly, 2016). The Nadelson and Seifert (2017) definition retains the uniqueness of each STEM discipline, but it also encompasses emergent pedagogies for integrating STEM within and across disciplines (Hjalmarson et al., 2020). This concept of integration reflects an "organized, open-ended approach to investigation that promotes creativity, invention and prototype design, along with testing and analysis" (Jolly, 2016, p. 18). Our assumptions about integrating STEM are informed by our own prior experiences as women in advanced STEM degree programs and as former secondary teachers in mathematics and science. We see the transformational potential of integrated STEM education, particularly at the elementary level, to empower teachers and students as problem solvers who seek to understand the changing world and its complex challenges. Although our conceptualization of STEM education is not the focus of this study, it informs the ways in which we describe and strive to advance our teachers' perspectives on STEM.

Successful STEM integration in PK-12 classrooms depends on teacher knowledge and beliefs (Moore et al., 2020), yet there is limited evidence of teachers' initial conceptions of STEM education in professional development contexts. Educational researchers have used drawings (e.g., Ring et al., 2017), phenomenographic models (e.g., Dare et al., 2019), and concept maps (e.g., Holmlund et al., 2018; So et al., 2021) to elicit teachers' conceptions of STEM education within professional development activities. Concept maps were especially appropriate for formative assessment in our university contexts because they capture a "structure of knowledge" (Novak, 1995, p. 79) with a flexible layering of ideas, links, and connecting language at varying levels of depth and complexity based on prior STEM experiences (So et al., 2021).

The following research questions guided this study:

1. How do prospective and practicing PK-12 teachers interpret STEM within their teaching contexts?
2. How do concept maps as formative assessments reveal teachers' conceptions of STEM education?

Methods and Context

A grounded theory approach was used in our study of prospective and practicing teachers' interpretations and conceptions of STEM education. Participants in this study were enrolled in one of two online graduate-level courses on STEM education. These courses were part of two separate graduate education programs for in-service teachers at two large public universities on the east coast of the United States (one in the southeast and one in the mid-Atlantic). One of the courses was a core requirement for a master's degree in elementary STEM education and the other course was an elective for an advanced master's degree program in teaching and learning for PK-12 educators. The courses had both synchronous and asynchronous components.

The authors of this study co-planned and taught the courses in parallel during the Summer 2021 and collected research data throughout the courses. The learning objectives centered on integrated STEM teaching as defined by Nadelson & Seifert (2017). The weekly modules and course assignments challenged students to identify and apply methods to effectively teach integrated STEM with an emphasis on equitable access. The module content provided tools for them to sustain these practices in their curriculum, classroom instruction, and school communities.

A total of 20 teachers (10 from each university) participated in this study. Our participants included practicing elementary teachers (n=14), practicing secondary math and science teachers (n=4), a pre-service secondary math teacher (n=1), and an elementary media specialist (n=1). With the exception of the pre-service teacher, all participants had three or more years of teaching experience. Three additional teachers were enrolled in the courses but did not participate in this study. All teachers in the study shared that they had minimal experience integrating STEM and expressed interest in improving their STEM teaching practice.

Data Collection

The data analyzed in this study were collected through a purposeful sequence of asynchronous activities at the beginning of courses. First, the teachers responded to the open-ended question "Are you a STEM teacher? Why or why not?". Teachers' responses to this question ranged in length from short phrases to multiple paragraphs. Participants then read articles on STEM integration (Vasquez, 2015) and equity in STEM (Mensah, 2021) to activate their prior knowledge and to build their working vocabulary about STEM education. Finally, they created concept maps in response to two questions: (1) What is your understanding or conception of STEM education? (2) What do you see as the most important ideas and sub-ideas? Our goal was to capture their personal and professional perspectives about STEM teaching and STEM education. Participants were provided with links to online digital tools (e.g., http://popplet.com/, https://bubbl.us/, https://coggle.it/, https://www.mindmup.com/) they could use to create their concept maps along with an online video tutorial about creating concept maps. They were also given simple directions about connecting ideas and sub-ideas related to the central idea of "STEM Education".

Data Analysis

Thematic qualitative analysis techniques were used, including constant comparative methods (Glaser, 1965; Kolb, 2012), to identify initial themes around teachers' conceptions of STEM and STEM education. Teachers' open-ended responses to the survey question, "Are you a STEM teacher?" were coded by the researchers to better understand how teachers interpret their roles in the context of STEM education. Teachers' concept maps were used as supporting data in this survey question analysis, particularly when responses to the question were very brief. The concept maps were first open-coded using in-vivo coding to capture the words of the participants (Saldaña, 2021) using an iterative process that examined the language within and across levels of the concept maps, the connections between concepts, and the nature of the nouns and verbs used (e.g., action verbs). Researchers then engaged in a cycle of focused coding (Saldaña, 2021) to construct new codes that were subsequently used to recode the concept maps for consistency, coherence, and completeness. The final themes are the organizing categories for reporting our findings.

Findings

Distinct themes emerged from our analysis of the open-ended survey responses and concept maps as formative assessments. Survey responses revealed two interpretations of STEM teaching, while the concept maps allowed researchers to identify six categories within teachers' conceptions of STEM education.

Interpretations of STEM Teaching

The two themes that emerged from analysis of teachers' response to the question, "Are you a STEM teacher?" included a ***disciplinary interpretation*** and an ***integrative interpretation*** of STEM. A disciplinary interpretation equates STEM teaching with curriculum and instruction in any of the four separate and distinct content areas. This interpretation is consistent with a disciplinary view of STEM integration as the transfer of subject-based content and skills as defined by Vasquez et al. (2013). Teachers with an integrative interpretation envision STEM teaching as more than a focus on content areas in isolation. They strive to draw on knowledge, skills, and processes from across the STEM disciplines. This interpretation matches the field's transdisciplinary view of integrated STEM (Nadelson & Seifert, 2017).

Half of the participants (n=10) expressed a disciplinary interpretation of STEM teaching. One elementary teacher responded that she was a STEM teacher simply because she taught science, while another elementary teacher responded, "I am a STEM teacher because I teach content areas of science and math, and I am more excited to learn about the tech and engineering side of STEM." Teachers with a disciplinary interpretation of STEM teaching focused on their teaching within specific content areas, like one middle school teacher who noted "Yes I am a STEM teacher. My content focus is physical science but I like to incorporate the use of different technologies, connect math content, and use hands-on activities." This teacher described STEM teaching as linking different disciplines to deepen science knowledge.

The other half of our participants (n=10) expressed an integrative interpretation of STEM teaching. One elementary teacher noted "I teach math and science in isolation. Some STEM practices are covered in my teaching but I don't necessarily feel like I give my students the opportunity to engage in STEM activities." In contrast with teachers who equate math or science with STEM, this teacher's reluctance to label siloed math or science instruction as STEM reveals an integrated perspective. Similarly, a secondary science teacher responded:

> Yes, science teachers are STEM teachers because we incorporate science, technology, engineering, and math into our classes. There are overlapping skills taught and used in each of those areas in a typical "science" classroom. So much about teaching science involves students using our content to critically think, problem solve, gather data, and ask questions.

The emergence of two distinct interpretations of disciplinary and integrated STEM teaching deepened our analysis of teachers' STEM education concept maps. We were able to interpret each concept map as more than a synthesis of readings about STEM education. We could triangulate their visual representations with their professional perspectives.

Conceptions of STEM Education

Analysis of the participants' concept maps revealed six categories of teachers' conceptions of STEM education, including (1) utilitarian; (2) acquisition of disciplinary knowledge; (3) activities and resources; (4) access to meaningful problem-solving experiences; (5) advocacy for systemic change; and (6) buzzwords. Each concept map was identified as representing one or two categories, demonstrating that some teachers expressed overlapping conceptions of STEM education. The six themes are discussed below with multiple excerpts from teachers' concept maps to illustrate each theme.

Utilitarian

A utilitarian view of STEM education is one that is career-oriented and focused on practical or economic benefits of pursuing STEM degrees. A utilitarian view of

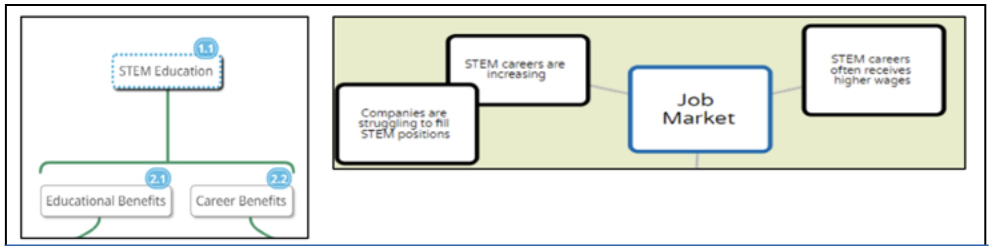

Figure 1. Excerpts of two concept maps coded as utilitarian

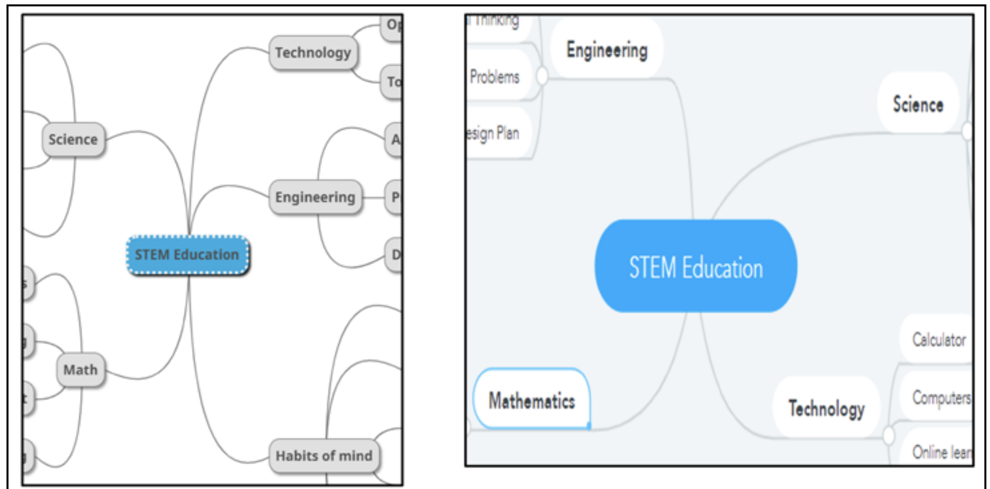

Figure 2. Excerpts from two concept maps coded as acquisition of disciplinary knowledge

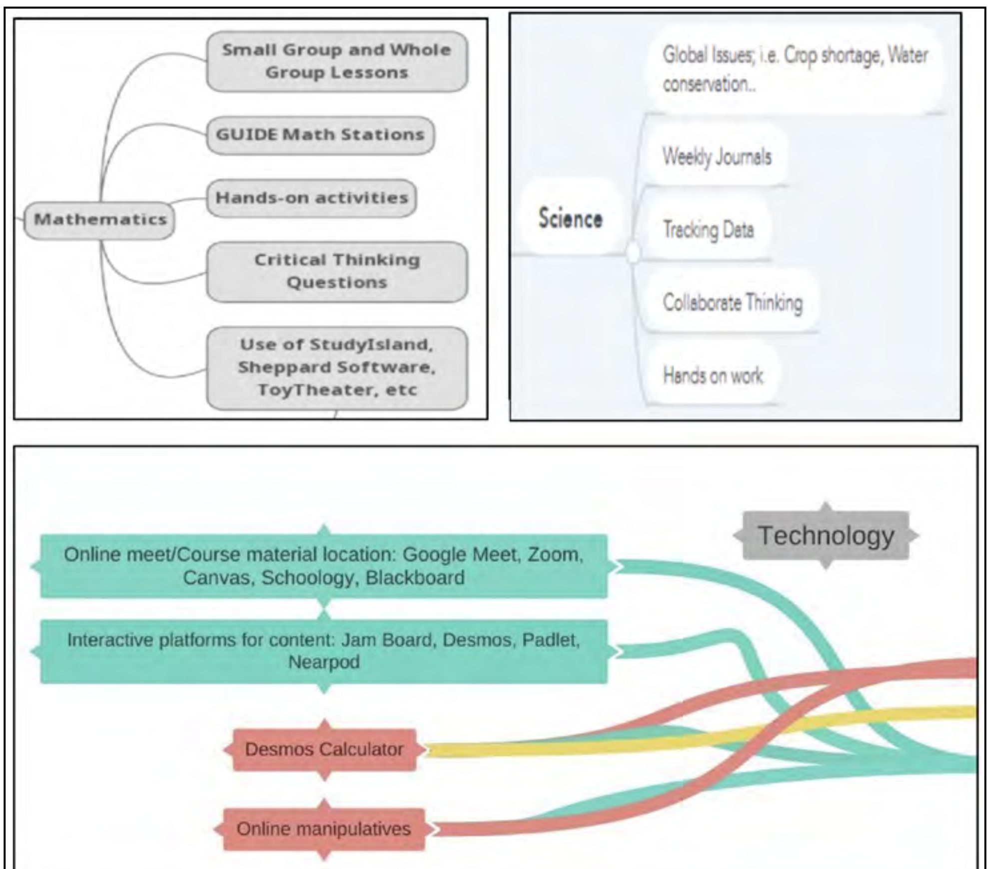

Figure 3. Excerpts of three concept maps coded as activities and resources

STEM education was expressed by four teachers. Concept maps that were utilitarian connected STEM education to career readiness. (see Figure 1). One of the teachers with this conception focused on educational and career benefits, while another noted "STEM careers are increasing" and "more hands-on learning leads to interest in pursuing a career in STEM". This goal of STEM education is common outside of education (e.g. Chesky & Wolfmeyer, 2015), but only 20% of the teachers in this study expressed this conception.

Acquisition of Disciplinary Knowledge

A conception of STEM education as the acquisition of disciplinary knowledge is represented in distinct nodes for science, math, engineering, and technology (see Figure 2). The five teachers who explicitly represented these content areas also expressed a disciplinary interpretation of STEM in their response to the question, "Are you a STEM teacher?" In their concept maps, they connected these subject areas to either activities or standards without elaborating on how they might integrate the disciplines. One teacher created concepts with paraphrased standards for mathematical domains and science core areas. Another teacher struggled to envision a place for engineering as a discipline within her elementary teaching context, connecting to engineering with the question, "How can this be done with younger students?" This theme of acquiring disciplinary knowledge was always associated with one of three other concept map themes (utilitarian, activities and resources, or buzzwords).

Activities and Resources

A conception of STEM education as activities and resources is a teacher-centered view that focuses on the tools teachers could use in the classroom rather than on the transdisciplinary STEM learning in which P-12 students can engage. Five of the teachers in our study conceptualized STEM education as the activities and resources teachers use to bring STEM into the classroom. They listed non-domain specific activities or technological resources with a general focus on student engagement (e.g., Nearpod, Quizlet, Cahoot, weekly journals, problem-solving) or computational thinking (e.g., Desmos, Scratch, robotics). While teachers with this conception listed activities and resources they would use in the classroom (see Figure 3), they did not make connections to the STEM skills or mindsets they sought to develop. All five of these teachers also had a disciplinary interpretation of STEM in their response to the question, "Are you a STEM teacher?".

Access to Meaningful Classroom Experiences

A view of STEM education as access to meaningful classroom experiences is a student-centered conception that focuses on the specific STEM experiences that teachers envision happening in their classroom and how these experiences support student learning. Six of the teachers expressed this conception of STEM education. These teachers identified opportunities for students to engage in STEM learning rather than listing specific activities (see Figure 4). Many included statements about what they envisioned students doing in the classroom, including "students make improvements to design," "students should have an opportunity to reflect and revise", "working with another to create a solution," and "finding out what others

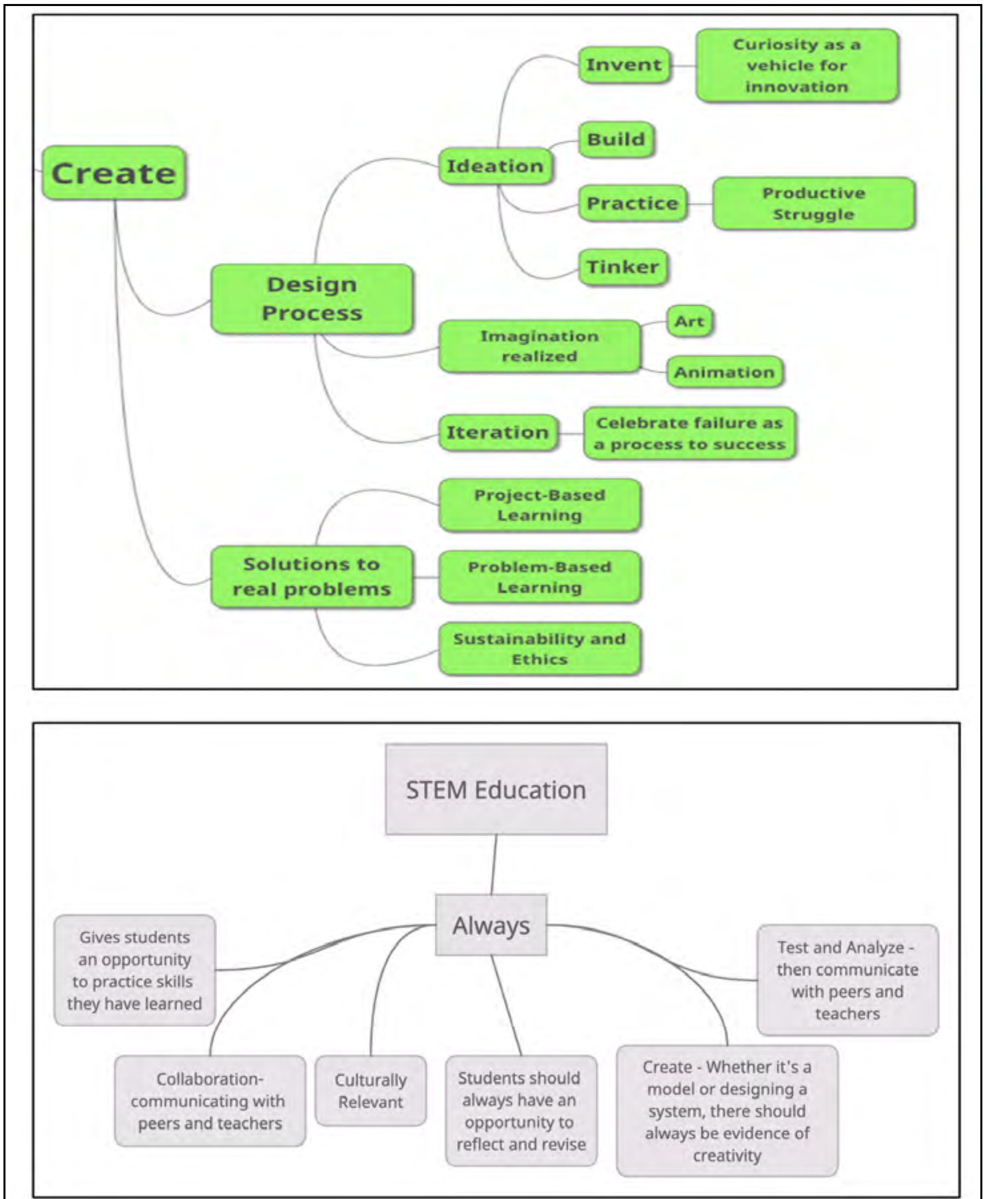

Figure 4. Excerpts of two concept maps coded as access to meaningful classroom experiences

have done and learning from them." All six of the teachers who conceptualized STEM education as access to meaningful classroom experiences had an integrative interpretation of STEM in their response to the question, "Are you a STEM teacher?".

Advocacy for systemic change.

The three teachers who conceptualized STEM education as advocacy for systemic change explicitly positioned STEM as a way to address equity (see Figure 5). One of the teachers with this conception organized the first level of her concept map with active verbs (organize, grow, create, integrate), and included statements like "opportunity for all students, not just gifted classes," "ditching deficit mindsets with value-added" and "increased representation by under-valued groups of students." Another teacher was cross-coded as having a utilitarian conception of STEM, but with an advocacy orientation (e.g. "Girls and BIPOC seeing themselves in STEM positions"). This same teacher identified ways that bringing STEM into the classroom is difficult for teachers, with a focus on contextual barriers such as time, money, and support from administrators. All teachers with a conception of STEM education as advocacy for systemic change had an integrative interpretation of STEM in their response to the question, "Are you a STEM teacher?".

Buzzwords

A buzzword conception of STEM education is an ill-formed collection of words and ideas that are commonly associated with STEM. Although we note that STEM is itself a buzzword, the teachers with this conception included ideas often associated with STEM but without thoughtful connections to instructional goals or student learning, such as the 4 C's of 21st-century learning (critical thinking, communication, collaboration, and creativity) (Partnership for 21st Century Skills, 2006), project-based learning, and problem-based learning. The seven teachers with a buzzword conception presented definitions, quotes, and images taken directly from the two assigned readings without any evidence of synthesis or filtering (see Figure 6). During our initial in-vivo coding, we referred to these concept maps as "braindumps," as most lacked organization and made few interpretable connections between STEM ideas. Although some of these concept maps may have been completed quickly or with little thought, most were constructed with enough detail to suggest that they were a reasonable reflection of the teachers' STEM conceptions at the time.

Teachers with a view of STEM education as a collection of buzzwords communicated excitement about STEM but lacked a cohesive and actionable vision of what STEM teaching should look like. One of the secondary science teachers with this conception included the statement, "STEM can occur in ANY classroom--it is everywhere!" This statement is problematic because it lacks recognition of the role of problem-solving and engineering design in STEM. All but one of the seven teachers who held a buzzword conception of STEM had a disciplinary interpretation of STEM. A buzzword conception suggests that teachers did not draw on personal or contextual STEM experiences as they built their concept maps.

Discussion

The data presented in this study reveal practicing teachers' conceptions of STEM education at the beginning of a graduate course for practicing teachers. Our findings suggest that teachers bring wide-ranging conceptions of STEM to their graduate coursework. We found that many teachers had not yet begun to consider the integrative potential of STEM at the beginning of our courses. While we cannot make any inferences about the sufficiency of the six identified categories in capturing all in-service teachers' conceptions of STEM education, we noted trends that could inform not only our design of our graduate courses but future research on the sustainability of integrated STEM practices.

Analysis of teachers' responses to the question "Are you a STEM teacher?" led to our realization that teachers' interpretations of STEM education in the form of concept maps became a lens we could use to understand teachers' readiness to integrate STEM in their classroom practice. Teachers with a disciplinary interpretation of STEM education often had an ill-formed or shallow view of STEM education, while teachers with an integrative interpretation of STEM education created concept maps that reflected a deep understanding of the transformational potential of STEM education.

Conclusions and Implications

As teacher educators and researchers who seek to advance teachers' understanding of the relationship between integrated STEM and meaningful learning, we now better understand the value of making their teachers' initial conceptions of STEM education visible. While other

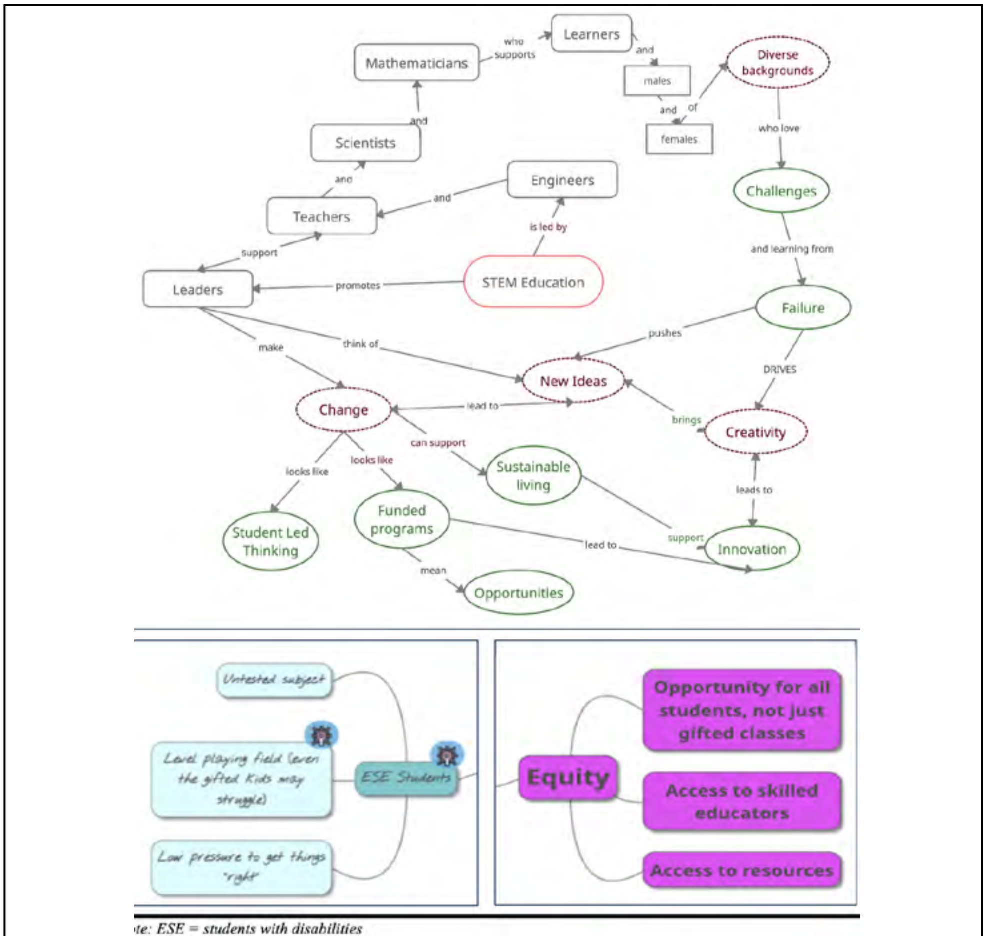

Figure 5. Excerpts of three concept maps coded as advocacy for systemic change

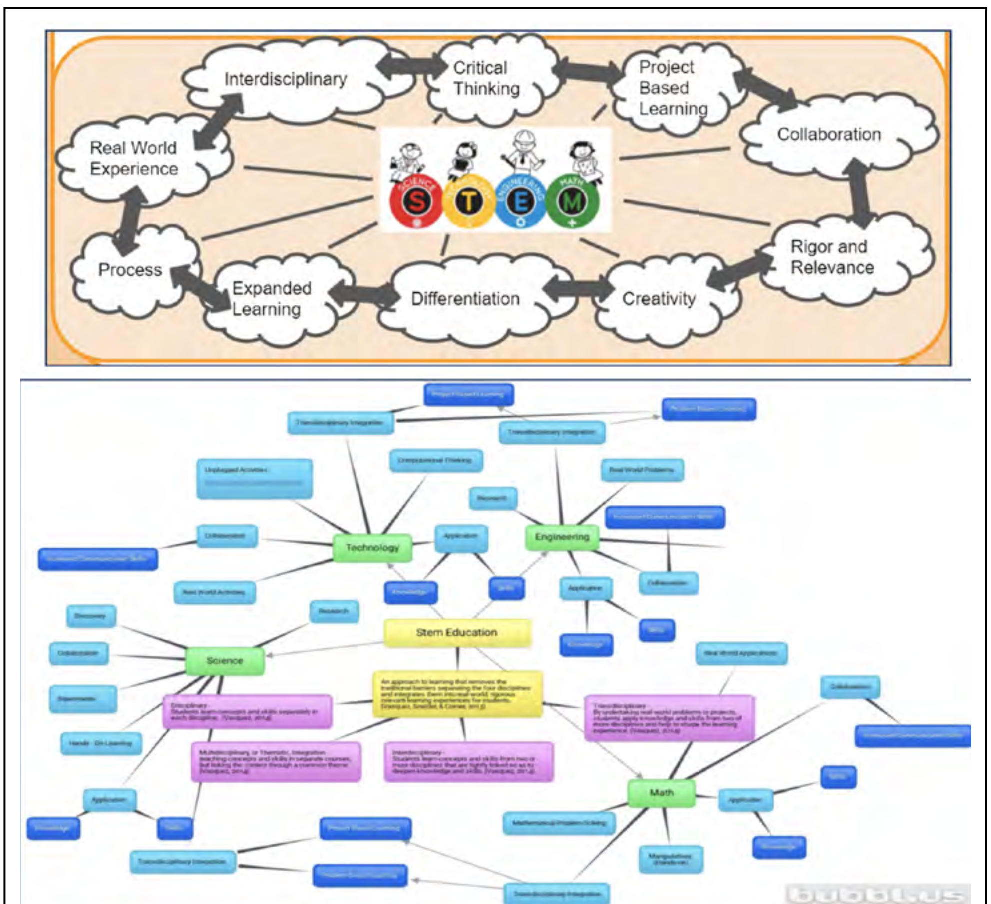

Figure 6. Screenshots of concept maps coded as buzzwords

researchers have described conceptions of STEM education in teacher preparation programs (e.g. Radloff & Guzey, 2016) and after professional development experiences (e.g. Ring et al., 2017), our study is unique in that we elicited visual representations of STEM education as a formative assessment to inform our graduate course-decision making. By capturing these conceptions of STEM within a formative assessment, we were better positioned to challenge unproductive conceptions in the ways we taught our courses. We have a deeper appreciation of the importance of challenging teachers' ill-formed or surface-level conceptions of STEM education in our instructional decision-making.

Eliciting evidence of teachers' conceptions in the form of concept maps provides a "baseline" that teacher educators can use to design curriculum and facilitate productive dialogue. If we take the stance that an integrated perspective of STEM education is a necessity for more equitable, student-centered STEM learning experiences, then we must examine teachers' initial conceptions of STEM in order to challenge ill-formed or surface-level conceptions. STEM teacher educators in both preservice and in-service contexts cannot treat all teachers as a homogeneous group with the same experiences and conceptions. By capturing the different perspectives our teachers bring to the classroom, we can capitalize on these differences in our planning in order to broaden teachers' conceptions of STEM education.

Directions for Future Research

The field's empirical understandings of teachers' beliefs about STEM are often limited to self-reports in interviews and surveys in which the researcher writes the questions. The open-ended nature of concept maps provides an authentic representation of teachers' interpretations of STEM education. Future research should explore the use of concept maps to assess teachers' evolving conceptions of STEM education at select points within graduate coursework or professional development. The six categories identified in this paper serve as a starting point for future research on the complex relationship between teachers' STEM conceptions, their experiences as learners and teachers, and their readiness to integrate STEM in their own classrooms.

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Nancy Holincheck is an Assistant Professor of STEM Education at George Mason University. A former high school physics teacher, she mentors doctoral students and teaches in-service teachers in science and STEM education, teacher research, and teacher reflection. Her research centers on teacher reflection and STEM education across grade levels, including elementary STEM teacher identity, physics student identity, and recruitment and retention of students who are under-represented in STEM.

Terrie M. Galanti is an Assistant Professor of Secondary Mathematics and STEM Integration/Computational Thinking at the University of North Florida. She synthesizes her thirty years of experience as an electrical engineer and K-12 mathematics teacher in her qualitative and quantitative research on STEM education and conceptual readiness for STEM fields of study. Her research interests connect mathematics education as a reasoning and sense-making endeavor with computational thinking in K-12 curriculum and classrooms. She works with preservice and practicing teachers to empower them to integrate STEM in the form creative and innovative problem-solving opportunities.