J Sci Educ Technol (2016) 25:759–774
DOI 10.1007/s10956-016-9633-5

Investigating Preservice STEM Teacher Conceptions of STEM Education

Jeff Radloff[1] · **Selcen Guzey**[1]

Published online: 14 July 2016

Abstract Surrounding the national emphasis on improving STEM education, effective STEM educators are required. Connected, yet often overlooked, is the need for effective preservice STEM teaching instruction for incoming educators. At a basic level, preservice STEM teacher education should include STEM content, pedagogy, and conceptualization. However, the literature suggests no leading conception of STEM education, and little is known about how preservice STEM teachers are conceptualizing STEM education. In order to explore preservice STEM teacher conceptions of STEM education, preservice teachers at a large, Midwestern research university were given an open-ended survey eliciting both textual and visual responses. Here, we report and discuss the results of employing this instrument in relation with the current STEM conceptualization literature.

Keywords STEM education · Exploratory study · Preservice teacher research · Conceptualization

Introduction

Over the past 30 years, discussion about Science, Technology, Engineering, and Mathematics (STEM) education has proliferated all levels of education in the US. Most recently, reports by the National Research Council and National Academies of Engineering have called for alterations in current teaching styles toward STEM instruction, emphasizing the need for explicit and intentional integration of STEM subjects (NAE and NRC 2014; NRC 2012, 2013). Concurrently, the President's Council of Advisors on Science and Technology (PCAST) has pushed to have 100,000 newly prepared STEM teachers utilizing STEM instructional approaches in the classroom by the year 2020. The need exists for preparing effective STEM teachers proficient in STEM instructional approaches (Lynch et al. 2014; Outlier Research & Evaluation 2014).

Yet, there are barriers in doing so. Namely, current STEM educators feel uncomfortable with using STEM instruction and content, making them unlikely to adopt STEM approaches in their classrooms (Nadelson et al. 2013). Likewise, they have been found to possess merely basic conceptions of STEM. This could be both detrimental to imparting adequate STEM conceptions to students, as well as their own implementation of STEM teaching approaches (Magnusson et al. 1999).

To combat these obstacles and foster integrated conceptions of STEM, educators need earlier exposure to effective STEM experiences and instruction. Yet, although STEM professional development opportunities have been provided for *in-service* teachers (S3, OSPrl), STEM development throughout *preservice* teacher preparation is lacking (O'Brien et al. 2014). However, student conceptions are utilized in creating more informed instruction (Morrison 1999). In order to both (1) further our knowledge of how teachers' beliefs are aligned with reform efforts around integrated STEM and (2) begin to create effective preservice STEM teacher instruction to enhance that understanding, we need to know how preservice teachers are currently conceptualizing STEM.

Developing an informed conception of STEM would not only assist preservice teachers with teaching STEM through integrated approaches, but help them become more

✉ Jeff Radloff
jradloff@purdue.edu

[1] Purdue University West Lafayette College of Education, 100 University St, Lafayette, IN 47907, USA

comfortable teaching in that way before they enter the classroom. Therefore, the current study aimed to explore preservice teachers' conceptualization of STEM, utilizing the following question for direction: How are preservice teachers conceptualizing STEM education?

Conceptions of STEM Education

First, we need to understand what comprises STEM content and practices and what STEM conceptions look like. Descriptions of all of these vary in the literature, especially conceptions of STEM education (Breiner et al. 2012). Summarily, agreement has not been reached on a leading conception, but with four fields and their sub-fields inherent within "STEM," there are many facets to discuss and flesh out. Authors do, however, appear to discuss it one of three ways: (a) instructionally (b) as a set of integrated or interconnected disciplines, or (c) as more dependent on the stakeholders or context in which it is viewed or conceptualized. Pertaining to pedagogy, Johnson (2013) defines it as "an instructional approach, which integrates the teaching of science and mathematics disciplines through the infusion of the practices of scientific inquiry, technological and engineering design, mathematical analysis, and 21st century interdisciplinary themes and skills" (pp. 367). This definition also brings to bear a focus on STEM thought processes and skills instead of the traditional emphasis over content. Tsupros et al. (2009) defines it instructionally as: "an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons in contexts that make connections between school, community, work, and the global enterprise" (pg 2). As a set of integrated disciplines, Merrill (2009) defines STEM education instructionally as "a standards-based, meta-discipline residing at the school level where … discipline specific content is not divided, but addressed and treated as one dynamic, fluid study." Here, STEM is addressed as transdisciplinary. Koonce et al. (2011) define STEM more simply by its disciplines, writing that "STEM stands for the four primary discipline families of Science, Technology, Engineering, and Mathematics … (pp. 2)." Breiner et al. (2012) discuss it contextually, suggesting "most stakeholders who hold interests in promoting STEM would claim to understand the meaning, yet the finer points of this construct often cause confusion" (pp. 2). Summarily, various conceptions exist.

In Bybee's (2013) publication, *The Case for STEM Education: Challenges and Opportunities*, the author leaves STEM ill-defined for this same reason (preface). He suggests that while readers may be looking for a concise definition of STEM education, the most accurate one(s) may come from one's personal context and needs. Arguably, the most robust and detailed definition of STEM education is provided by Moore et al. (2015), whose definition was adopted for this study (as such). They define it as "the teaching and learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies." To them, five characteristics distinguish integrated STEM instruction from other teacher pedagogy: (a) the content and practices of one or more anchor science and mathematics disciplines define some of the primary learning goals; (b) the integrator is the engineering practices and engineering design of technologies as the context; (c) the engineering design or engineering practices related to relevant technologies requires the use of scientific and mathematical concepts through design justification; (d) the development of 21st century skills is emphasized; and (e) the context of instruction requires solving a real-world problem or task through teamwork. This conceptualization of STEM is grounded in learning research.

As discussed above, however, one can begin to see how hazily STEM education has been defined, sometimes on purpose (Bybee 2013). Depending on contextual factors such as the roles of stakeholders in implementing a STEM program, a whole plethora of definitions are possible. But what does this mean within the context of creating effective preservice STEM teacher education programs and how (given a fluid definition) can we help create more effective instruction for preservice STEM teachers?

STEM Visualizations

Conceptualizations of phenomena are often utilized to inform the creation of effective instruction (Morrison 1999). Pertaining to preservice STEM teacher education, availability of visual representations for learning could be extremely beneficial. STEM visual representations have been found to help maintain attention and motivation (Cook 2006), add information not able to be gathered by text alone (Mayer et al. 1996), and increase what is learned through connected text (Peeck 1993). Importantly, visualizations have been found to help STEM students integrate new scientific information (Roth et al. 1999). They also can be used to show unseen or intangible phenomena that cannot be directly detected or experienced (Buckley 2000). All of these characteristics describe situations or activities preservice teachers commonly engage with while in their preservice STEM teacher programs. On a basic level, visual representations are widely used throughout all STEM disciplines—as graphs or diagrams—essential to understanding and interpreting data.

Although visual representations are used across all STEM disciplines, teaching, and learning, within the realm of visualizing *STEM* education, little has been accomplished. When reviewing the literature, we found few resources with any integrated STEM visualizations. For instance, a chapter was found within Bybee's (2013) publication, *The Case for STEM Education: Challenges and Opportunities* (Chapter 8, "What is Your Perspective of STEM Education?"). Here, Bybee presents the reader with nine possible visualizations of STEM education that can be held by STEM practitioners. These range on one side of the spectrum from viewing "STEM" as a single subject or discipline, to the other side of the spectrum in which practitioners can view STEM as completely transdisciplinary, or more associated with its real-world application.

Suggested by the title of the chapter, these conceptions are diverse, and furthermore dependent on STEM educators' perspectives. Namely, he highlights the fact that school administrators could choose to adopt one of these visualizations for their whole school and that could be different than neighboring schools. Because his visualizations are theoretical and only cover nine possible ways to visualize STEM education, Bybee (2013) also leaves his number of interpretations open to other possibilities. At the end of the chapter, he adds the disclaimer that "no doubt there are others" (pp. 80).

Yet the reader is left wondering what these possibilities are, and furthermore about the use of having so many representations. For that matter, how are preservice STEM teachers actually thinking about STEM education? This is an important question to answer in creating effective instruction for future STEM teachers. If we begin to understand what they are actually thinking, then we can start to perhaps come to a more collective, instructional representation by which preservice STEM educators can learn about STEM education more easily.

Given vague definitions of STEM education, preservice STEM teachers cannot be expected to have a complete understanding of it. However, both preservice teachers and STEM researchers would benefit from having access to visual framework(s) of STEM backed by research. In starting to fill these gaps, this research was aimed to explore how STEM preservice conceptualize STEM education visually—to start providing groundwork for future preservice STEM teacher instruction and research. To do so, preservice STEM teachers at a large, Midwestern research university were given a survey which probed them to (a) conceptualize STEM education (b) illustrate what STEM looks like to them, and (c) provide a rationale for their illustration.

Theoretical Framework: Constructivism

We approached this study through a constructivist lens. Simply put, constructivism provides the groundwork for understanding how people are incorporating new knowledge into existing knowledge, and come to understand this new knowledge (Tobin 1990). Within this approach, participants actively construct new knowledge, potentially through drawings or diagrams. Constructivism also acknowledges experience, which directly affects both our existing knowledge and knowledge acquisition.

However, while many forms of constructivism exist, such as personal constructivism (Kelly 1955), radical constructivism (Von Glasersfeld 1995), and social constructivism (Kim 2001), we use the term "constructivism" deliberately. As Bodner and Orgill (2007) write, while learning happens socially, "it is ultimately the individual who does the learning" (pp. 30). Another reason for utilizing the term "constructivism" is that we adopted Bybee's (2013) theoretical STEM visualizations to help code participant drawings—a finite number of conceptualizations. This was to meaningfully organize our data for further analysis, perceive any new visualizations, and test his theory.

However, one could also argue that utilizing Bybee's set of visualizations is imposing or assuming a "correct answer," which aligns with individual constructivism (Bodnar et al. 2001). We emphasize that learning is done within communities, by the individual. We aimed to flesh out and synthesize multiple truths about STEM education, to understand as many viewpoints as possible.

Research Design and Methods

The purpose of our survey, then, was to investigate preservice STEM teachers' visualizations of STEM education. Below we describe the major components of our study including procedures, design, and instrumentation.

Survey Design

Surveys were preferred because they could be administered to a larger group of people, and data could be turned around quickly (minus coding of visualizations). It could also potentially be generalized (Fowler 1988) if given to larger numbers of participants. However, this particular population was conveniently located (Babbie 1990) and may not fully represent the larger population of preservice STEM teachers. The survey was cross-sectional, with the data collected over a 2-week period at the beginning of the Spring college semester of 2016 (January, 2016). The form of data collection was self-administered questionnaire (Fink 1995). Strengths of our survey included being distributed in large numbers all at once, being private and anonymous, and requiring no interviewer training or bias. All participants completed the survey, so we also had a high response rate. Because a researcher was in the room during implementation, respondent questions could be clarified. Weaknesses associated with the survey included: (1) a few respondents did not answer all questions (Question #11 and Question #12; see "Appendix"), (2) it was not assessed for its psychometric properties (a content validity analysis was performed only), and (3) it was not a powered study.

Experimental Procedures

After we created, tested, and revised the survey based on tester feedback (see below Instrumentation; Survey Validation), we implemented the survey in eight preservice STEM teacher classrooms. At the time of implementation, a researcher entered the classroom, discussed research details with participants (research background, anonymity), and passed out the survey. Respondents were allowed to ask any questions they wanted and were simply supposed to be quiet while the survey was out (so answers were not influenced by other students). Respondents flipped their surveys over when they were finished and the researcher came by and picked them up.

Population and Scale

The population in the study was 159 preservice STEM teachers in various stages of their Elementary Education program at a large, Midwestern research university. Basic demographic information was gathered through the survey, but no participants were directly identifiable. Being that we the researchers were a STEM education faculty member/researcher and a research assistant/former STEM student, they had direct access to the preservice teachers through personal relationships with their teachers. As we sampled the participants directly, it was a single-stage sampling design. We deliberately chose preservice elementary STEM teachers to comprise our sampling pool. They are in transition to becoming in-service STEM teachers, and potentially STEM experts as well. We posited that this meant they had an interest in STEM, which would contribute to what they had learned about it previous to taking the survey. As STEM teaching is only starting to be adopted, participants were also in the unique position of potentially not experiencing STEM teaching before.

While the population we chose for our study were not outright stratified, we did collect basic demographic information (age, ethnicity, gender) that could be used to stratify them. Besides basic information, participants were also asked to self-report about other factors such as teaching experience and style (e.g., student, teacher-centered).

Instrumentation

The survey we used was an instrument designed specifically for this research, comprised of 12 questions (see "Appendix"). They were four closed-ended questions, two multiple-choice style questions, five open-ended questions, and one question utilizing a Likert scale. While textual questions were utilized, the focus was on participant visualizations of STEM. Textual responses were utilized to *support* analyses of visualizations.

The first three survey questions were used to gather basic demographic information (sex, ethnicity, and age). The next two questions were to gather information on participant teaching experience. Questions 6–7 were to find out what teaching styles the participants had experienced growing up (K-12), and whether they wished to teach differently in their own classrooms. Questions 8–9 asked participants to define "STEM Education" and then asked them to identify how connected STEM disciplines are (Likert scale; numbers 0–10, "10" meaning "highly connected"). In the next question, participants then had to provide a rationale for why they chose the amount of connectedness that they did. These questions were to gather a baseline conceptual understanding of STEM education and disciplines. The last two questions asked participants to draw a diagram of how they visualize "STEM," as well as why they drew their diagram the way they did. This was to elicit an explanation of their illustrations.

Survey Validation

Previous to implementation, we tested the survey on: five graduate students in the Science Education PhD program, one STEM assessment specialist, four preservice teachers in the first year of their Elementary Education program, and three STEM preservice teacher faculty (STEM experts) at a large, Midwestern research university. The assessment specialist made sure we included all pertinent categories in the demographic questions (see "Appendix"). The STEM faculty suggested we include "(K-12)" in the sixth question. The STEM graduate students suggested the sixth and seventh questions include a definition of "teacher-directed" teaching. STEM faculty suggested including that "current reform requires teachers to teach (and students to be exposed to) STEM education." Changes were made to the survey before implementation. Aligned with these changes, open-ended responses were coded in conjunction with the type of question asked. For example, Questions 8, 10, and 12 corresponded with *instructional*, *conceptual*, and *application-based* aspects of STEM education; participant responses were coded to make sure these types of answers were gathered from each of these questions.

Measurement of Data

Constant comparative methodology and interrater reliability were utilized in measuring data. We followed Charmaz (2006), comparing answers both within and across individuals, and, who suggested reaching 90 % coder agreement, after which a high level of reliability allowed the first author to code the rest of the open-ended questions. Specifically, both researchers started by coding a systematically identified small sample using Bybee's visualizations. They meeting afterword to discuss their interpretations, codes, and any coding discrepancies. It was decided new codes needed to be added, and sample data were coded again. In the second round of coding, close attention was paid to the visualizations that did not fit Bybee's visualizations to make sure the new codes adequately addressed the unique characteristics of those visualizations. Researchers deliberately examined the visualizations to achieve greater specificity in codes. Weekly coding, reviews, and de-briefing sessions occurred to align both researchers' interpretations of visualizations. The second author then coded the remainder of the visualizations. In an attempt to further establish the trustworthiness of the data, the second author looked for anomalies or visualizations that may cause multiple interpretations. At the end, both researchers agreed on all codes. Anomalies found are discussed in more detail following Fig. 1 below.

Results

Overall, results suggested a large variation in preservice teacher conceptions of STEM education. Here, we present a summary of our findings, providing examples of preservice teacher responses for each set of questions. Findings are organized according to what aspects of STEM conceptualization we attempted to gather: visual conceptions, textual conceptions (supporting visual conceptions), and demographic information (to better inform both visual and textual conceptions).

Visual Conceptions of STEM Education

To elicit preservice teacher visualizations of STEM education, participants were asked to make a diagram or drawing of how they understand STEM education, using the letters S-T-E-M. Below are the six most common types of visual representation with a small summary of each (Fig. 1). It should be noted up front that following coding our findings matched up with Bybee's theoretical visualizations (Bybee 2013).

Overall there were six main types of preservice teacher visualizations (shown above; Fig. 1). Referred to by letter markers (a–f) in the above figure, these visualizations were referred to as: (a) *Nested*, (b) *Transdisciplinary*, (c) *Interconnected*, (d) Sequential, (e) Overlapping, and (f) *Siloed*. Distributions of these visualizations can be found below (Table 1).

Nested visualizations [letter marker (a); Fig. 1] signified a view of STEM in which there was one overarching discipline. This was denoted in the figure by *S*, *T*, and *E* being nested inside the overarching *M*, representing mathematics. Interestingly, while the literature suggested science or engineering are often the overarching disciplines, numerous participants in this study proposed *mathematics* to be the most prominent (33.33 % nested visualizations). *Transdisciplinary* visualizations [letter marker (b); Fig. 1] suggested a focus on the real-world, application-based nature of STEM (Bybee 2013; Moore et al. 2015). This view also suggested a completely integrated view of STEM. Aside from the microscope shown in the above panel, other visualizations in this category included computers and robots. *Interconnected* visualizations [letter marker (c); Fig. 1], which were the most abundant, showed double-arrows drawn between all the STEM disciplines. As Bybee (2013) described this type, "concepts, processes, and resources are coordinated across boundaries to separate disciplines" (e.g., mathematics is used in science and engineering; pp. 71). *Sequential* visualizations followed most closely with conceptualizations of STEM as a series of or successive STEM disciplines. Bybee (2013) suggested *Sequential* visualizations were associated in the STEM classroom with having students "study problems or conduct investigations…progressing through the STEM disciplines" (pp. 71). *Overlapping* visualizations [letter marker (e); Fig. 1], showed two overarching subjects, connected by "lesser subjects." The majority of participants with this type of visual representation (90 %) annotated *S* and *M* as overarching disciplines, and *E* and *T* as simply connective. *Siloed* visualizations [letter marker (f); Fig. 1] portrayed the way STEM has been historically taught in schools—in isolation of each other. Here, each STEM discipline was related, but could also stand alone.

It should be noted here that to differentiate between *Interconnected* and *Sequential* types, arrow direction, and styles were used. Interconnected were always double-sided arrows connecting the disciplines. *Sequential* was always single arrows in a linear or circular fashion. Participants also often responded with Venn diagrams, which were interpreted as *Transdisciplinary* (transdisciplinary/application-based), or *Interconnected* (completely shared components). If the Venn diagram had an annotated "STEM" section in the middle (suggesting complete integration), it

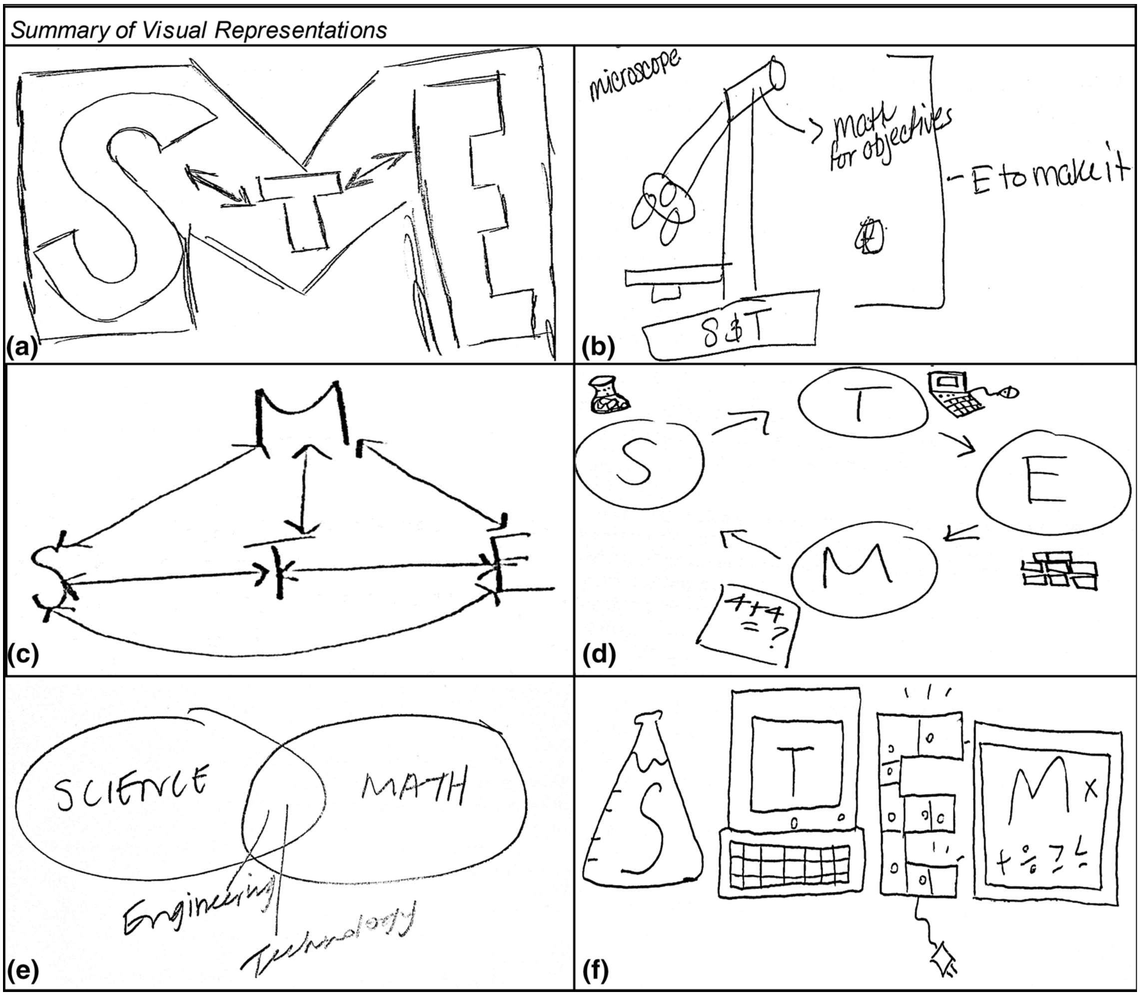

Fig. 1 Summary of visual representations

Table 1 Frequency of preservice STEM education visualizations

Type	#	%
A	18	11.3
B	21	13.2
C	54	34.0
D	9	5.7
E	5	3.1
F	28	17.6
None	17	10.7
New	7	4.4
Total	159 participants	

Letters used for type are from Fig. 1

was coded as *Transdisciplinary*. Overall distributions are summarized below (Table 1).

The visual representation most drawn by participants was *Interconnected* (34 % total; Table 9). It was found that the bulk of these visualizations came from only two groups of participants: preservice STEM teachers with either: (a) elementary teaching experience, (b) no opportunity to teach. The second-most created visualization was *Siloed* (17.6 % total). Next were *Transdisciplinary* (13.2 %) and *Nested* (11.3 %). These were followed by *None* (10.7 %), *Sequential* (5.7 %), *New* (4.4 %) and *Overlapping* (3.1 %). The codes *New* and *None* were used for those visualizations not readily interpretable utilizing our framework. The code *None* was used for instances of preservice teachers either not responding, or responding that they did not know how to draw (STEM).

There were seven *New* visualizations, annotated by letter markers (a–g) in the figure above (Fig. 2). Letter (a) suggested a connection between mathematics and both science and engineering, yet technology was only seen between science and engineering. In the letter (b) visualization, science and mathematics were connected with straight lines within a circular STEM shape. This suggested

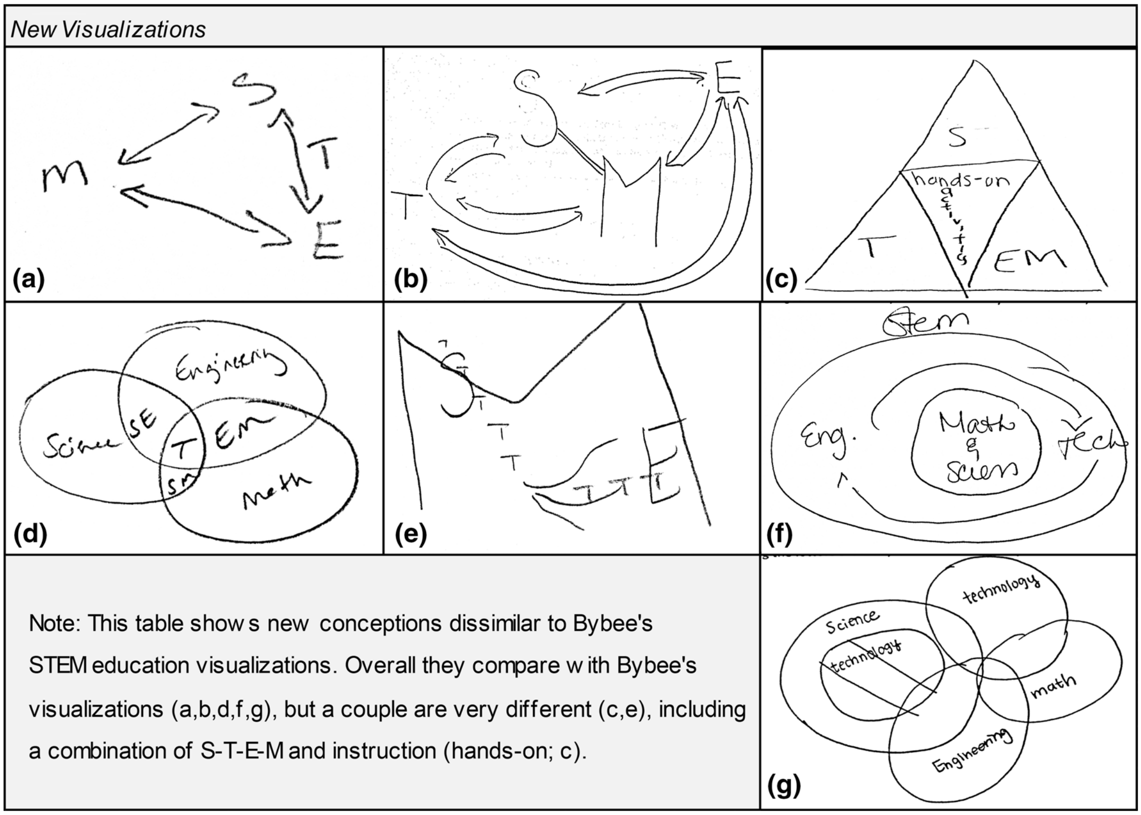

Fig. 2 New visualizations

it was a variation on *Nested*. Letter (c) showed engineering and mathematics in the same bottom right triangle, while all STEM disciplines were connected through *hands-on activities*. This appeared to demonstrate an understanding of STEM education directly involving instruction. Letter (d) displayed one variation of a Venn diagram. However, whereas others labeled the middle sections simply as *STEM*, here the respondent labeled the inner areas as *SE*, *SM*, *EM*, and at the middle is simply *T*. This seemed to reflect technology as an accumulation of the other STEM disciplines. Letter (e) indicated mathematics as the overarching subject, with science and engineering being connected by technology. This appeared to be a possible combination of *Nested and Overlapping*, or perhaps a variation of *Overlapping*. Letter (f) presented integration between all subjects, yet mathematics and science were given more importance. This could be viewed as a combination of *Overlapping* and *Transdisciplinary*. Finally, letter (g) showed a Venn diagram without the middle portion labeled. Interestingly, technology was given two areas—by itself, but also within science. Next, we analyzed textual conceptions of STEM education to help analyze and qualify our visual representations.

Textual Support for Visual Conceptions

To try and support visual conceptualizations (through textual response), participants were first asked to provide definitions of STEM education. They were then probed to choose how connected they felt STEM disciplines were and provide a rationale of why they picked the response that they did. They were also asked to provide an explanation of why they drew what visualization that they did.

Defining STEM Education

The first open-ended prompt was to provide a definition STEM education ("Appendix"). Table 2 (below) summarizes the coded results. In the case respondents could not recall or did not know simply what STEM was, we provided that it stood for "Science, Technology, Engineering, and Mathematics."

All but five preservice teachers defined it from an instructional perspective (above; Table 2). The themes that came out of their responses were (a) *Instruction*, (b) *Discipline*, (c) *Exclusion*, and (d) *Integration*. Reported percentages are within groups. Some responses were coded under multiple categories.

Table 2 Preservice teacher instructional conceptions

Theme	Category	#	%	Theme	Category	#	%
Instruction	Application	4	2.9	Discipline	Connected	6	20.7
	Contextual	2	1.5		Ranked	13	44.8
	Creativity	5	3.6		All	8	27.6
	Critical thinking	17	12.4		Exposition	2	6.9
	Discovery	4	2.9				
	Hands-On	37	27.0				
	PBL	25	18.2				
	Student-centered	19	13.9				
	Teamwork	2	1.5				
	Vague	11	8.0				
	Other	12	8.8				
Total instruction: 138 participants				Total discipline: 29 participants			
Exclusion	No humanities	12	52.2	Integration	Other	8	66.7
	Less prominent	5	21.7		Only STEM	4	33.3
	Other	6	26.1				
Total exclusion: 23 participants				Total integration: 12 participants			

Responses under the *Instruction* theme were those that mentioned specific characteristics of STEM teaching as found in the literature (Moore et al. 2015). These included: real-world application and context, creative and critical thinking, discovery or hands-on learning, problem-based learning (PBL), student-centered instruction, and working in teams. *Vague* coding was reserved for those answers too general to place into any other category, yet still directly highlighted instruction as important in STEM education. The *Other* category was for responses suggesting misconceptions, or likewise which suggested other characteristics of STEM instruction not mentioned in the literature. For example, these included answers like "(STEM is) more focused," "(STEM involves) thinking differently," or "(there is) one right answer in STEM."

Other participants defined STEM education by its disciplines (Table 2; *Discipline* theme). The *Connected* code was used for responses that simply talked about STEM involving associated disciplines. For example, one response was: "It's incorporating all these subjects into one." Another participant wrote, "It's integrating these four subjects together in the classroom more often." Participant responses were coded as *Ranked* if they ranked the STEM disciplines they talked about. These codes included responses such as, "The primary focus on Engineering and Technology, which most schools do not offer," or "STEM instruction focuses more on the mathematics and science part of education." In both of these cases, the participants differentiate between subjects, but also point out some subjects instead of talking about STEM as a whole. Participants that *did* talk about all STEM subjects had responses coded as *All*. Two participants in this category suggested simply that students need to be exposed to these disciplines. These responses were differentiated further and given the code *Exposition*.

Preservice teacher instructional conceptions of STEM education also focused on subjects that were being excluded by implementing STEM approaches. These responses fell under the *Exclusion* theme. The *no humanities* code (52.2 % of responses) was for those that talked about STEM excluding a humanities class. For example, "It's more technical and less integrated with the humanities," or likewise, "There isn't a focus on language or reading skills". Some participants actually pointed out that STEM disciplines are those usually not as present (coded as *Less Prominent*; 21.7 % of responses). These included things like "STEM is different from traditional elementary education classes that have an emphasis on language arts and mathematics," or "It focuses in areas that are important, but sometimes forgotten or overlooked." Finally, the *Other* code was for responses suggesting STEM is "hard for students" (two participants), non-responses (four participants), and interestingly those that suggested STEM is a government initiative (two participants). *Other* made up 34.8 % of *Exclusion* responses.

Finally, other preservice teachers talked about STEM education by highlighting the aspect of *Integration*. The *Other* category here referred to those emphasizing STEM disciplines integrated with other disciplines such as language arts or literacy. For example, one respondent wrote, "STEM instruction is often times integrated with other courses." Another said "It combines them. These subjects can be integrated in other subject areas." These codes made up 66.7 % of responses. The other 33.3 % came from those that talked about only integrating STEM disciplines. "STEM is the incorporation and inclusion of all four subjects into one curriculum/instructional method," said one participant, while another wrote, "STEM integrates S-T-E-M and many types of instruction into teaching a single concept."

Connectedness of STEM Disciplines

After defining STEM education, participants were then asked to choose (on a scale of 1–10) how connected they thought STEM disciplines were (Table 3).

In response, a connectedness of "6" or greater was chosen by 90 % of participants (e.g., moderate connection or greater; Table 3). The answer "8" was chosen significantly more than any other answer. A connectedness of "5" or lower was chosen by 10 % of participants. Five of these participants explained this was because, while STEM disciplines are connected, they are also unique (can stand alone).

Following delineation of connectedness of STEM disciplines, participants provided a rationale of their choice (Table 4). Three themes emerged from coding these responses: *Specialized*, *General*, or *Other*. Specialized responses included codes of: (1) *Dependent*, (2) *Dependent*, *Ranked*, (3) *Processes*, and (4) *Ranked*. The *Dependent* coding was chosen for responses suggesting that STEM disciplines were dependent on each other. For example, one respondent wrote "With STEM courses, it seems like you cannot have one without the other." Another wrote, "They all overlap. In order to do one discipline, you must use one or more of the others." The *Ranked* coding referred to when a respondent ranked the STEM disciplines. *Processes* coding referred to when a participant suggested that STEM disciplines were connected through thought processes or skills. For example, "Engineering and technology require a lot of mathematics. Each requires knowledge in each field." Another participant wrote "You do mathematics in physics and science, and you use technology in all of those areas."

General responses were comprised of the *Related*, *Related*, *but unique*, *Related*, *dependent*, *Related*, *processes*, and *Related*, *ranked* codes. The *Related* coding was used for answers simply saying that STEM disciplines were related. For example, one participant wrote "I think they all intertwine and connect. They lean on one another to teach the certain topics," and another wrote "They are more related than other subjects." *Related*, *but Unique*, coding was used when respondents differentiated the connectedness of disciplines with their ability to stand alone. One participant said, "They are their own entities. But, they all integrate extremely well and use one another frequently." The codes *Related*, *dependent*, *Related*, *processes*, and *Related*, *ranked* were similar to the way the *Specialized* responses were coded.

Finally, some respondents were either *Vague* in their response, left no response (*None*), or said simply that all of STEM "is hard." An example of a vague response here was when one participant wrote "They go together." Another wrote "They are all similar," and yet another said that "You have to work with what you have and know to then build more information for yourself." Percentages of responses were distributed evenly, although the bulk of types of responses were coded as *General* (68.6 % of all responses).

Table 3 Perceived connectedness of STEM disciplines

Scale[a]	#	%		#	%
10	22	13.8	5	13	8.2
9	26	16.4	4	1	0.6
8	58	36.5	3	1	0.6
7	30	18.9	2	1	0.6
6	8	5.0	1	0	0.0

[a] Scale 1–10; choosing 10 means STEM disciplines completely connected

Table 4 Conceptual understanding of STEM connectedness

Theme	Coding frequency	#	%
Specialized	Dependent	9	5.7
Specialized	Dependent, ranked	1	0.6
Specialized	Processes	7	4.4
Specialized	Ranked	10	6.3
General	Related	31	19.5
General	Related, but unique	29	18.2
General	Related, dependent	20	12.6
General	Related, processes	15	9.4
General	Related, ranked	20	12.6
Other	Vague	15	9.4
Other	None	1	0.6
Other	Hard	1	0.6
	Total	159 participants	

Explaining Visualizations

Following creating STEM education visualizations, preservice teachers were asked to provide a rationale of why they drew what they did (Table 5). These results are presented here since codes were expected to be similar to previous coding (which they were). With the exception of the *Application* code, all codes here were used previously (Tables 4, 6). The *Application* code was needed to describe two responses of participants using *Transdisciplinary* visualizations and who did not mention STEM disciplines or any other connections to their visualizations at all.

The most common rationale for participant visualizations was simply that "STEM disciplines are related" (Table 5). Combining all variations of relatedness (Related; Related, Dependent, Ranked; Related, Processes; and Related, Ranked) described 66 % of all responses. This correlated with the symbols used to connect STEM disciplines in the visualizations (e.g., arrows, shapes, and lines) and also appeared to correlate with *General* responses.

Other responses were coded as *Instruction*, *Vague*, and *None*. Examples of *Instruction* here included things like "If I could draw I would draw hands of a student completing a task because STEM is very interactive," or "Students should be working in groups and have the teacher engaging only when necessary." The code *Vague* was chosen for responses such as: "Because they are all used together," or "I think each of these pictures correlates with the subject discussed (*Siloed* drawing)." Overall, then, participants provided textual answers suggesting they understand STEM instructionally, as a set of disciplines, and visually in a variety of ways, but is there a connection between responses and participants' previous experiences?

Table 5 Preservice rationale of visual representations

Code	#	%
Application	2	1.3
Dependent	1	0.6
Hard	1	0.6
Instruction	8	5
Ranked	18	11.3
Related	45	28.3
Related, dependent, ranked	42	26.4
Related, processes	3	1.9
Related, ranked	15	9.4
Unique	3	1.9
Vague	14	8.8
None	7	4.4
Total	159 participants	

Table 6 Preservice teacher demographic information

	#	%		#	%
Gender			Ethnicity		
Male	7	4.4	Caucasian	148	93.1
Female	152	95.6	African American	2	1.3
			Latino	4	2.5
			Asian	5	3.1
Age					
18–29	158	99.4			
30–49	1	99.4			
Total	159 participants				

Demographic Information and Teaching Approaches

To try and investigate this, we collected participant demographic and background information (Table 6).

As shown in Table 6, the majority of preservice teachers were Anglo-females. Participants from underrepresented populations made up only 7 % of the total population. The bulk of the participants also fell in the 18–29 age group, potentially teaching or having taught after the introduction of STEM approaches in standards.

Table 7 provided a summary of preservice teachers' prior teaching experience (or lack thereof). As the majority of participants were transitioning into in-service teachers, these numbers represented mainly teacher placement experiences (e.g., teaching for two semesters at local schools throughout the Spring and Fall semesters). Since most were in their first or second year of the Elementary Education program, most responses were (a) elementary experience and (b) no opportunity.

Table 8 summarized participant self-reporting on what major style of teaching they experienced growing up (throughout K-12) versus what teaching style they wished to adopt in their own classrooms following schooling. This was shown in conjunction with the differences between responses—derived to view participant alignment with the student-centered aspect of STEM education. Results pointed toward an understanding or interest in STEM education approaches: 89 % of participants reported teacher-centered teaching styles through K-12 but wished to adopt student-centered teaching approaches in their own classrooms. Only 4 % reported wanting to adopt more teacher-centered approaches, and 8 % reported no change in approach.

Discussion

Similar to the arrangement of results, below we discuss: visualizations, supporting textual responses, and relationships between those responses and participant experiences. To start, a range of visual representations were elicited from participants (Fig. 1; Table 1). This was not surprising considering the variety of conceptions of STEM found in the literature. Yet, most of these could actually be interpreted within Bybee's (2013) set of theoretical visualizations and were supported by textual responses.

Overall, *Interconnected* visualizations were used significantly more than any other (34 % total responses), followed most closely by *Nested*, *Transdisciplinary*, and *Siloed* (Table 1). *Interconnected* visualizations suggested STEM disciplines completely connected. This was supported by Likert scale data and textual data surrounding the

Table 7 Preservice teacher teaching experience

Subjects planned to teach	#	%	Levels already taught	#	%	Average years
Elementary education	158	99.4	Elementary	51	32.1	2.9
Special education[a]	4	99.4	Middle	1	0.6	1.6
			High	2	1.3	3
			Undergraduate	4	2.5	2.25
			Graduate	1	0.6	2
			No opportunity	81	50.9	2
			Combination[b]	19	11.9	N/A

[a] Special Education was a specialization within Elementary Education

[b] Combination signified teaching at a combination of grade levels

Table 8 Preservice teacher perceived teaching styles

	#	%		#	%
Throughout K-12			Own classrooms		
Teacher-centered	62	39.0	Teacher-centered	1	0.6
Somewhat teacher-centered	55	34.6	Somewhat teacher-centered	21	13.2
Somewhat student-centered	33	20.8	Somewhat student-centered	53	33.3
Student-centered	9	5.7	Student-centered	84	52.8
Change					
Toward teacher-centered	6	3.8			
Toward student-centered	141	88.7			
No change	13	8.2			

connectedness of STEM (disciplines are "related"). On the contrary, *Nested* visualizations indicated a preference or ranking of connectedness between STEM disciplines. As evidence, 66 % of participants who chose *Nested* textually ranked STEM disciplines as well. Interestingly, mathematics was often seen as the discipline connecting all others. We suggest participants chose mathematics as predominant because of its use in all STEM disciplines. The amount of *Transdisciplinary* visualizations was surprising as well. A view highlighting STEM disciplines as seamlessly connected suggests a very complex conception of STEM, not often supported by participants' more general responses (Table 4). Given this contrasting data, results could likewise represent misconceptions or misunderstandings held by participants. *Siloed* visualizations most closely aligned with how STEM subjects have historically been taught in schools—separate from each other, each with its own application (Moore et al. 2015). Supporting this point, many participants actually provided STEM examples along with their visualizations (e.g., the computer is technology, the equation is mathematics, and the beaker is science). Given the lack of STEM professional development currently, we suggest *Siloed* visualizations were often drawn because of participants' own STEM experiences growing up (K-12 schooling). If an integrated view of STEM is desired by the STEM community, these findings also suggest a need for more emphasis on the *integration* of STEM, not each discipline separately.

Aside from these six main visualizations found, there were also some new variations (Table 2). Since these were interpreted earlier in detail, we point to larger implications here. For example, these visualizations represent an even higher variation in the ways of thinking about STEM education than acknowledged in the STEM visualization literature. While nine visualizations are a high number (Bybee 2013), findings point that many more *are* possible. According to the arrangement of STEM disciplines in these new visualizations, they also point to higher variation in which STEM subjects should be emphasized in the elementary classroom than was previously thought. As described above, participants' visualizations also begin to illuminate the types of misconceptions and misunderstandings preservice teachers possess about STEM. More specifically focusing on the new visualizations found in Fig. 2 (for example), why in panel (c) is engineering and mathematics in the same triangle? In the visualization labeled as letter (d), why is technology in the middle? In the panel (a), visualization technology was placed *between* science and engineering, but not connected with mathematics at all. How can that be explained? Perhaps as Anderson et al. (2013) suggests, students may not understand how to create or reason with visualizations without explicit instruction. However, we also need expert visual conceptions of STEM (backed by fieldwork) as well. Currently, neither are available.

Yet other, more direct misunderstandings were made present through participants' *textual* responses. For example, some participants suggested STEM was characterized by teacher-directed environments (instead of student-centered; Table 2). Others proposed that STEM disciplines were actually more prevalent or important than "excluded" disciplines such as social studies, language arts, and literacy (humanities). This is in stark contrast to the emphasis of language and literacy on current standardized testing (Skiba and Rausch 2004). Furthermore, students do not often receive formal science teaching until fourth or fifth grade (Rodriguez 2015). Some participants also suggested STEM is "facts-based," and there is "less room for creativity." However, it is actually characterized by problem- or project-based learning—both heavily open-ended and driven by creativity. While likely required to teach STEM, some respondents wrote that STEM subjects were "harder" or more difficult for either themselves or their students. This thought pattern can actually serve to discourage students from later entering STEM fields (Hurtado et al. 2010), and furthermore lead to less adoption of STEM approaches by teachers. At the very least, these STEM conceptions be remediated before more preservice STEM teachers reach groups of students in their own classrooms. Yet, how did these conceptions (both visualizations and textual support) come to fruition? Were they connected with participants' experiences?

Surprisingly, it did not appear as such. Although the majority of participants were Anglo-females, ages 18–29, all interested in student-centered, elementary STEM teaching (Tables 6, 8)—their conceptions (both visual and textual) were largely different from each other. This variation is shown further in conjunction with teacher experience in "Appendix" (Figs. 3, 4). Actually, the only pattern that emerged when comparing STEM conceptions with teaching experience was a common disposition to draw Interconnected visualizations—by both *experienced* and *non-experienced* preservice teachers. Yet, although *Interconnected* was drawn most—across all levels of experience—textual definitions surrounding STEM education were equally variable across groups (Tables 2, 4, 5). For example, Tables 2 and 4 both show a majority of participants describing STEM disciplines as simply "related," and many rehash this reasoning for why they drew what they did (Table 5). However, when consulting the STEM literature, experts (Bybee, Koontz, Johnson, and Moore) provide rich descriptions of STEM moving far beyond being simply "related."

To describe participants' disposition to *Interconnected* then, results suggest that this type of visualization represents: (a) an easy, yet effective way of visualizing STEM, (b) a nonsignificant artifact of the data, or (c) both. Given that participants using *Interconnected* visualizations possessed a range of textual conceptions surrounding STEM education (Tables 2, 4, 5), the data suggest that it may represent *both*. While the instrument used here could not differentiate between these possibilities, the range of existing conceptions allow for future studies.

Encouragingly, however, results gathered from this study *did* show future educators thinking progressively about instruction. Namely, although a majority of them reported experiencing teacher-centered classroom environments throughout K-12 schooling, the same proportion also desired to adopt student-centered teaching methods. These responses suggest that although preservice teachers may not have experienced STEM education growing up, they appear to recognize the effectiveness of student-centered teaching. Given the amount of rich detail provided when asked about STEM *instruction* (Table 2), we suggest participants are internalizing instruction, or at least feel more comfortable talking about it (Sherin 2007). Another avenue of future studies is to connect these results with classroom practice (operationalization).

Overall, results of this study suggest a large variation in visual and textual conceptions of STEM education at the level of future STEM educators. Yet they point directly back the literature. Not only is there a large variation in the way STEM has been defined, but also a small number of available STEM visualizations. Aside from the literature, there is also a lack of preservice STEM teacher professional development opportunities. However, this study has begun to fill those gaps by gathering and analyzing preservice teacher STEM education conceptualizations to aid in the creation of effective instruction. To our knowledge, this was the first study exploring preservice STEM teacher understanding of STEM education both visually and textually.

Yet, at the core of this argument is also the point that not even STEM experts are thinking about STEM similarly (via textual descriptions). Given the effectiveness of visualizations in STEM (Anderson et al. 2013; Cook 2006; Roth et al. 1999) however, at minimum, preservice teachers should have access to a series of visualizations to reason with and apply in different teaching contexts. These could be used toward cognitive goals (e.g., teaching *about* STEM approaches in preservice STEM teacher methods courses), as well as adapted for investigating or evaluating STEM classroom teaching experiences by both researchers and teacher educators.

Another important application of these findings could be to help with the creation of support through teacher induction. Specifically, they could be used to help anchor teachers to focus on certain aspects of STEM (e.g., integration; a certain discipline) when either teaching or planning. Past research has shown that new and novice teachers often revert back to "safe" or familiar teaching

Table 9 Frequencies of visual representations by group

Exp level				Exp level			
Vis type	% Group	% Total	#	Vis type	% Group	% Total	#
Combination				*High school*			
Nested	5.3	0.6	1	Siloed	0.5	0.6	1
Transdisciplinary	21.1	2.5	4	New	0.5	0.6	1
Interconnected	47.4	5.7	9				
Sequential	5.3	0.6	1				
New	21.1	2.5	4				
Total			19	Total			2
Elementary school				*No opportunity*			
None	9.8	3.1	5	None	14.8	7.5	12
Nested	7.8	2.5	4	Nested	14.8	7.5	12
Transdisciplinary	13.7	4.4	7	Transdisciplinary	11.1	5.7	9
Interconnected	35.3	11.3	18	Interconnected	30.9	15.7	25
Sequential	5.9	1.9	3	Sequential	4.9	2.5	4
Overlapping	3.9	1.3	2	Overlapping	3.7	1.9	3
Siloed	21.6	6.9	11	Siloed	19.8	10.1	16
New	2.0	0.6	1				
Total			51	Total			81
Middle school				*Graduate school*			
None	1.0	0.6	1	Nested	1.0	0.6	1
Total			1	Total			1

methods: either what they experienced growing up, or likewise the teaching styles of their teacher placement mentors (Rodriguez 2015). In this case, participants often reported experiencing teacher-directed orientations growing up, focused on lecturing and direct instruction. Findings could also help with counter-resistance measures as well. Since we have begun to understand teacher beliefs, both positive and negative surrounding STEM, we can begin to alleviate negative beliefs or feelings such as “STEM is hard.” Overall, we as STEM researchers can also begin to understand what conceptualizations are useful in what contexts (if differentially effective). Given the push to prepare effective STEM educators, preservice STEM teachers need access to effective tools toward their development.

Conclusions

Summarily, our exploratory study about preservice teachers’ conceptions of STEM education yielded many findings and future directions. High variation existed in both textual and visual conceptions of STEM education, not readily connected with teacher experiences. Although there were commonalities in responses (for example Interconnected visualizations), new visualizations were found as well. Overall, this suggests the need to understand what educators and researchers at all levels are thinking about this topic. From drawings of robots to Venn diagrams, and responses that STEM is a government initiative or “too hard” for children to grasp, much more needs to be done both *conceptually* and *instructionally*.

Yet, at the most basic level, our research gets at a single, common truth across many national preservice teacher development programs—the need for more effective STEM instruction. Quick visualizations may help provide effective visual frameworks for future STEM educators by which to better internalize STEM knowledge. Coupled with effective pedagogical instruction, effective STEM visualizations could help immensely with future STEM teacher development. While rich textual definitions surrounding STEM education may exist, we need to deliver preservice STEM educators the means to excel—to clearly, and literally show them the way.

Appendix

Preservice Teacher STEM Education Survey.

Below we provided the front and back pages (Figs. 3, 4) of the STEM survey we utilized during the course of this study, with all prompts and questions. Immediately below is the front page (Fig. 3).

Below is the back page of the STEM survey utilized during this study (Fig. 4).

<u>**Directions:** This survey is about STEM education. Please answer each question the best you can.</u>
<u>Thank you!</u>

1. **Sex:**
   Male_____ Female_____ Other (please fill in)_____

2. **Ethnicity:**
   Caucasian_____ African American_____ Latino_____ Asian____
   American Indian_____ Native Hawaiian or Other Pacific Islander_____
   Other (please fill in)_____

3. **Age**
   18-29_____ 30-49_____ 50+_____

4. **Subject(s) you plan to teach: ____**

5. **Levels taught at already (if you have taught):**
   a. Elem; Yrs_____ b. Middle; Yrs_____ c. High; Yrs_____ d. Undergrad; Yrs_____
   e. Grad; Yrs____ f. I have not had the opportunity to teach yet______

6. **Think of the teaching styles you experienced growing up as a child (K-12). Were they more expository/teacher-directed, or more active teaching/student-directed? Expository teaching style can be defined as direct instruction in which the teacher is in front of the room lecturing and students are taking notes.**
   Expository Teaching, ←--→Active Teaching,
   Teacher-directed Student-directed

   __a. mostly teacher-directed ___b. somewhat teacher-directed
   ___c. somewhat student-directed ___d. mostly student-directed

7. **Now think of the teaching styles you wish to adopt for yourself. Are they more expository/teacher-directed, or more active teaching/student-directed? Expository teaching style can be defined as direct instruction in which the teacher is in front of the room lecturing and students are taking notes.**
   Expository Teaching, ←--→Active Teaching,
   Teacher-directed Student-directed

   __a. mostly teacher-directed ___b. somewhat teacher-directed
   ___c. somewhat student-directed ___d. mostly student-directed

Fig. 3 The front page of the survey given to the preservice teacher participants

8. **Recently, new reform requires teachers to teach (and students to be exposed to) STEM education. The letters S-T-E-M in "STEM" stand for Science, Technology, Engineering, and Math. Given this information, what characterizes STEM instruction from other types of instructional methods?**

9. **How related to one another do you perceive STEM disciplines to be? _____**

   1 2 3 4 5 6 7 8 9 10

   Not connected ←-------------------------------→Well connected

10. **Why did you pick that answer (e.g. how are they related to one another or not)? Please Explain.**

11. **Now, visualize STEM in your mind. How do you visualize it? Draw a diagram how you visualize it using the letters S-T-E-M, as well as how they are connected, below:**

12. **Finally, why did you draw it this way?**

THANK YOU FOR YOUR HELP. Please turn in your survey to Author on the way out of the classroom.

Fig. 4 The back page of the survey given to the preservice teacher participants

Table 9 represents a breakdown by teacher experience and visualization type, showing percentages of visualization types by group as well as total participants.

References

Anderson TR, Schonborn KJ, du Plessis L, Gupthar AS, Hull TL (2013) Identifying and developing students ability to reason with concepts and representations in biology. In: Multiple representations in biological education. Springer, Netherlands, pp 19–38

Babbie ER (1990) Survey research methods. Wadsworth Pub, Co Belmont

Bodnar G, Klobuchar M, Geelan D (2001) The many forms of constructivism. J Chem Educ 78(8):1107

Bodner GM, Orgill M (2007) Theoretical frameworks for research in chemistry/science education. Pearson Prentice Hall

Breiner JM, Harkness SS, Johnson CC, Koehler CM (2012) What is STEM? A discussion about conceptions of STEM in education and partnerships. Sch Sci Math 112(1):3–11

Buckley BC (2000) Interactive multimedia and model-based learning in biology. Int J Sci Educ 22(9):895–935

Bybee R (2013) The case of STEM education: challenges and opportunities. NSTA Press, Arlington

Charmaz K (2006) Constructing grounded theory: a practical guide through qualitative research. Sage Publications Ltd, London
Cook MP (2006) Visual representations in science education: the influence of prior knowledge and cognitive load theory on instructional design principles. Sci Educ 90(6):1073–1091
Fink A (1995) The survey handbook, vol 1. Thousand Oaks, CA
Fowler CW (1988) Population dynamics as related to rate of increase per generation. Evol Ecol 2(3):197–204
Hurtado S, Newman CB, Tran MC, Chang MJ (2010) Improving the rate of success for underrepresented racial minorities in STEM fields: insights from a national project. New Dir Inst Res 2010(148):5–15
Johnson CC (2013) Conceptualizing integrated STEM education. Sch Sci Math 113(8):367–368
Kelly GA (1955) The psychology of personal constructs. Norton, New York
Kim B (2001) Social constructivism. Emerg Perspect Learn Teach Technol 1(1):16
Koonce DA, Zhou J, Anderson CD, Hening DA, Conley VM (2011) What is STEM? Retrieved from http://www.asee.org/public/conferences/1/papers/289/view
Lynch SJ, Peters-Burton EE, Ford MR (2014) Building STEM opportunities for all. Educ Leadersh 72(4):54–60
Magnusson S, Krajcik J, Borko H (1999) Nature, sources, and development of pedagogical content knowledge for science teaching. In: Gess-Newsome J, Lederman NG (eds) Examining pedagogical content knowledge. Springer, Berlin, pp 95–132
Mayer RE, Bove W, Bryman A, Mars R, Tapangco L (1996) When less is more: meaningful learning from visual and verbal summaries of science textbook lessons. J Educ Psychol 88(1):64
Merrill C (2009) The future of TE masters degrees: STEM. In: Presentation at the 70th annual international technology education association conference, Louisville, Kentucky
Moore TJ, Johnson CC, Peters-Burton EE, Guzey SS (2015) The need for a STEM road map. In: Johnson CC, Peters-Burton EE, Moore TJ (eds) STEM road map: a framework for integrated STEM education. Routledge, p 1
Morrison JA (1999) Investigating teachers' understanding and diagnosis of students' preconceptions in the secondary science classroom. Retrieved from Oregon State University Library. http://hdl.handle.net/1957/33374
Nadelson LS, Callahan J, Pyke P, Hay A, Dance M, Pfiester J (2013) Teacher STEM perception and preparation: inquiry-based STEM professional development for elementary teachers. J Educ Res 106(2):157–168
National Academy of Engineering and National Research Council (2014) STEM integration in K-12 education: status, prospects, and an agenda for research. National Academies Press, Washington
National Research Council (2012) A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. National Academies Press, Washington
National Research Council (2013) Monitoring progress toward successful K-12 STEM education: a nation advancing?. National Academies Press, Washington
O'Brien S, Karsnitz J, Sandt S, Bottomley L, Parry E (2014) Engineering in preservice teacher education. In: Purzer S, Strobel J, Cardella ME (eds) Engineering in pre-college settings: synthesizing research, policy, and practices. Purdue University Press, pp 277–300
Outlier Research & Evaluation. (2014). What do STEM schools do? 78 components of inclusive STEM high schools. Retrieved from http://outlier.uchicago.edu/s3/findings/infographic/
Peeck J (1993) Increasing picture effects in learning from illustrated text. Learn Instr 3(3):227–238
Rodriguez AJ (2015) What about a dimension of engagement, equity, and diversity practices? A critique of the next generation science standards. J Res Sci Teach 52(7):1031–1051
Roth WM, Bowen GM, McGinn MK (1999) Differences in graph-related practices between high school biology textbooks and scientific ecology journals. J Res Sci Teach 36(9):977–1019
Sherin MG (2007) The development of teachers' professional vision in video clubs. In: Goldman R, Pea R, Barron B, Derry S (eds) Video research in the learning sciences. Routledge, New York
Skiba R, Rausch MK (2004) The relationship between achievement, discipline, and race: an analysis of factors predicting ISTEP scores. Children left behind policy briefs. Supplementary Analysis 2-D. Center for Evaluation and Education Policy, Indiana University
Tobin K (1990) Social constructivist perspectives on the reform of science education. Aust Sci Teach J 36(4):29–35
Tsupros N, Kohler R, Hallinen J (2009) STEM education: a project to identify the missing components. Intermed Unit 1:1–35
Von Glasersfeld E (1995) Radical constructivism: a way of knowing and learning. Studies in mathematics education series: 6. Falmer Press, London