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Disentangling the meaning of STEM: implications for science education and science teacher education.

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Disentangling the Meaning of STEM: Implications for Science Education and Science Teacher Education

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We have a wide variety of teaching experiences, from formal settings in elementary school (Valarie), high school (Alex, Taukir, and Meize), higher education (Steven), and teacher education (all) to international settings (Angela, Meize, and Taukir) and also to informal settings (Angela and Alex). Despite our multiple teaching settings and experiences, and the fact that all of us have been responsible for teaching science, technology, engineering, and mathematics (STEM) in one fashion or another, none of us could really define any characteristics of STEM that would indicate it was a separate discipline. If we were supposed to teach STEM, then there should be some indication of what STEM would actually be. Although all but one of us are science educators (the exception being Meize, who is a scholar in instructional systems technology at Indiana University), none of us has ever taken an engineering course, though we are familiar with the engineering standards in the Next Generation Science Standards (NGSS Lead States, 2013). We did a bit of research and found that Bybee (2013) suggested that the meaning of STEM is ambiguous and could even be considered political. It could be seen as a buzzword to gain attention and funding. Instead of stating that their work is in STEM education, researchers could share their STEM project, which could gain attention and possibly more funding as it connects to the newest buzzword. Is STEM (or any of its variations) more than a buzzword? How can we include all of the components of STEM in education in an integrated and meaningful fashion, and how can we help prepare teachers to do so? We decided to do a bit more research. We focused on describing and defining the natures of the disciplines that make up STEM—science, technology, engineering, and mathematics—and then attempted to combine these characteristics to define the nature of STEM (Peters-Burton, 2014). To provide ourselves with some background knowledge, we broke off into pairs or worked individually and conducted research on the natures of the individual disciplines. Of course, if we had had a team that had included math educators and engineering educators we would have asked them to take the lead on the natures of mathematics and engineering. Meize took the lead on describing the nature of technology. So first, we briefly describe the natures of these individual disciplines, from our perspectives as (mostly) science educators from Indiana University. Though we are an international group, with half of us being from outside of the United States, we take a U.S. perspective simply because we are all currently at Indiana University. We are speaking from our context at Indiana University and acknowledge that reactions and work in conceptualizing STEM may be different in other settings. We would be interested in knowing what others do and perceive.

Nature of science (NOS)

While discussing NOS, it is important to take into account some aspects of the philosophy of science. Philosophers of science emphasize that NOS is more than a list of tenets (Eflin, Glennan, & Reisch, 1999). Lederman, Wade, and Bell (1998) stated that the values and assumptions related to NOS include, but are not limited to, independence of thought, creativity, tentativeness, an empirical base, subjectivity, testability, and cultural and social embeddedness, which is not a list of tenets to memorize but ideas to conceptualize. From that point of view, we can assume that NOS is closely related to the epistemology of science.

The Next Generation Science Standards contain ideas about NOS for students to learn in kindergarten–Grade 12 (K–12) science lessons that are derived from ideas from the philosophy of science. Within the Science and Engineering Practices section there are four aspects of NOS that students should know by the end of high school. First, scientific investigations use a variety of methods. One can still see a poster of the steps of the scientific method posted on a classroom wall, when in reality scientists do not use one single method. Second, scientific knowledge is based on empirical evidence. All scientific knowledge is at least partially based on observations of the natural world. In addition, all scientific theories and laws can be checked against what actually occurs in the natural world, which will substantiate the scientific knowledge and allow for predictions. Third, scientific knowledge, though robust, is open to revision in light of new evidence. If new evidence is found, the scientific knowledge can be changed or modified. Similarly, reinterpreting existing scientific knowledge allows for changes in scientific knowledge. Fourth, scientific claims, including laws and theories, explain natural phenomena. Laws describe relationships among observable phenomena, and theories are inferred explanations for observable phenomena.

There are also four aspects of NOS found within the Crosscutting Concepts section that K–12 students should conceptualize. First, science is a way of knowing different from other ways of knowing. Second, science addresses questions about the natural and material worlds. Third, scientific knowledge assumes an order and consistency in natural systems so we can search for patterns in data and empirical evidence and make predictions and form generalizations to explain the natural world. And fourth, science is a human endeavor, which means that data are subject to human interpretation and creativity as well as being theory laden and subjective and socially and culturally embedded. We keep in mind that these aspects of NOS are not distinct because there is an interconnectedness among them that should be embedded in the context of any science topic or investigation and incorporated into science teaching.

Nature of technology

Because the boundaries among technology, science, and engineering are somewhat blurred, the nature of technology has not been as strongly emphasized as the other STEM disciplines or even as the use of technologies. As Arthur (2009) mentioned, the "- ology" part is missing in research in technology. Although scholars are not consistent on the definition of technology (Wahab, Rose, & Osman, 2012), some common characteristics still emerge. These characteristics are the nature of physical production; knowledge, skills, experience, and approach of application; and organization into systems. Arthur identified technology as an orchestration of phenomena that are programmed for a useful purpose. Technology is organized around a concept or principle and is expressed in a physical component form. The evolution of technology is combinatorial, modularized, recursive, and systematic. With this broad definition, especially when computers start to play an important role in technology, technology could be presented as different by individuals in different disciplines that develop as the domain evolves. However, Kruse (2013) discussed the importance of understanding technology not just as electronic technologies. He suggested some important critical nature of technology ideas for technology education. These ideas include identifying technology (i.e., different types of technology and how they are used), the nature of technological progress (i.e., its positive and negative impacts on our lives), the fact that technology is not neutral (technologies are not evenly distributed or available to all), the limitations of technology (technology cannot solve all problems and may even create problems), technological tradeoffs, and the interactions of technology and culture.

Multiple organizations provide curriculum standards related to technology, for example, the International Society for Technology in Education (formerly known as the National Educational Technology Standards), the International Technology and Engineering Educators Association, and the Computer Science Teachers Association. States can choose these existing standards or develop their own. In the curriculum standards of Indiana, technological literacy is closely connected to engineering and computer science and is combined within science standards. Even though K–12 academic standards address technological literacy and computer science, incorporating technology into K–12 teaching still grabs more attention among scholars, teacher educators, and professional developers than teaching about the nature of technology. There is a stronger focus on the use of technology over the nature of technology. A question remains as to whether the imbalance and absence of nature of technology will make technology seem less important in STEM than the other disciplines or simply a vehicle to progress the other disciplines.

Nature of engineering

Engineering is a process for creating the "human-made world, the artifacts and the processes that never existed before" (National Academy of Engineering & National Research Council, 2009, p. 9). Engineering design is a systematic and intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints (Dym, Agogino, Eris, Frey, & Leifer, 2005). Engineering standards have been proposed in terms of three big idea categories: knowledge, skills, and habits of mind. Skills include designing under constraints, using tools and/or materials, and mathematical reasoning (Sneider & Rosen, 2009).

Engineering components were included in national science standards for the first time in the standards titled A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (National Research Council, 2012). Although crosscutting concepts have been proposed by the National Academy of Engineering, rather than establishing stand-alone engineering standards the Academy has suggested infusing engineering into existing standards, that is, integrating engineering into other subjects through concept mapping (Sneider & Rosen, 2009). For example, Indiana's new science standards format poses all standards as process standards. Within these process standards, NOS and the design process of engineering are both explained and integrated into the four content areas of physical science; earth and space science; life science; and a new area called science, engineering, and technology (SEM). The SEM area utilizes science discovery to inform engineering design and problem solving as students design and improve technologies (Carr, Bennett, & Strobel, 2012). Although it has been suggested that crosscutting themes be used to incorporate engineering into existing standards, it is important to acknowledge differences between the disciplines. Engineering design is an approach to solving or achieving goals, whereas technology is a fundamental attribute of human culture. Science and engineering differ in terms of goals, processes, and products (Sneider & Rosen, 2009).

A K–12 STEM standards survey conducted across the United States sought to arrive at a consensus around whether the big ideas of engineering already exist so that they could be infused into state or national standards. The survey revealed that 41 states' standards included engineering skills and knowledge embedded within either science or technology and vocational standards (Carr et al., 2012). Although big ideas of engineering have been identified and standards do exist, uniformity or systematically introduced standards are less prevalent. The next step for engineering appears to be to decide and then, at the national level, implement engineering as a separate set of standards or incorporate it into established standards via crosscutting concepts that include the big ideas that have been proposed in numerous definitions and identified nationally: identifying problems, design process, constraints, solving problems and iterative testing and analysis of models and products.

Nature of mathematics

Although there is not yet an agreed-on definition of the nature of mathematics, mathematics education researchers such as Pair (2017) have proposed some core characteristics of mathematics, at least in the subdiscipline of pure mathematics. Pair suggested that mathematical ideas and practices are part of cultural identity, mathematical knowledge is dynamic and subject to modification, mathematical inquiry is an exploration of mathematical ideas, and that these ideas are tested via social argumentation. He acknowledged that he follows the fallibilist, humanist philosophy of mathematics, that is, the notion that mathematics is a human construct and therefore is never beyond revision and correction (Hersh, 1997). This view of mathematics has paved the way for fallibilist mathematical thinkers to call for educational reform (Pair, 2017). These types of thinkers suggest that current mathematical education in schools focuses on Western commercial-administrative mathematics (Harouni, 2015) in which students are taught to use mathematical procedures but are not required to understand why they work. This educational practice perpetuates assumptions that mathematics produces certain solutions that are not subject to change. Some mathematicians and mathematics teachers who adhere to the view that mathematical knowledge is certain and unchangeable – the absolutists – argue that mathematics exits beyond the human kind and that humans simply discover mathematics rather than invent it (Hersh, 1997). This notion is based on Platonist and formalist views of mathematics and is viewed by some as outdated.

The Common Core State Standards for Mathematics (Common Core State Standards Initiative, 2010) recognizes the need for students to be able to "construct viable arguments and critique the reasoning of others" in their standards for mathematical practice (p. 6). The National Council of Teachers of Mathematics (2000) have also stated that a key component of mathematical literacy includes having an understanding and appreciation of mathematics as a cultural and intellectual human achievement. Despite these examples of the insurgence of fallibilist mathematical philosophy into mathematics standards, many teachers retain their absolutist view (Pair, 2017), so the advancement of the humanist outlook may fall to mathematics teacher educators.

Nature of STEM

Once we had some idea about the natures of the individual disciplines, we debated and tried to define a nature of STEM that would combine these disciplines. After quite a bit of thought and debate we said as a group, "There is no STEM—it is nothing!" We ultimately agreed on a definition that STEM itself is a socially constructed label that is in response to economic and global pressure. It has always existed but was simply the individual disciplines that compose it, influencing and building on one another. We put a name to what already existed. We then asked ourselves two questions: (a) Does calling what we do STEM change what we are doing? and (b) Does calling what we teach STEM change what and how we are teaching? To both questions, we answered, "Well, no." For those of us who are science educators, doing STEM literally means doing science; for our instructional systems technology person it means to teach SEM through technology. Teaching STEM is to most of us teaching science while making connections as we can to the other disciplines composing STEM. For Meize, technology is at the forefront while making connections to the three other STEM disciplines. None of us has an engineering background, and so we all feel a bit uncomfortable attempting to teach about engineering, and how to teach engineering, to our preservice or in-service teachers. We also acknowledge a struggle making connections to engineering through science or technology lessons. The difficulties of including engineering within a science methods course were highlighted by Capobianco (2016) and include (a) relying on self-learning by the science teacher educator to learn about engineering as well as how it connects to science and (b) questioning the role of engineering in science teacher education. We believe we definitely share these same difficulties.

We did indeed attempt to define characteristics of STEM, or the nature of STEM, but realized that the characteristics we identified, though we attempted to include all STEM disciplines, were generally similar to those aspects of NOS that we are accustomed to studying and teaching to teachers, such as creative, theory laden, socially constructed, observational, and even no universal STEM method. The only characteristic that we really identified that we thought was unique to STEM was that it was interdependent. We also realized that we are viewing the nature of STEM through our lenses as science educators, and that is likely why the aspects we described were more like NOS ideas. A group of mathematics educators, for example, would likely have a very different conception of the nature of STEM. We finally realized that the interdependent aspect really defined the intention of STEM—that it describes the connections between and influences of individual disciplines on other STEM disciplines. STEM is not a discipline in and of itself and therefore has no nature—there is no nature of STEM, but there are natures of the individual disciplines that compose STEM.

Implications for science teacher education

Again, we all can recall being asked to teach STEM. But we are not sure what that really means, as it means something different for each of us, and depending on which letter of STEM a person is most aligned with, the focus is different. By being told to teach STEM, and to teach teachers to teach STEM, it seems that STEM is a discipline itself. Yet we tried very hard in 3 months of work to develop a nature of STEM that made sense, but could not. We now believe, through our research, that STEM is not a discipline—no one really gets a degree in STEM, but people do get degrees in the disciplines that are part of STEM. If we are going to be asked to teach STEM as a discipline itself, and to teach teachers to teach STEM, do we need to prepare teachers to understand the natures of each of the disciplines that compose STEM as well as the connections among them? It seems that teachers would need to know the natures of the disciplines they are to teach. It would seem that teachers (and teacher educators) would need a sound understanding and foundational knowledge in each of the disciplines, as well as the connections between those disciplines, and methods for making those connections explicit to their students. But if we have not been successful in the past in helping teachers better conceptualize NOS, as well as teach it, how can we help them better conceptualize all four disciplines, plus the connections among them, and then teach these ideas to students? A search for a definition of the nature of STEM and then for developing a nature of STEM yielded no results.

As we who read the Journal of Science Teacher Education are generally science teacher educators, in an era when STEM education is in vogue, we are wondering how we can possibly teach teachers the individual disciplines of STEM, including the natures of these disciplines, when we ourselves are focused on science. As science educators we likely have science minors and have taken numerous science education doctoral and research courses and precious few, if any, pure mathematics (other than quantitative statistics or research methods) or technology courses. We believe it would be even more rare for a science educator to have taken even one engineering course. This background is quite similar to that of science teachers, who major in a science and become certified to teach at some range of grade levels. Although some mathematics is included in all majors, and possibly one technology course, rarely do any science teachers take an engineering course. And at Indiana University at least, preservice elementary teachers take four science courses, one or two science methods courses (if they are science concentration students they take two), one technology course, one math methods course, and four math content courses. There are zero engineering courses. So the problem is compounding—the science teacher educators with no engineering backgrounds are preparing the science teachers, who also have no engineering backgrounds, so they can teach STEM. Whatever that actually means. Which leads us to ask whether it is such a bad thing to have science teachers actually teaching science? Why the focus on STEM? Do we need to connect all of the other STEM disciplines in a science class to have a good lesson? And we still have not been able to successfully help all (or at least most) K–12 science teachers conceptualize NOS, which is their (and our) focus discipline. This lack of progress in teaching and learning NOS makes us question why we are adding more to their (and our) plates when no single individual (well, maybe an omniscient being) can deeply conceptualize the nature of all of the individual disciplines, plus the content of those disciplines, as well as their interdependence and methods for making meaningful explicit connections among those disciplines. It seems to us that our emphasis on science teacher education should be stronger on NOS to better prepare science teachers to teach science. Lederman and Lederman (2014) raised the concern that NOS may be "going, going, gone," in part because of its treatment in the Next Generation Science Standards, but we believe that another way it is being pushed aside is through the advent of the STEM movement.

Again, these are our perspectives as scholars currently at Indiana University, and we are curious how others view STEM and how they deal with these ideas. It has always seemed like we have asked a lot of teachers, but it seems that now we may be asking the impossible of them. Or like we asked while exploring these ideas: (a) Does calling it STEM change what is being done? and (b) Does calling it STEM change how it is taught? We think the answer is no. But fund our STEM programs please.

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