Defining the 'S' in STEM: Nature of Science as a Component of STEM Literacy

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How did We Get to "STEM?"

It seems we have a new acronym "STEM," which is sometimes even "STEAM" (just add "art") or "STIM" (just add "informatics") depending on what the individual letters stand for and who is using the term. Typically "STEM" stands for Science, Technology, Engineering, and Mathematics. But why do we have this new acronym, and what does it really mean? Bybee (2013) states that the meaning is ambiguous and could even be considered political. It could even be seen as a buzzword to gain attention and funding. Instead of stating that their work is in science, technology, engineering, or technology education, researchers could state they have a "STEM" project, which could gain attention and possibly more funding as it connects to the newest buzzword. How can we make "STEM" (or any of its variations) more than a buzzword? How can we include all the components of STEM in education, in an integrated and meaningful fashion? Is STEM just a slogan, or can it be a meaningful way of education?

My own perspective is from that of a science educator, trained as a science educator. In my work I help prepare preservice elementary teachers to teach science. And yet, it seems that I am now I am also supposed to be preparing them to teach STEM. Yet, what is STEM? Is it "simply" science, technology, engineering, and mathematics? Or is it bigger than that?

First—Scientific Literacy

Whatever your definition of STEM, one thing is common—we all agree on the goal for a scientifically literate public (NSTA, 1982), even if we don't exactly agree on the same definition of "Scientific Literacy."

What is clear is that "simply" understanding science content is not enough for scientific literacy. Knowing scientific laws and theories, as well as concepts that are found in all the science textbooks is not enough to be considered scientifically literate. Knowing how that knowledge has developed through scientific "practices" is also not enough. People need to actually be able to use the scientific knowledge to help them make informed decisions about issues that affect them, their lives, and their world. Unless individuals understand science as a way of knowing, in addition to the content and practices, then they would not be able to use the knowledge to make informed decisions, and therefore would not be considered scientifically literate. Lederman and Lederman (2014) share their idea that science can be thought of in at least three interrelated parts: (a) science as a body of knowledge—the content part of science, the science that you read in textbooks, (b) strategies for developing scientific knowledge—the methods of science, the practices of science, and (c) characteristics of the knowledge itself—the very nature of scientific knowledge (NOS).

Knowing how scientific knowledge is developed, and the characteristics of that knowledge, is essential to making informed decisions. Without being able to weigh claims made by scientists, and understanding the strengths and even weaknesses of that scientific knowledge, people will not be able to make informed decisions about issues in society. Therefore it is essential that the general public have an accurate understanding of the very nature of science itself.

In the United States we now have the Next Generation Science Standards (NGSS) (2013). These Standards now also incorporate not only science content and scientific practices, but also engineering practices, that teachers K-12 are responsible for teaching. Unfortunately, with the exception of a few secondary science teachers, most public and private school teachers never take even a single engineering course, and likely have very little understanding of engineering itself. Not only that, but most university science and mathematics educators, who are responsible for preparing science teachers, also have never taken an engineering course, and therefore also have limited understanding of engineering, which limits the connections that can be drawn and interwoven among the components of science, technology, engineering, and mathematics—STEM.

Despite the lack of formal engineering coursework, K-12 teachers are responsible for teaching science across the three dimensions included in the NGSS. These dimensions are the Disciplinary Core Ideas, the Science and Engineering Practices, and the Cross-Cutting Concepts. The Disciplinary Core Ideas are basically the content of science—the knowledge that has been developed about science—the content found within the science textbooks. The Science and Engineering Practices include conceptualizing how scientific and engineering knowledge is developed—the methods used by scientists and engineers in developing knowledge. The Cross-Cutting Concepts include ideas that transcend all science content, and are considered then, as part of science. It is within the Science and Engineering Practices and the Cross-Cutting Concepts that we find ideas about NOS and scientific inquiry. In the next section we look into the specific aspects of NOS that are present in the Science and Engineering Practices as well as the Cross Cutting Concepts. We then turn our attention now to research on NOS and scientific inquiry.

Nature of Science

The Next Generation Science Standards contain ideas about Nature of Science (NOS) that need to be included in K-12 in science lessons. Within the Science and Engineering Practices section there are four aspects of NOS to be found that K-12 students should know by the end of high school. First, scientific investigations use a variety of methods. One can still often times see a poster of the steps of "The Scientific Method" posted on a classroom wall, when in reality scientists do not use one simple method. In fact, many investigations are descriptive and/or correlational, and simply do not fit "the scientific method." Second, scientific knowledge is based on empirical evidence. For something to be a scientific way of knowing, there needs to exist empirical data that supports the idea. All scientific knowledge is at least partially based on observations of the natural world. In addition, all theories and laws can be checked against what actually occurs in the natural world, which will substantiate the scientific knowledge, as well as 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 can also allow for changes in scientific knowledge. Fourth, scientific models, laws, mechanisms, and theories, explain natural phenomena. These are different types of scientific knowledge, but all help explain phenomena and all arise from interpretation of empirical evidence. Laws describe relationships among observable phenomena and theories are inferred explanations for observable phenomena.

There are also four aspects of NOS to be found within the Cross-Cutting Concepts section that students K-12 should conceptualize. The first is that science is a way of knowing, that is different from other ways of knowing, such as history, art, philosophy, and religion. Scientists attempt to explain natural phenomena, and are not involved in questions that cannot be answered by science, such as whether God exists. Third, science address questions about the natural and material world. It does not seek to answer questions outside the natural world. Those questions are important, but cannot be answered by science. Third, scientific knowledge assumes an order and consistency in natural systems. By assuming this order we can search for patterns in data and empirical evidence, and then make predictions and form generalizations to explain the natural world. And fourth, science is a human endeavor, meaning data are subject to human interpretation and creativity, as well as being theory-laden and subjective, and socially and culturally embedded.

NOS and Scientific Inquiry—Influence of Research

There has been ample research on student and teacher understanding of NOS as well as scientific inquiry over the past six decades. While it is clear that student and teacher conceptions can improve, generally the same misunderstandings are held by students and teachers now as they were decades ago (Lederman, 2007). Unfortunately, these misconceptions about NOS and scientific inquiry clearly mean that little progress has been made in helping students and teachers attain scientific literacy. It is clear from empirical research that student and teachers' learning about NOS and scientific literacy is most effective through explicit reflective instruction (Lederman & Lederman, 2014). Explicit reflective instruction requires teachers to facilitate discussion and reflection about the very nature of science itself as investigations are taking place, or as they are debriefed after being concluded. Therefore the students will be explicitly reflecting on ideas about NOS as part of their science instruction.

However, this explicit reflective instruction rarely takes place. Unfortunately, despite the empirical research, there is little change to curricula, or classroom practice. The act of embedding NOS explicitly takes tremendous effort in adapting lessons and ensuring it is completed (Akerson, Pongsanon, Nargund, & Weiland, 2014). It is not typically included in curricula, and therefore even teachers who want to include it need to spend much time in adapting lessons. This lack of emphasis on NOS in the curricula has influenced the amount of NOS instruction that takes place in a science classroom—it is still very little, unless a teacher is very committed to such instruction.

Now, not only are K-12 teachers to teach about science, including NOS, but they also need to include connections to technology, engineering and mathematics—STEM. And maybe art too, if they are teaching "STEAM." Or if you are at Indiana University and have no engineering department, "Informatics" instead of engineering, and you are "STIM." However, with teachers still struggling to not only teach about NOS, despite the years of empirical research supporting teaching methodology for effective NOS instruction, it definitely means our job in teacher preparation will entail even more, to prepare teachers for what they need to do. If they need to conceptualize the Nature of Science as a way of knowing, certainly they should be able to conceptualize other ways of knowing that are part of STEM—in essence, what is the nature of the "TEM?"

Defining the Nature of the "TEM"

As a science educator, but also a part of current society, I sought to locate statements on the nature of technology, the nature of engineering, and the nature of mathematics. I did what anyone would do—a Google search. In this way, I was able to find what anyone would commonly find when doing such a search. I conducted this search for definitions of the Nature of Technology, Nature of Engineering, and Nature of Mathematics. These definitions will be reported in the sections below.

Nature of Technology

When searching for information regarding Nature of Technology, I was able to locate an entire book (Arthur, 2011) that described "The Nature of Technology: What it is and How it Evolves." In essence, the Nature of technology involves three definitions. First, technologies are combinations of elements that exist. Second, the elements that comprise technology are technologies themselves. Finally, all technologies use phenomena to some purpose. Therefore, technology is purposeful. In addition to these three definitions of technology, Arthur adds three meanings of technology to the nature of technology—or the characteristics of technology. First, there exists individual technologies, or "a means to fulfill a human purpose." Technology, again, is purposeful, and the purposes are to solve issues or problems of a human nature. The second includes the bodies of technologies, such as semi-conductors, or robotics, or "an assemblage of practices and components." This portion of the definition to me is similar to the content part of science—the "stuff" of technology. The third meaning of technology is its largest sense, "The entire collection of devices and engineering practices available to a culture, and is dependent on scientific knowledge." This portion of the definition, as I read it, comprises the content, products, and practices of engineering, more of the "nature" of technology.

Nature of Engineering

A search for a definition of the Nature of Engineering enabled me to locate the National Academy of Engineering's president Wulf's definition from 1997. They state simply that, "Engineers apply their knowledge in science and mathematics to design and create things, develop existing technology, and invent new methods and processes." Their definition is very brief and there did not seem to be an updated definition, at least not one that turned up easily in the search. Regarding the definition, it is apparent that engineers base their designs, in part, on their scientific knowledge, and use that to develop new ideas, processes, and technologies. Note that there is no description of the "engineering design process" that is part of many K-12 STEM curricula.

Nature of Mathematics

Like the search for the definition of the Nature of Engineering, my search for the definition of the Nature of Mathematics similarly turned up an older document—this time a full book chapter within the *Handbook of Research on Mathematics,* by Dossey (1986). A search for a more current version was not readily found, so I used this chapter. From this chapter I gleaned that mathematical objects are invented or created by humans. These creations are not arbitrary, but arise from activity with already existing mathematical objects, and from the needs of science and daily life. Once these mathematical objects are created they have properties that are well-determined with we may have great difficulty in discovering, but which are possessed independently of our knowledge of them. To me, this means that mathematics is also a problem-solving entity that is also connected to science, as its creation arises as a result of the needs of science. Once it exists and is created by humans, it has characteristics that then remain, independent of human knowledge about them.

Back to STEM

If we are going to teach STEM as a discipline itself, do we need to prepare teachers to understand the nature of each of these disciplines that comprise 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. But if we haven't been successful in the past in helping teachers better conceptualize nature of science, 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 for the nature of STEM yielded no results. Does this mean that we need to define what is exactly the nature of STEM? Would that be the way to go, to have only one term about which to conceptualize its nature?

And what about scientific literacy? Do we now focus on STEM literacy instead? But if we cannot agree on a definition of scientific literacy can we agree on a definition of STEM literacy? Bybee (2013) offers the following suggested definition of STEM literacy:

(1) Knowledge, attitudes, and skills to identify questions and problems in life situations, to explain the nature and designed world, and to draw evidence-based conclusions about STEM related issues.

(2) Understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design.

(3) Awareness of how STEM disciplines shape our material, intellectual, and cultural environments

(4) Willingness to engage in STEM issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen.

It would seem evident that to demonstrate STEM literacy, as defined above, individuals would need to conceptualize the nature of the disciplines that comprise STEM, as well as the kinds of knowledge generated in each discipline, along with the connections among them. Not an easy feat to conceptualize these, or to teach these ideas. How then, do we get to STEM literacy? If we look back at the definitions of the "TEM" in STEM, we can see that Nature of Technology—is dependent on *scientific* knowledge, Nature of Engineering—Engineers apply their knowledge in *science*, and Nature of Mathematics, mathematical artifacts are created not arbitrarily but arise from activity with already existing objects, and from the needs of *science*. All the other disciplines in STEM connect somehow to science. It seems the "S" in STEM is important.

This insight into science being a very important component of STEM raises the question how can technology, engineering, and mathematics progress without an understanding of science and its nature? Science is a part of each discipline's nature. It would be difficult for these disciplines to make progress without understanding the nature of scientific knowledge. Therefore it is not only important for NOS to be understood by those studying science, but also those studying STEM disciplines.

Therefore, I raise a call for renewed emphasis on research on NOS in science as well as STEM. How can accurate conceptions of NOS influence conceptions of STEM? What does an accurate conception of NOS mean for those who operate in the STEM field, or for those required to teach STEM K-12?

We need a definition of STEM that we can agree upon, as well as a definition of the nature of STEM. How do we know when we are "doing STEM?" Many projects claim to be STEM projects or programs, but what are the natures of those projects—are there some essential components that are necessary to be included in order to be labeled "STEM?" Or to be labeled "good STEM?"

Are there different kinds, or levels of "STEM?" What does it mean to be STEM? And yes, the S in STEM really is that important—we need to know NOS as part of scientific literacy, but also as part of STEM literacy. There is no STEM without the S.

CONCLUSION

Let us all work hard with our research toward resolving these issues about defining STEM and its nature. And not only just conduct the research, but also make impact on classroom practice. The research on teaching NOS effectively is clear, yet still little change has been seen in classroom practice. Making an impact on classroom practice is easier said than done, as past research on teaching NOS has shown. Hopefully working together to define these ideas we can make better, and quicker, impact, helping improve scientific and STEM literacy.

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