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Teachers' Conceptualizations of Integrated STEM

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Abstract

While improved science, technology, engineering, and mathematics (STEM) education has received national attention, the integrated nature of the these disciplines has not been prominent. Our data suggests that teachers may not recognize the nuances and complexity of the nature of science, technology, engineering and mathematics that allow for more integration and do not experience pressure from policy or administrators to do so. We articulate a model of teachers' views of integrated education and discuss barriers that keep them from fostering it in their classrooms.

Introduction

If importance is measured by ubiquity, the significance of science, technology, engineering, and mathematics—education can scarcely be exaggerated. Education improvement in these areas is seen as the panacea for improved workforce development and global economic competition for the US ((Brown, Brown, Reardon, & Merrill, 2011; Herschbach, 2011; The President's Council of Advisors on Science and Technology, 2011; Subotnik, 2010; Wieman, 2012). Envisioned improvements to STEM education include calls for changes towards better integration of the various disciplinary knowledge and skills bases in each area. Proposed changes to practice and structures include abandoning specific disciplines, such as biology and physics, for more integrated science courses at the high school level (Herschbach, 2011), as well as forming specialized schools (The President's Council of Advisors on Science and Technology, 2011) that, in theory, may allow for students to develop knowledge and skills underlying the disciplines in greater synergy.

As the *Next Generation Science Standards* and *Common Core Standards for Mathematics* are adopted, secondary teachers will be operating under national-, state-, and district level policy regarding inclusion of engineering and technology practices and mathematics within science classrooms. The NGSS require elements of integration exemplified by students using mathematics to support scientific claims and knowledge from across science and mathematics to determine solutions for engineering problems (National Science Teacher Association, 2013). According to some, educators are now obligated by the national standards to incorporate elements from each arena into their existing curriculum (Bybee, 2011).

What remains to be seen is to what degree this policy will be implemented and to what level of fidelity across education environments. How might the new push for integrated of science technology, engineering and mathematics (hereafter *iSTEM*) avoid some of the documented pitfalls of diffusion of other education policy and innovation? What may influence educators' commitment to and implementation of this type of education? Specifically, how will their conceptions of these disciplines, pedagogy, and K-12 education structures and norms influence their beliefs and practices? We ascertain that baseline data is needed regarding these questions towards illuminating the processes that unfold concerning this complicated reform movement.

This paper considers teachers' current implementation and perceptions of iSTEM in concept and in practice. Our inquiry is guided by the following research questions—How do secondary teachers teaching in the target content areas:
1) Conceptualize the acronym and disciplines of STEM?
2) Enact or envision iSTEM curriculum and instruction in the classroom?
3) Recognize and react to the iSTEM movement and associated policy/mandates?

Defining iSTEM

Herschbach (2011) presents two models for instruction that we find most relevant to our work. *Correlated curriculum* relies on the current system of distinct subjects but requires the inclusion of activities that transcend subjects (Herschbach, 2011) and is the model most prevalent amongst much of the current education literature and championed by the NGSS (Bybee, 2011; Crismond, 2013; Locke, 2009; Sneider, 2012). A *broad fields curriculum*, in contrast, has educators abandoning individual subject-specific courses for integrated courses (Herschbach, 2011, p. 101). The lack of a coherent definition of integration and the unpreparedness of educators to teach with either model are seen as obstacles in the implementation of integrated instruction (Czerniak, 2007). Yet the "unpreparedness" of these educators is largely assumed.

Educators' Conceptions of STEM

Researchers have claimed that educators may be hesitant regarding the inclusion of a new set of knowledge and practices that they are likely untrained to teach (Crismond, 2013; Czneriak, 2007); yet this is still largely conjecture at this time. Herschbach (2011) writes, "It is hard to discern what exactly is meant by STEM" (p. 98). The novelty of the education reform movement may explain the lack of research into current conceptualizations and implementations by educators. However, one study, performed by Brown et al. (2011) in Illinois examined 27 K-12 educators' perception and enactment of this type of education. Even for the many educators who placed importance on, and possessed an accurate definition, Brown et al. concluded the integration of these areas into the curriculum was lacking, disjointed, and specific to the educator.

A study by Daugherty and Wicklein (1993) looked at secondary science, mathematics, and technology teachers' perceptions of including technology component within schools. Via analysis of 154 surveys completed by these teachers, the authors concluded that technology education as a field needs to overcome teachers' oversimplified ideas, such as those regarding *computer literacy*, that fail to recognize such as a major field of study that possesses its own knowledge base and skills. They offered that teachers across the three disciplines needed to come to agreement as to what technology education should look like across classrooms, by first discussing their perceptions of technology education, and then fostering collaboration to improve the connections between their content areas. At least, per this study, the implementation and integration of technology, lacks uniformity within schools.

It is also telling to consider at the implementation of the engineering component. Nathan, Tran, Atwood, Prevost, and Phelps (2010) argued that teachers' more general views regarding student capabilities played a direct role in that teacher's effectiveness in incorporating engineering curricula at the K-12 level. Through two sample groups, the first group consisting of 143 teachers from across the Midwest, and the second group consisting of 82 teachers from across the United States, the authors determined that science and mathematics teachers primarily believe that high performance in science and mathematics content areas is a direct link to success in engineering at the secondary level, thus determining which students would benefit from engineering education and which would not. Engineering teachers, specifically, felt that the engineering content area was in itself sufficient to create a well-rounded education for students and should be available for all students (Nathan et al, 2010, p. 13). These differing views on who deserves engineering education may affect the level of engineering education that is incorporated at the K-12 level.

Theoretical Framework: Teachers' Understanding and Enactment of Nature of Disciplines

Our study was based on the assumption of iSTEM as composed of a number of different facets and types of disciplinary knowledge. Herschbach (2011) presented a scheme towards conceptualizing fields as integrated. To do so, he considered each field's *organizational structure,* which consists of three substructures, the *formal*, *substantive*, and *syntactical*. Herschbach drew those terms from Schwab's (1978) description of substantive structures of a discipline, or the ways in which concepts are organized by various means within that discipline. Herschbach's (2011) use of syntactical structure is consistent with Shulman's (1986) description of syntactic structures, which Shulman described as rules for determining the legitimacy of information and arguments within a particular discipline.

Herschbach (2011) noted in [math and science] tends to convey a broad and deep understanding of the organizational, substantive and syntactical structures of the fields. Indeed, as previously stressed, a structural understanding is essential to learning (Bruner, 1960; Herschbach, 2011; McNeil, 1990). (p. 5) Using this perspective, a model of integrated disciplinary areas depends on the teachers' knowledge of formal, substantive, and syntactical aspects of each discipline. Yet it is the substantive and syntactical aspects of knowledge that seem to be most problematic for teachers to learn and use in their instruction. As Slekar & Haefner (2010) noted,

> When the syntactic knowledge is omitted from science and history, missing are aspects associated with the nature of the disciplines. As a result, learners are left unsure of how knowledge is constructed within the norms of the disciplines. If learning about the nature of the discipline is left out of the subject matter courses taken by preservice teachers, where are the opportunities to learn it?" (p. 10).

The issue that Slekar & Haefnar (2010) raise about syntactic knowledge also applies to substantive knowledge. That is, teachers not only are often unable to teach with these types of knowledge in mind, but they are unaware that these types of knowledge exist, are important, and can support an epistemology of integrated disciplines. We hypothesize that conceiving of the structure of knowledge in light of the boundaries (formal), the questions and theories (substantive) and the methodologies (syntactical) from each of the disciplines promotes not only an understanding of each discipline, but also the ways in which they are compatible with one another. At the same time, difficulty in conceiving of disciplines as integrated likely results from a dearth in one of these areas.

Methodology

Subjects and Setting

A semi-structured interview protocol was utilized consisting of open response questions posed via interviews with 20 educators selected on a voluntary basis but intended to represent science, technology, engineering and mathematics. Interviews lasted roughly 30-45 minutes. Interviews were conducted with educators at three high schools in the United States in Spring 2013. The first was a school of 1,368 students. The race demographics of the school list 2.0% of students as Asian, 2.0% Pacific Islander, 1.9% Black, 1.4% American Indian, and 93% White. The school has students from both the highest and lowest socioeconomic status (SES) neighborhoods in the community with a significant sector of students receiving free or reduced fee lunches, consisting of 325 (27.2%) receiving free or reduced fee lunches. The second was of a school of 1,150 students. The race demographics at the school list 6% of the student as Asian, 2% as Pacific Islander, 5% Black, 5% American Indian, 15% Latino and 67% White. The school has students from primarily low socioeconomic status neighborhoods with 55% of the students receiving free or reduced lunches. In the third school there were 519 students. Of the 519 students, there were 128 freshmen, 147 sophomores, 125 juniors, and 199 seniors. Of the school population 11 students were American Indian, 5 were Asian/Hawaiian/Pacific Islander, 48 are Hispanic, 11 were black, and 456 were Caucasian. There were 185 students that participated in the free lunch program and 59 students that qualified for the reduced price lunch.

Data Collection and Analysis

Analysis was inductive regarding educators' perceptions conceptions of, enactments of, and motivation to pursue iSTEM. Two researchers analyzed each third of the data set independently and a third and a fourth researcher then checked for reliability of conclusions across the data set.

The following questions were asked of each respondent:

1. What position do you currently hold at this school?
2. What does the acronym STEM mean to you?
3. How does your conceptualization of STEM education affect the curriculum and instruction in classrooms (in your classroom)?
4. Do you place equal emphasis on the four components on STEM for (when) teaching?
5. What do you feel is the relationship between technology and engineering?
6. Is education that integrates all four components of STEM important? Why or why not?
7. Can you envision more integrated STEM education within the classroom? What would that look like?

8. Do you feel that this type of integrated STEM education is for all students?
9. Do you feel pressure to implement STEM education (in your classroom)? If yes, what is the source?
10. Reflecting upon this interview, what experiences have shaped your responses?

Findings

Finding 1: Teachers' Conceptions

All 20 teachers stated that each component of STEM was crucial for students to develop understanding about. At the same time, they also viewed the integration of the disciplines as important for their own practice. Teachers' reasons for identifying these disciplines as important ranged from developing an educated citizenry (e.g. "Students need to be well versed in all of the areas or understand what goes on in each of the areas") to important for problem solving ("Our students need basic literacy in mathematics and science to solve some of the most difficult problems of our time.") to important for issues like climate change ("Science is applying logic to a problem." Why important today? Because all issues today, such as climate change and abortion, require problem solving. There are different ways to approach problems, religion is one, but science is another"). Almost all 20 teachers identified the ability to solve complicated, real-world problems as an important consequence of integrating STEM disciplines. However, it is also clear that they envisioned a collection of "siloed" subject areas with distinct boundaries, rather than as a cohesive endeavor. Concurrently, they also appeared to conceive of each subject area at the *formal* level, or mostly focused on the content needs of each discipline. There was little evidence that they attended to the substantive or syntactical structure of each discipline, which also may have contributed to their notion of each area as siloed.

Finding 2: A Way of Knowing and Learning vs. a Teaching Method

Though all 20 teachers identified the integration of the disciplines as important, the teachers' responses to the question of how they implement, or could envision, iSTEM in their classroom led us to conclude that their conception of it centered on their teaching practices (instructional moves and decisions) rather than as epistemology of learning and thinking. For instance, teachers' responses ranged from using examples from different disciplines ("It drives what I do everyday. I try to show how engineering and tech cannot be done without mathematics and sciences. For example, physics", "I try to use examples from each discipline if possible in chemistry class") to the integration of disciplines ("I always bring together math and physics because I can teach them inseparably", "I always link biology and chemistry because they are so tightly related to each other"), to tying instruction to various career fields ("I tie my instruction to each career field. Whenever I can tell students the real-life applications of science and math concepts, I do").

When asked to discuss the integration of science and mathematics broadly (not just in their classrooms) teachers again envisioned a method of teaching ("Applications from other disciplines cross over classes. Maybe classes work on common problems, though I am not sure how that would work", "Teach your main area, but try to have students engage in problems that require attention to the other components", "I imagine students having the right science, math and engineering to solve a really hard problem").

Thus, teachers' conceptualization of iSTEM centered on teaching practices rather than an epistemology. Put another way, teachers conceived of an organization for their teaching practices rather than considering how knowledge/practices of teaching and learning affect student activity/cognition. This conception allowed many of the teachers to conceive of "doing their part" to accomplish math or science or engineering instruction. They felt that if they held up their end of the bargain (e.g. did enough mathematics instruction or science instruction) then the other teachers would do their part. There was little attention to the development of students, but an enormous focus on practice. This notion of "doing their part" also emphasizes the teachers' continued focus on the content of each discipline rather than their practices, theories or methods. We think it is likely that the teachers' conceptions at the formal level (rather than at the syntactical or substantive levels) allowed them to see their teaching as a direct means to impart knowledge to their students. We hypothesize that had they also considered learning and thinking the syntactical or substantive levels, they may have gone beyond simple conceptions of STEM as a teaching practice.

Finding 3: Barriers to iSTEM

The majority of teachers (14 of 20) said that they did not bring consider the relationship between science, technology, mathematics and engineering into their classroom. Responses consistent with this approach ranged from a focus on one discipline ("I focus on biology, sometimes I guess I bring in math and other sciences", "Not at all, I focus on mathematics", "I focus on the M, math") to being uncomfortable bringing in other disciplines "I focus just mostly on technology and am not comfortable bringing in math", "I just feel like bringing in math confuses students who are learning science"). Our analyses suggested two predominant reasons for the teachers avoiding integration of these disciplines.

Barrier 1 - Little Understanding of How to Promote Integrated STEM

The first barrier was related to teachers' content knowledge. As one would expect, individual teachers do not have expertise in all content areas. Instead, the teachers had little knowledge of the broad approaches that disciplines like engineering, mathematics and areas of science use to solve problems. While this is to be expected, their responses clearly articulate the need for this type of professional development to occur. These responses ranged from a need to know about math and science ("I am an expert in math and in some sciences but I have a really hard time seeing how their broader practices can possibly be connected to each other") to a desire to integrate chemistry and mathematics ("I love both chemistry and math, but I am stuck when it comes to figuring out how to help students use each discipline to complement the other or to see the links between the two that are broader than just the content present") to a desire to have professional development ("I feel like we get all of these slick teaching techniques but still do not get things like how to connect various areas for our students or for our teaching").

While this disconnect is to be expected given the specific foci of teacher training programs and their content requirements, it is also plausible to expect teachers to be aware of some of the broad practices, such as problem solving techniques, used across science, mathematics and engineering. We think that the teachers' inability to support integrated of disciplines was a direct result of this missing focus in their preparation and continued professional development.

Barrier 2 – Lack of Resources, Support and Pressure

The second chief barrier was at an institutional level. All 20 teachers, some of whom were also administrators, said they felt no pressure from the state or local education agencies to implement instruction to support STEM. However, even if they had been asked to implement instruction of this type, many of the teachers emphasized that they did not believe it was possible due to reasons ranging from lack of resources (“There is a problem though, resources have not kept up with that need. We need more access to universities and resources”) to lack of time (“You can't do everything. You can foreground something and have other components in the background, like math and technology”) to lack of resources (“I simply do not have the technology or capabilities to create authentic learning experiences for my students that would help them gain an appreciation of the various areas”). Together with their inability to conceive of practices common to STEM disciplines, these two barriers constrained teachers from integrating, or even thinking about integration of these disciplines into their classrooms and teaching.

Conclusions

We return briefly to our three research questions to articulate the contribution of our study to those questions.

Conceptualizations of Acronyms and Disciplines of STEM

All of the educators were aware that the letters represented science, technology, engineering and mathematics. As our results demonstrate, teachers envisioned a collection of “siloed” subject areas with distinct boundaries, rather than a cohesive endeavor between disciplines. These siloes often corresponded to the discipline with which the teacher was most familiar. Moreover, the educators also appeared to attend to each subject area at the *formal* level, or mostly focused on the content needs of each discipline. There was no discussion about the practices or methods of science, technology, engineering and mathematics.

Enact or Envision iSTEM Curriculum and Instruction in the Classroom

Teachers’ conceptions of iSTEM centered on their teaching practices (what they would do, how they would do it, and what they would use to support their teaching) rather than as epistemology of learning and thinking. Put another way, teachers conceived of an organization for their teaching practices rather than considering how knowledge/practices of teaching and learning affect student activity/cognition. Thus, if teachers had created an environment for integrated disciplines (which most of them did not) that integration would have focused on their teaching, rather than attention to students’ development of ways of thinking.

Recognize and React to the iSTEM Movement and Associated Policy/Mandates

All of the teachers in the study, including some whom were also administrators, said they felt no pressure from the state or local education agencies to implement instruction to support STEM. Thus, while many were aware of the movement, they did not perceive of any policies or mandates that affected them at the individual level. Yet, even if they had known about policies or mandates associated with integrated disciplinary areas, their responses suggested that they would have been unprepared to modify instruction to meet those mandates.

Discussion

Our findings make clear that while teachers are interested in and think integrated STEM is a good idea, they face tough barriers in adjusting their practices and knowledge to meet these challenges. Chief in these needs is the development of teacher knowledge, which we consider at three levels. With respect to *formal* structure of knowledge, it is important for teachers to be aware of what separates disciplines from each other and what makes them similar. This does not require deep knowledge of each content area, but does require a working understanding of the ways in which disciplinary areas complement each other. We hypothesize than an understanding of the broader practices and methods of disciplinary areas is crucial to conceiving of them as a connected body of complementary disciplines. As such, we propose that an extension of this compartmentalized approach to STEM requires teachers to attend to the theories, data, and methods of each discipline. This attention relies upon *substantive* and *syntactical* structure, and promotes a conception of the disciplines as composed of both their content knowledge and their broader practices. We anticipate that it is at the level of these broader practices (e.g. modeling scientific phenomena) that teachers can make the connections between disciplines and support their students in developing an image of STEM as a way of knowing and learning. However, our findings also make clear that this support must explicitly focus on formal, syntactical and substantive knowledge structures. Without all three components, we anticipate that the current use of compartmentalized areas will continue to be prevalent.

Going Forward

What will it take to create meaningful change in STEM instruction? Our exploratory research with 20 teachers, admittedly a limited sample, revealed that while teachers found iSTEM important, they also viewed it more as a teaching method than a way of knowing and learning for students. Those teachers who claimed to integrate these subjects in their classrooms did so at what Herschbach (2011) called the formal level. Subsequently, we identified two barriers to the teachers' integration of these disciplines. Our results suggest that challenges facing teachers to implement iSTEM require appropriate professional development and administrative support that a focuses on the nature of the disciplines, including their content, practices, and theories, or their organizational structure as *formal*, *substantive*, and *syntactical*. Exploration of a more nuanced and holistic conceptualization of the structure of knowledge is a natural place to begin. However, in order for this shift to occur at the formal, substantive and syntactical levels, the teachers need both the support from professional development intended to engender this type of knowing and learning in conjunction productive pressure from leaders at the school, local, state and national levels.

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