Authentic STEM Learning and Teacher Mindsets

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Abstract

Many teachers in today's classrooms, regardless of subject area, have little experience in the kind of learning they are asking students to engage in (Elmore, 2016). Rigorous standards in science and mathematics have set a new bar for what can be considered "authentic" STEM learning by requiring that students develop specific disciplinary skills, such as collaboration, application, argumentation, critical thinking and inquiry-based problem solving (NGSS Lead States, 2013). As states and school districts in this country continue to charge teachers with the challenging task of supporting students to engage in "authentic" STEM learning, teachers must develop the knowledge base and instructional aptitude implicated by these rigorous goals for students' learning. Simultaneously, as teachers develop and refine their knowledge and practices of what is considered "authentic" learning in STEM, their views of student capability become integral to their instructional decisions. To have sustainable and successful policy reforms, school districts cannot afford to overlook teachers' background knowledge, mindsets, and beliefs, including their potential deficit views of students. Therefore, attending to teachers' mindsets and beliefs about what "authentic" STEM learning is and who is capable of it must be a priority for district leaders as they seek to implement effective and sustainable STEM-based reform initiatives across their schools. Several considerations are presented for districts seeking to help their teachers develop the instructional repertoire necessary to support students to engage in the disciplinary practices of authentic STEM learning.

Keywords: *authentic STEM learning, STEM-capable, STEM disciplinary practices, teacher mindsets*

Introduction

Since the release of a *Nation at Risk* (1983), the United States has sought to increase the rigor of math and science courses in order to compete with global rivals, close what some have termed an achievement gap within STEM disciplines (Carnegie Corporation of New York, 2009), and address the needs of an increasingly diverse student population. The recent release of the *Next Generation Science Standards* (NGSS) in April of 2013 extended these efforts by introducing rigorous national curricular standards for science classrooms. Supporting students to meet the challenging goals set by these standards requires that teachers ideally develop and learn new ways of teaching as well. Professional development for teachers is one medium by which districts can support improvement in teachers' knowledge and instructional practices in STEM. Yet, the history of large-scale improvement efforts in mathematics, science and other subject matter areas have rarely produced lasting or significant changes in teachers' instructional practices (Bair & Bair, 2014; Cobb & Jackson, 2011).

Many teachers in today's classrooms, regardless of subject area, have little experience in the kind of learning they are asking students to engage in (Elmore, 2016). Rigorous standards in science and mathematics have set a new bar for what can be considered "authentic" STEM learning by requiring that students develop specific disciplinary skills, such as collaboration, application, argumentation, critical thinking and inquiry-based problem solving (NGSS Lead States, 2013). Such disciplinary practices are vital for students to be *STEM-capable* (Carnegie Corporation of New York, 2009) and prepared for the rigor of STEM undergraduate courses, as well as promote their development of positive disciplinary identities. As states in this country and school districts continue to charge teachers with the challenging task of supporting students to engage in "authentic" STEM learning, teachers must develop the knowledge base and

instructional aptitude implicated by these rigorous goals for students' learning. Simultaneously, as teachers develop and refine their knowledge and practices of what is considered "authentic" learning in STEM, their views of student capability become integral to their instructional decisions. Sustainable and successful policy reforms often fail for one or both of the following reasons. Firstly, traditional professional development in districts often overlooks teachers' existing cognitive structures, such as background knowledge, beliefs, and attitudes (Spillane, Reiser, & Reimer, 2002). Secondly, school districts and designers of professional development often fail to acknowledge potential deficit views of students that teachers may bring with them into schools (Battey & Franke, 2015; Jackson, Gibbons, & Sharpe, 2017; Sengupta-Irving & Mercado, 2017). Therefore, attending to teachers' mindsets and beliefs about what "authentic" STEM learning is and who is capable of it must be a priority for district leaders as they seek to implement effective and sustainable STEM-based reform initiatives across their schools.

A Transformational STEM Education Reform Agenda

When school districts expect teachers to develop ambitious instructional practices, they are asking them to potentially deconstruct and then reconstruct their existing practices and beliefs. This is no modest task, as evidenced by numerous reform attempts in science and mathematics education over the past decade, and more recently under the umbrella of STEM, that have not produced the desired change in student performance (Johnson, 2012). Given a disappointing historical trail of reform efforts, this paper seeks to contribute to an existing body of scholarship that advocates for changes to STEM professional development. These changes should address teacher mindsets and beliefs about authentic STEM instruction and students' capabilities. This paper promotes a twofold agenda that gives equal attention to both developing

teachers' understanding of and skills needed for ambitious STEM instruction and to addressing unproductive or deficit-oriented views of students. According to Hammerness, acknowledging and surfacing teachers' personal visions or beliefs may help policy makers and reform implementers move beyond thinking about teachers as either 'advocates' or 'skeptics' and towards a deeper and more productive understanding of their response to reforms (as cited by Munter, 2014). Districts should realize that reforms often ask teachers to learn, think, and construct their identities as STEM educators in potentially different and novel ways. Through my analysis of what I consider to be "authentic" STEM learning and how teachers' mindsets and beliefs impact how they support students to engage in such learning experiences, I hope to provide districts and professional developers with more information to consider as they seek to implement ambitious STEM reforms.

Furthermore, this paper seeks to advance the conversation about the importance of teachers' views of their students when engaging in ambitious instructional reform, no matter the discipline. Asking STEM teachers to reorganize and potentially transform their instructional practices to align with notions of authentic learning in these disciplines requires that they both believe it to be valuable or more advantageous than their current practices, and that they believe their students are capable of meeting such rigorous goals for learning. Sommerfield Gresalfi and Cobb (2006) contend that "students' development of interest or sense of affiliation with a discipline is inextricably linked to the ways in which they engage with that discipline" (p. 50). Providing students with opportunities to engage in authentic disciplinary practices of STEM helps them develop both increasingly positive dispositions towards STEM and the knowledge base and skillset they need to succeed in more advanced STEM courses. However, if teachers do not view these authentic disciplinary practices as meaningful or their students as capable, the

development of positive student disciplinary identities may fail to be realized, potentially

exacerbating the underrepresentation of certain populations in STEM fields. Professional

developers should make space for conversation around deficit narratives of students in STEM

fields. Teachers should be provided with opportunities to "to shift their perspective on what it is

that their students are capable of as they work to implement forms of practice that reflect more

rigorous goals for their students' learning" (Jackson, Gibbons, & Sharpe, 2017, p. 3). At the

expense of students, professional learning can no longer ignore teachers' views that their

students' capabilities are relatively static. Instead, professional learning should integrate the

process of transforming or deepening teachers' understanding of authentic STEM disciplinary

practices with opportunities to shift and alter their views of student abilities if *all* students are to

be provided with an excellent STEM educational experience.

A Vision of "Authentic" STEM Learning

For the purposes of this paper, I am defining "authentic" STEM learning for K-12

students as the development of key STEM disciplinary practices that are recognized in literature

as helping students shift from *knowing* content to *constructing* and *using* their understandings as

tools to make sense of the world around them. In order for STEM learning to be authentic, I

posit that the learning process of students in STEM classrooms should parallel the processes by

which STEM professionals construct knowledge, make meaning of information, and

problematize claims. From this perspective, authentic STEM instruction involves teachers

supporting students to make sense of phenomena and meaningfully engage with their own

questions and ideas while working through challenging, non-routine tasks. This contrasts with

more didactic and procedural-oriented methods of instruction that usurp student authority in the

classroom space. The disciplinary practices that qualify "authentic" STEM learning enable

students to develop complex skills in reasoning, social interaction, and communication. These

skills then aid students in their pursuit to productively solve problems, make evidence-based

decisions, and critique others' claims.

I am aware that scholars in the field of STEM education argue that the disciplinary

practices and epistemologies of each of the STEM fields contain certain discrepancies and

nuances (e.g. Mathis, Siverling, Glancy, & Moore, 2017; Sengupta-Irving & Mercado, 2017).

Existing literature and research tends to separate the STEM disciplines and focus on an

individual field due to these acknowledged differences and the complexity of unifying them

under a collective banner. For example, Lewis notes that "while scientific inquiry and

engineering design are conceptually comparable approaches to problem solving, they…differ in

ways that have direct implications for teaching" (as cited by Sengupta-Irving & Mercado, 2017,

p. 109). However, in this paper, I will examine "authentic" learning across STEM fields

collectively. I consider all four of the STEM disciplines together (i.e. science, technology,

mathematics, and engineering) because recent national reforms and policies consider the fields as

a whole, and as such, it is useful to look at STEM in an integrated manner. For example, the

national education reform program, Race to the Top, required states to commit to policy aimed at

developing a comprehensive strategy for improving STEM education in order to be eligible for

award moneys. The states awarded a share of the funds, including Tennessee, Ohio, and North

Carolina, were required to establish policy that included "the creation of statewide STEM

education networks, regional STEM hubs, STEM high schools, K-8 student programs, and

STEM teacher professional development" (Johnson, 2012, p. 45). Additionally, designers used

science *and* engineering disciplinary practices as guidelines for the development of the *Next Generation Science Standards* (NGSS Lead States, 2013).

The benefit of looking at STEM collectively is that the disciplines exist in the service of each other. The disciplinary practices of one field are intrinsically entangled with certain disciplinary practices of at least one of the others. For example, studies by the National Research Council have identified similar foundational capacities between mathematics and science that all students should develop: productively struggling through real-world problems, theorizing possible solutions or models, and testing, critiquing, and refining answers (Carnegie Corporation of New York, 2009). Furthermore, the disciplinary practices of mathematics and science open the door for students to understanding new technologies and innovative engineering feats. I believe that it is insufficient for districts to promote authentic mathematics learning and build the capacity of their teachers to support students in this endeavor, without simultaneously doing the same for science, engineering or technology. The interdisciplinarity of these subjects becomes evident when they are taught with authenticity relative to how they are used in the world beyond classroom walls. Connecting the different STEM fields in one domain can provide students with meaningful opportunities to engage with interesting questions, address salient problems, and develop positive disciplinary identities. In order to address the commonalities in the authentic disciplinary practices of each of the STEM fields, I will first examine them on an individual basis in accordance with how the body of current scholarship exists. However, I will use my analysis of the fields separately to then highlight the commonalities in authentic disciplinary practices between each of the STEM fields.

Key Disciplinary Practices of Authentic STEM Learning

Authentic Science Learning

Typical and traditional science instruction teaches students that the discipline is made up of incontrovertible facts that describe the world rather than a process of building and revising models and theories about the world (Sandoval & Reiser, 2004). When the sole authority of content lies with the teacher, students are no longer afforded the opportunity to serve as producers of scientific knowledge themselves. Students are not engaged in authentic scientific practices when instruction treats scientific ideas as pedestrian explanations for everyday occurrences, promotes procedures rather than a way of thinking, and relies on curriculum to provide guiding questions. Such instructional practices stand in stark contrast to *authentic scientific inquiry* (Chinn & Malhotra, 2002) that mirrors the research that scientists actually carry out. Chin and Malhotra (2002) argue that "an important goal of science education is to foster the development of epistemologically authentic scientific reasoning" (p. 213). Learning becomes authentic to the disciplinary practices of scientists when "students learn to generate coherent explanations of natural phenomena using a variety of intellectual and social resources; they understand how claims are justified, how to represent their thinking to others, critique one another's' ideas in ways that are civil and productive, and revise their ideas in response to evidence and argument" (Windschitl, Thompson, Braaten, & Stroupe, 2012, p. 881). Students' engagement in authentic scientific practices pushes them beyond a rote performance of scientific actions or processes and instead shifts them purposefully toward pursuing the "overarching goal of developing evidence-based, explanatory models of how and why the natural world works in the ways that it does" (Berland, Schwarz, Krist, Kenyon, Lo, & Reiser, 2016, p. 1085). Authentic scientific learning means that students are given the opportunity to generate their own

research questions, select their own variables to investigate and even invent their own complex procedures to address student-generated questions of interest. In science classrooms, students should be given opportunities to perform multiple studies on the same topic, coordinate the results, investigate possible methodological errors, and study the research and work of other scientists. These practices promote a greater level of authenticity than traditional learning methods that promote a view of scientific reasoning as simple, certain, algorithmic, and focused at only a surface level of observation (Chin & Malhotra, 2002).

However, Sandoval and Reiser (2004) argue that having students simply engage in scientific inquiry is not enough to develop students' ideas about the nature of science and their understanding of authentic disciplinary practices. Science educators must also make argumentation and scientific epistemological development a central goal for students in their instruction as well. Argumentation is a "core epistemic practice" of science, according to Bricker and Bell (as cited by Kuhn, 2010), and therefore the goal of science education must collectively be the mastery of scientific concepts and the learning of how to engage in scientific discourse. Students should learn how to problematize knowledge and scrutinize explicit connections demonstrated between a claim and data underlying some natural phenomena. Authentic learning opportunities in science classrooms should enable students to explain nature through the articulation of coherent and causal accounts, use data to support their causal claims, rule out alternative explanations in favor of the best explanation, and document the limitations of their causal explanation. Such activity helps students develop their ability to engage in scientific practice, as well as their epistemological conceptions of that practice (Sandoval & Reiser, 2004). Students should be given the opportunity to interrogate how they know what they know and determine whether or not they have actually answered the central question(s) of their

investigation. Classroom activities should help students learn how to integrate evidence into their argument, both to support their own claim as well as challenge a peer's claim. Ford (2008) notes that "student-to-student critiques, when done well, should drive the construction of new knowledge claims and their explicit connections to nature" (p. 419).

Lastly, in contrast to the view that scientific inquiry is an individual endeavor, "a growing body of work in science studies asserts that disciplinary authority in science is social" (Ford, 2008, p. 406). Within the scientific community, peers play an important role in making decisions about what can be considered a new knowledge claim in the discipline. Even though individual scientists may construct a case for a new knowledge claim, the surrounding disciplinary community critiques it. In this fashion, scientists are not viewed as purely objective reasoners; they rely upon their peers to critique their construction of phenomena and collected data in terms of how well they elucidate nature's structure and form. Therefore, authentic science learning teaches students that scientific practice is a "dialectic of reasoning through both the construction and critique of knowledge claims" (Ford, 2008, p. 409) in collaborative and public manners. Teachers should support the formation and operation of a classroom community that decides what counts as a new knowledge claim, while also providing their students with opportunities to critique their peers' scientific arguments.

Authentic Mathematics Learning

Traditional forms of mathematics teaching often engage students in procedural tasks with limited opportunities for mathematical reasoning as they follow expectations of mastering known procedures and solving predictable problems (Jackson, Gibbons, & Sharpe, 2017). Mathematics classrooms that emphasize algorithmic practices and the reproduction of procedural methods

cause students to find the discipline to be highly structured, rule-bound, and stale. Sommerfield Gresalfi and Cobb (2006) argue that this type of mathematics learning is not productive for students in the short-term learning of content or in the long-term development of their interests in the discipline and a desire to take more mathematics classes in the future. Authentic learning in a mathematics classroom calls for instructional shifts away from demonstrating procedures towards facilitating whole class discussions. In this type of classroom setting, students are given the authority to explore content; problematize ideas, errors and possible contradictions; construct and justify viable mathematical arguments; critique the reasoning of others; and engage in discourse about varied strategies and methods. In working with leaders of four collaborating districts, Cobb and Jackson (2011) identified cores areas in student practice that capture ambitious instruction and authentic mathematics learning: conceptual understanding of key mathematical ideas, procedural fluency in a range of discipline areas, ability to communicate mathematical reasoning effectively by mastering increasingly sophisticated forms of mathematics argumentation, and ability to use and make connections between multiple mathematical representations, whether symbolic, graphic, numerical, or tabular. These practices position students with the intellectual authority to approach mathematics as something to think about rather than a prescription of steps to follow. Authentic mathematics learning is realized because such practices apprentice students into the kinds of epistemic language and disciplinary thinking that actual mathematicians engage with.

Authentic Technology and Engineering Learning

Research has historically focused on the disciplinary practices and teaching of science and mathematics, and as such, studying the teaching of pre-college engineering is a relatively

novel area within education literature (Sengupta-Irving & Mercado, 2017). Evidence of

engineering and/or technological design has typically been integrated into science standards

(Moore, Tank, Glancy & Kersten, 2015; NGSS Lead States, 2013), and the field of engineering

is often seen as a means of incorporating all STEM subjects (Mathis et al., 2017). For example,

the National Research Council's report, *Standards for K-12 Engineering Education?*, suggested

"embedding the necessary and relevant goals of engineering into the standards of other STEM

disciplines" (as cited by Moore et al., 2015, p. 299). In this manner, engineering provides

students with a real-world context for learning the disciplinary practices of mathematics, science,

and technology. The disciplinary practices of technology are also often integrated into standards

for the other three STEM disciplines and are used as a means by which students are able to reach

those standards' explicit goals and learning outcomes. Moore et al. (2015) states that "precollege

engineering education is vital for developing technological literacy" (p. 315); students become

technologically literate when they engage in the practices of engineering. Because core

disciplinary practices of engineering and technology are entangled together and with those

identified for mathematics and science, it is challenging to tease them apart in standards and in

practice.

　　Argumentation, for example, is identified across all STEM fields as a practice authentic

to professionals working in these domains. Engineers are required to make evidence-based

decisions just as scientists do. In their study, Mathis et al. (2017) analyzed STEM integration

curricular units and found that certain lessons involved the disciplinary practice of

argumentation: students were asked to make predictions, collect data, and form conclusions by

justifying their reasoning and using data to support their claims. These three aspects of the

argumentation process (making claims, supporting them with evidence/data, and justifying them

with content knowledge) can be seen in the design-build-test disciplinary practices of engineering. Students must be able to present a claim supporting a final design solution, provide evidence of their design's success through tested results, and justify their design's features using specific content knowledge and mathematical and computational thinking. Throughout this process, students are also engaged in practices of productive discourse and social engagement with their peers. As students engage in a design-build-test pedagogical model, they are given autonomy to critically think, wrestle with ideas that have unknown outcomes, and engage in the habits of mind common to engineering professionals.

Authentic Learning Across the STEM Disciplines

Across all four of the STEM disciplines, literature illustrates commonalities between the practices of what makes learning authentic for students. Students engage in authentic STEM learning through the common disciplinary practices of:

- Defining and making sense of a problem

- Building on current understandings and knowledge areas

- Connecting conceptual and interdisciplinary ideas

- Authoring their own learning

- Engaging in productive discourse and various forms of argumentation

- Problematizing and critiquing others' claims

- Entertaining alternative possibilities, models or methods

- Reflecting on and revising models, solutions or processes in response to evidence and argument

Such disciplinary practices provide students with the opportunity to experience their actions as purposefully moving towards a sensemaking goal (Berland et al., 2016); this is a shared objective across each STEM discipline even though the desired outcome may be different. Students are no longer going through academic motions of providing evidence or articulating mechanisms only to fulfill an impersonal "school goal" or "teacher goal." Instead, students are investing in the work of building knowledge "that foregrounds disciplinary sensemaking goals" (Berland et al., 2016, p. 1103).

As stated earlier, both science and engineering situate inquiry within the disciplinary practices of model building, testing, and revising. Additionally, argumentation has been identified in literature as a core epistemic practice across all STEM domains. What appears to make the disciplinary practices of each STEM field distinct in academic literature is not in the "what," but in the "why"; the purposes of the disciplinary practices mentioned above are different and specific to each domain. For example, Sengupta-Irving and Mercado (2017) claim that scientific practices guide "inquiry into natural phenomena," while engineering practices guide "the deliberate design of solutions to human problems" (p. 115). The differences between the practice of argumentation in the fields of engineering and science lie in its purpose. Mathis et al. (2017) claim that "scientists use arguments for evaluating and explaining natural phenomena," while engineers use this disciplinary practice "for finding the best solution to a problem with a given set of constraints" (p. 78). Scientific claims are about natural phenomena, engineering claims are about a proposed design solution, and mathematical claims may be about conveying ideas and knowledge that support the first two fields.

Examining Teachers' Mindsets and Beliefs

Teachers' Beliefs about Authentic STEM Learning

According to van Driel, Beijaard, and Verloop (2001), the identification of teacher's

beliefs is critical to any educational reform process. Building from this idea, I argue that

teachers' beliefs about authentic STEM learning are tightly interwoven to their understanding of

it; their beliefs act as filters through which any new knowledge is interpreted and integrated into

their existing instructional practices. If teachers do not view authentic STEM learning as

advantageous or achievable by their students, it is unreasonable to assume that their instructional

practices would transform to align with any changes being asked of them. Learning to teach

towards authentic disciplinary practices in STEM classrooms requires teachers to reorganize

conventional models of instruction. These instructional changes inherently involve the view that

students can learn through authentic STEM instruction and that it is better than what is currently

being done in a classroom. Otherwise, teachers would not see these new ways of teaching as

appropriate or valuable for their students.

Before teachers can support their students to develop specific STEM disciplinary skills,

they must first understand what those skills are and believe them to be beneficial for students.

Elmore (2016) argues that asking teachers to do things they might not yet know how to do is not

asking them to "implement" something, but rather asking them to "learn, think, and form their

identities as teachers in different ways" (p. 531). Districts cannot expect STEM teachers to

implement STEM-based reform initiatives with fidelity unless they purposefully develop teacher

understanding of what constitutes "authentic" STEM learning. Additionally, districts should

help teachers shift any unproductive beliefs about the instructional changes being asked of them.

Research has shown that teachers may nominally adopt a novel practice or reject it entirely if it is

seen as incommensurable to their underling theory of instruction or goals (Thompson, Windschitl, & Braaten, 2013). Therefore, it is important for district leaders to not overlook possible existing pedagogical narratives of their teachers that influence what they believe is important for students to learn in STEM disciplines and what kind of teacher they want to develop into.

Teachers' Beliefs about Their Students

In addition to considering how teachers' existing beliefs influence their construction of and esteem for authentic STEM learning, district leaders should also attend to teachers' beliefs about their students' capability of meeting the rigorous goals being asked of them. McLaughlin and Talbert contest that "policy coherence as intended by reformers and policymakers ultimately is achieved or denied in the subjective responses of teachers – in teachers' social constructions of students" (as cited by Jackson, Gibbons, & Sharpe, 2017, p. 4). From their study, McLaughlin and Talbert found that "whether or not the target of an instructional policy was actually reached depended, in large part, on whether teachers viewed their students as capable" (as cited by Jackson, Gibbons, & Sharpe, 2017, p. 4). If teachers view their students' capabilities as relatively static and maintain a deficit-oriented outlook of them, authentic STEM learning may not be realized for *all* students in STEM classrooms. Therefore, professional learning should tightly integrate teachers' understanding of authentic STEM learning and resultant instructional changes with opportunities to alter unproductive views of students' capabilities.

Districts seeking to implement ambitious STEM reforms that call for students to engage in authentic disciplinary practices should make space for conversation around deficit narratives of students in the design of their professional learning opportunities. Sengupta-Irving and

Mercado (2017) argue that stereotypes about engineering or who is best suited to be an engineer

"pose significant threats to achieving equity and grow in part from the way teachers

conceptualize the discipline and its teaching" (p. 109). When teachers hold deficit notions about

their students' capabilities, students are less likely to be given opportunities to participate or

succeed in rigorous authentic disciplinary practices across the STEM fields. Furthermore, when

deficit narratives go unchallenged, then existing ideologies that certain students cannot engage in

abstract STEM concepts, are too lazy or incapable of achieving at the rigorous levels being asked

of them, or are influenced by a culture that does not value education, also go unchallenged

(Battey & Franke, 2015). School districts should support teachers to actively examine and

deconstruct their own stereotypes and implicit biases if *all* students are to be provided with

opportunities to engage in and be successful with authentic STEM disciplinary practices.

Discussion

In this paper, I have discussed what authentic STEM learning is. I have highlighted the

disciplinary practices of each of the STEM fields separately according to existing research in

order to highlight commonalities between the practices of each field. I have presented an

argument for the importance of school districts and designers of professional development to

both engage their STEM teachers in understanding what authentic STEM learning is and to

attend to the existing and operating mindsets that teachers may bring with them into professional

learning spaces. I have also argued that, due to national reform efforts increasingly integrating

the STEM fields, school districts should consider how to structure professional learning for

teachers under a unified banner of STEM. These arguments raise a number of considerations

that provide direction for school districts and those who design future professional learning

opportunities for STEM teachers.

Implications for Future STEM Professional Development Models

Despite millions of dollars spent every year by schools, districts, and the federal

government on professional development for teachers, Borko (2004) argues that such in-service

teacher training is often "woefully inadequate…fragmented, intellectually superficial, and does

not take into account what is known about how teachers learn" (p. 3). Scholars like Gary Sykes

(1996) have even gone as far to claim that conventional professional development for teachers

and "one-shot workshops" have created one of the "most serious unsolved problem[s] for policy

and practice in American education" (p. 465). Traditional professional development models

often focus on improving educators' pedagogical skills or supporting them in implementing new

programs, strategies, and instructional techniques (Picower, 2015). Such approaches then tend to

blame teachers when reform efforts fail and cite teachers' inability to implement the particular

program or strategy with fidelity as the main reason for the lack of success. Teachers'

instructional practice, as opposed to their operating mindsets, drives professional learning goals.

Traditional professional development rarely considers teachers' existing pedagogical narratives

and beliefs. However, when these narratives and beliefs are considered, teachers have been

shown to reorganize their instruction accordingly. For example, Thompson, Windschitl and

Braaten (2013) found that changing a teachers' critical narrative or personal theory about what

can be considered productive teaching and student learning caused teachers' practice to also

change. Given these findings, I present three considerations for districts seeking to help their

teachers develop the instructional repertoire needed to support students with authentic STEM learning.

A Focus on Teachers' Beliefs

First, district leaders and professional development designers must be prepared to investigate teachers' existing knowledge and beliefs at the onset of a reform agenda. Sengupta-Irving and Mercado (2017) argue that it is critical for districts to consider in the early stages of reform what conceptions of the discipline govern a teacher's pedagogical work when they are designing new learning opportunities for students. As was mentioned before, if teachers do not view authentic STEM learning as valuable or achievable for students, it would be unreasonable to expect changes in their instruction. Professional development should provide teachers with the time and space to analyze and deconstruct any deficit views of students' capabilities while they work to develop ambitious instructional practices. Additionally, districts should intentionally challenge narratives that attribute student difficulty to inherent traits or deficits in their family or community; equity cannot be a byproduct of teachers' practice or an "add-on" concern that is not "integrated into the design and character of professional development" (Battey & Franke, 2015, p. 437). Given this, professional learning opportunities for STEM teachers should maintain two goals for teachers: developing the view that authentic STEM learning is a worthy and beneficial instructional pursuit and that students are capable of meeting rigorous goals for learning by engaging in the disciplinary practices called for by such instruction.

Districts and designers of professional development should provide intentional supports for teachers to uncover and work through their preexisting instructional mindsets about what is

considered authentic STEM learning. The goal for these supports and strategies is to foster

teacher understanding of what authentic STEM learning practically looks like in a classroom and

enable them to compare it against preexisting conceptions. District leaders can support teachers

to meet such goals by using informal observations and videotaping lessons in teachers'

classrooms in order to analyze changes in instructional practices and gauge teacher

understanding, interpretation, and internalization of what authentic STEM learning is.

Incorporating artifacts like instructional plans and assignments, videotapes of lessons, and

samples of student work (Borko, 2004) may also be a strategy for districts to use in professional

development for STEM teachers.

Districts could follow the model proposed by Battey and Franke (2015) to support

teachers in coming to view all of their students as capable of participating in rigorous STEM

disciplinary activity. In this study, teachers were asked to focus on what they could do

differently in their instruction "by noticing the intellectual contributions of students of color in

their mathematics classrooms" (Battey & Franke, 2015, p. 435). Having teachers collect

different kinds of evidence that counter broad deficit narratives about the failure and perceived

lack of ability of students of color in STEM is a design choice districts could use to help teachers

access and uncover existing narratives about their students. However, Jackson, Gibbons, &

Sharpe (2017) found that, even when teachers framed students' difficulties in meeting rigorous

goals as related to instructional opportunities, rather than inherent deficits, they still did not

respond in ways that might help students participate in the rigorous mathematical activity. This

suggests the need for districts to strategically create support systems aimed at helping teachers

both develop equitable instructional practices and problematize the action of lowering the rigor

of learning goals for certain groups of students. It is also important for district leaders to assess

how teachers' views of authentic STEM learning and their students' capabilities do or do not change over time so as to inform revisions to the ongoing professional learning opportunities for their STEM teachers.

Opportunities to be a Teacher-Learner

Second, if students are to learn and engage in STEM classrooms in ways that are authentic to the disciplinary practices of professionals in these domains, teachers must be provided with professional opportunities to learn and internalize what those practices are themselves and transform their instructional practices accordingly. It is insufficient for STEM teachers to hear about authentic STEM learning or see it modeled; they must be coached through its implementation and experience the instructional changes as learners themselves. Because authentic STEM learning calls for students to no longer be passive receivers of knowledge, it is unreasonable to expect teachers to do the same. STEM teachers can no longer be viewed as merely acting agents who execute the innovative ideas of others, i.e. researchers, curriculum designers, policy makers, etc. (van Driel, Beijaard, & Verloop, 2001). Helping teachers develop their understanding of what authentic STEM learning is and how students learn through this ambitious type of instruction will require that they engage in experiences that center them as learners in STEM activities. These activities could include having teachers solve complex mathematical problems with multiple approaches, conduct scientific experiments using a method they create, or walk through the design-build-test process of engineering to address a known human problem. Through these activities, teachers themselves would be given the opportunity to experience and engage in the authentic disciplinary practices of STEM mentioned earlier in this paper.

Sufficient Time and Ongoing Support

Lastly, district leaders should recognize that authentic change in teaching practice requires time and ongoing instructional support. District leaders ought to have a learning perspective and recognize that for teachers to support students in developing authentic disciplinary practices, compliance with policies should not be the focus; "significant learning on the part of teachers, coaches, and school leaders" (Cobb & Jackson, 2011, p. 25) must be recognized as the focus. As teachers reorganize their instruction and interrogate their views of student capability, they should be provided with sustained and strategic support to learn how to help students engage with the disciplinary practices of authentic STEM learning. In an iterative manner, as teachers grow in their understanding of authentic STEM learning and develop the instructional practices to support students with it in their classrooms, they will hopefully come to see all of their students as capable.

Because teachers are adult learners and are each on a unique developmental trajectory, school districts should not provide a singular approach in helping teachers understand how to support their students to reach these new disciplinary goals. Instead, districts should tailor and structure tools and curriculum according to different trajectories and levels of experience of the STEM teachers. Moreover, it is unreasonable for district leaders to assume that changes in teachers' instructional practices and student learning will happen quickly. Bair and Bair (2014) argue that effects of reform can be discerned only after several years of sustained support. Given this finding, school districts should consider how to structure and implement long-term professional development programs that help teachers restructure their knowledge, beliefs, and instructional practices to align with the goals of authentic STEM learning over time.

Implications for Future Research

Research has shown that teachers' development and enactment of ambitious practices relies on their pedagogical content knowledge (Borko, 2004; Windschitl et al., 2012), views and beliefs of what high quality instruction looks like in their discipline (Munter, 2014; Thompson et al., 2013; van Driel, Beijaard, & Verloop, 2001) and how they frame students' abilities to engage in challenging disciplinary activity (Battey & Franke, 2015; Jackson, Gibbons & Sharpe, 2017; Sengupta-Irving & Mercado, 2017; Sommerfield Gresalfi & Cobb, 2006). However, there also seems to be a consensus that more research is needed to understand how particular professional development models and supports can cooperatively shape teachers' vision of practice and views of student capability. More research is also needed on how to support teachers in developing more productive views of their students' capabilities in the STEM disciplines when having them engage in the rigorous disciplinary activity called for by authentic STEM learning. Such research can serve to inform and improve the design of professional learning opportunities for STEM teachers who serve in districts aiming to reform STEM education, especially those with diverse student populations and students typically underrepresented in STEM fields.

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