WHAT AND HOW MATHEMATICS SHOULD BE TAUGHT: VIEWS OF SECONDARY MATHEMATICS TEACHER CANDIDATES WITH STEM BACKGROUNDS

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This qualitative study examines what mathematics teacher candidates with STEM backgrounds think about their future work as mathematics teachers. The content preparation for a STEM career is not identical with that taken by traditional teacher candidates and may not develop the pedagogical content knowledge necessary for candidates to connect their experience with the grade 7-12 classroom. Candidates were found to emphasize applied mathematics in both what, and how, with little attention given to mathematical proof. Given their interest applications of mathematics, they, surprisingly, struggled to articulate how to meaningfully integrate science and mathematics.

U.S. K-12 students' continue to struggle in mathematics and science achievement. Recent PISA results show that US is outperformed in mathematics by 35 of 65 participating countries (Organization for Economic Cooperation and Development, 2013). One remedy to weak student performance is to increase teacher quality and a route for improving teacher quality in mathematics and science that is gaining popularity is to recruit teachers with expertise in science, technology, engineering and/or mathematics (STEM) content areas (e. g., Robert Noyce Teacher Scholarship Program, Woodrow Wilson Teaching Fellows program, Knowles Science Teaching Fellows program). The assumption underlying these programs is that individuals with strong STEM content backgrounds can be transformed into effective mathematics and science teachers in a shorter time frame than can traditionally prepared teacher candidates, and with minimal attention to content knowledge. The study reported here examines what mathematics teacher candidates with STEM backgrounds think about their future work as grade 7-12 mathematics teachers and their preparation for that work in a program with STEM discipline integration. We define STEM background as having an undergraduate degree in a STEM field or, in addition to a degree, having work experience as a STEM professional. This study is part of a larger research project whose goal is to determine how the content backgrounds and prior experiences of STEM graduates and STEM professionals influence their teaching.

OUR STEM TEACHER EDUCATION PROGRAM

Ohio University hosts a one-year master's program that prepares candidates with STEM backgrounds for certification in grades 4-9 or 7-12 mathematics or science teaching. The first cohort began the program in summer 2012, the second in summer 2013, and the final cohort in summer 2014. Each cohort completes the program one

2014. In Oesterle, S., Liljedahl, P., Nicol, C., & Allan, D. (Eds.) Proceedings of the Joint Meeting of PME 38 and PME-NA 36,Vol. 3, pp. 233-240. Vancouver, Canada: PME.

calendar year after beginning. Teacher candidates start the first summer semester with coursework focused on curriculum, learning, development, and making connections between STEM disciplines and grade 4-12 mathematics and science classrooms. A unique feature of the program in the first semester is that candidates seeking mathematics licensure or science licensure take courses together that focus on all STEM content areas. During fall semester, the candidates continue taking general education courses together, but also have content and content-specific teaching methods courses that are only for mathematics teacher candidates or science teacher candidates. They also work with a mentor teacher three days a week in a grade 4-9 or grade 7-12 mathematics or science classroom. In spring, they complete their professional internship (student teaching) under the supervision of the same mentor teachers. In their final summer semester, they complete and present their masters research thesis.

CHALLENGES FACING TEACHER PREPARATION FOR STEM EXPERTS

Programs such as ours are not a panacea for the nation's struggling students and schools. Programs that prepare teacher candidates with STEM backgrounds face challenges that are distinct from or more pervasive than those of a traditional teacher preparation program. Developing thorough content knowledge is often a key aim of mathematics teacher preparation programs. In programs for content experts this goal is often assumed to be met by candidates' prior experience and this assumption can be problematic for several reasons. First, content preparation of a mathematics or science major is not identical to that of K-12 mathematics teacher. The coursework taken to prepare for a STEM career is likely different than the STEM coursework taken by prospective teacher (e.g., a typical engineering or mathematics major does not take coursework in geometry). Second, even with an ideal content background, content knowledge alone does not determine teacher effectiveness (Monk, 1994). Pedagogical knowledge has been shown to have an impact on mathematics teaching effectiveness as well (Brown & Borko, 1992), but teacher candidates who were trained as STEM professionals have less exposure to pedagogical issues than their traditionally prepared counterparts. They are unlikely to have familiarity with or experience in K-12 schools (beyond their own tenure as a K-12 student) that would have been developed in the early years of traditional undergraduate teacher education program through coursework and field experiences. A third potential challenge a teacher candidate who was trained as a STEM professional may face is connecting her or his STEM background and previous coursework to the K-12 curriculum. Pedagogical content knowledge is more specialized than disciplinary content knowledge and includes more than knowing and doing mathematics well; it must also involve representing content in multiple ways, making challenging content accessible to students, and guiding students to a broad conceptual understanding of mathematics (Shulman, 1986). Teacher candidates with STEM backgrounds will have views of mathematics and science that are based on their prior STEM studies and experiences and that may not be conducive to the development of pedagogical content knowledge.

BACKGROUND

There is a small but growing body of literature related to STEM major and STEM career changer teacher preparation programs, but there is nearly no literature addressing how the content backgrounds and prior experiences of STEM graduates and STEM career changers influence their teaching. One exception is Vierra's (2011) work addressing the question of how a non-teaching STEM background influences the development of the content knowledge for teaching. In her study of 69 teacher candidates from multiple universities, she compared the entry-level pedagogical content knowledge of first year mathematics teachers with STEM career backgrounds to first year teachers with traditional backgrounds. Vierra found that there was no consistency in the pedagogical content knowledge in either STEM career changes or traditionally prepared teachers and no significant difference between these two groups. She concluded pedagogical content knowledge was not predictable based on a candidate's background.

More generally, the connection between knowledge of mathematics content and teaching effectiveness at the secondary level is poorly understood. Though content knowledge is an essential component of what makes an effective teacher (National Mathematics Advisory Panel, 2008), there is less evidence for a strong connection between teacher effectiveness and content knowledge in the absence of pedagogical knowledges (Goos, 2013). There is, however, a connection between mathematics teacher effectiveness and a teacher's pedagogical or specialized content knowledge (Ball, Thames, & Phelps, 2008), which is related to content knowledge. This literature suggests that a candidate's STEM background, in and of itself, will not guarantee their becoming an effective teacher; the formation of their pedagogical content knowledge (i.e., how they will use their knowledge in the classroom) will be critical to their success. As the teacher candidates are to build on their STEM backgrounds whilst becoming teachers, how their STEM background might influence their development of pedagogical content knowledge, and hence their development as effective teachers, is a nontrivial gap in the literature—especially in light of society's substantial investment in preparing STEM professionals to become teachers.

This study examined the views of mathematics teacher candidates with STEM backgrounds in regards to teaching and their teacher preparation in a program with integration among STEM disciplines. An implicit assumption of policies promoting the recruitment of STEM professionals into teaching is that the benefits of a STEM background are wholly positive. However, there exists the possibility that a STEM background may lead to misconceptions about teaching, learning, or the articulation of mathematics curricula. It is important to be aware of such issues so that teacher preparation programs can respond by tailoring experiences for this population. By examining this particular subset of teacher candidates' views on teaching at the outset of their preparation program, our study is a first step towards reaching this goal.

METHODS

In the larger study, the candidates are interviewed three times: immediately after the first summer term, at the conclusion of their professional internship, and at the end of their first year of teaching. The data reported in this paper is focused on the first interview, in which candidates were asked about the impact of their preparation for a career as a STEM professional and/or work experience in STEM fields on their preparation for careers as teachers. Admission to the program was selective: candidates were accepted based on strong content backgrounds and demonstrated potential for teaching. In the first cohort of 12, five sought initial licensure in grades 7-12 mathematics. All of those candidates had earned their bachelor's degree no more than five years before entering the program and two had prior work experience in a STEM field. Degree areas included chemistry, accounting, and mathematics (pure and applied) and biology. All five mathematics candidates participated in this study.

Interviews ranged in length from approximately 40 to 70 minutes. The interviewer used the questions listed in Figure 1 to guide these interviews and, as needed, used follow-up probes to help the canidate elaborate on or clarify an idea. The five interview transcripts comprised the data set for this study.

How did you become interested in (math, biology, chemistry and/or physics)?

Could you describe your school experiences (K-college) related to the study of (math, biology, chemistry and/or physics)?

Could you describe your work experiences related to the study of (math, biology, chemistry and/or physics)?

How do you think your school experiences (K-college) related to the study of (math, biology, chemistry and/or physics) will affect the content you will teach?

How do you think your school experiences related to the study of (math, biology, chemistry and/or physics) will affect the teaching methods you will use?

How do you think your work experiences related to the study of (math, biology, chemistry and/or physics) will affect the content you will teach?

How do you think your work experiences related to the study of (math, biology, chemistry and/or physics) will affect the teaching methods you will use?

How do you think experiences outside of school or work will affect the teaching methods you will use?

Figure 1: Interview questions

To analyze data, researchers read and coded transcripts using an open coding process (Denzin & Linclon, 2000) where researchers individually developed descriptive codes while reading the transcripts. At least three researchers read and coded each transcript with some team members reading all of the transcripts. The team noted which codes were common among all researchers and these became the basis for a composite coding scheme. For codes that were not common to all team members, discussion led to consensus to either to omit the code because it was too idiosyncratic, add it because it provided greater clarity, or merge it with another code because it was duplicative. In a few cases, discussion of codes led researchers to subdivide one code into several, each providing greater specificity. For example, the team divided the code *teacher influence*, a code common to all members, into three more specific codes: *influence from family member who was a teacher, influence from K-12 teacher*, and *influence from post-secondary teacher*.

With the coding scheme established, one coded transcript was compiled for each of the five candidates and researchers identified emergent themes. Then, each researcher returned to the transcripts to look for evidence of the salience of the emergent themes that had been suggested, identify alternative themes, and develop ideas about how to map back from the set of emergent themes to evidence in the data set. For each emergent theme, a summary was composed that included a description and the data supporting that theme.

This data analysis method contributed to the credibility of the findings not only through its careful attention to the data and its systematic approach to analysis but also through its reliance on investigator triangulation (Denzin, 1978). Because there were multiple readers of the transcripts, it was less likely for the preconceptions of one researcher to influence the ultimate interpretation. In the few cases where members of the team had different initial readings of the data or different perspectives about the salience of a potential theme, review of portions of the transcripts helped the group as a whole reach consensus. The eventual list of themes therefore represented the best judgment of the research team as a whole.

RESULTS

In framing our findings, we rely on two roughly synonymous constructs from mathematics and science education, respectively: teacher beliefs (Phillip, 2007) and teacher orientation (Friedrichsen, Driel, & Abell, 2011). The orientation scheme considers three categories of teacher conceptions: about the nature of the science, about the nature of science teaching and learning, and about the goals of science education. Beliefs in mathematics education are not as neatly divided, but several primary areas of research on beliefs parallel the structure of science education's orientation scheme: beliefs about mathematics (conceptions of discipline), beliefs about students' mathematical thinking, beliefs about curriculum, and beliefs about technology (conceptions of teaching). Following Pajaraes (1992), who warns that merely examining beliefs as a whole is unhelpful, we focus on particular "belief[s]-about". The themes presented here are organized by orientations/beliefs about: 1) *what* content should be taught, (candidates' understanding of mathematics) and 2) *how* the content should be taught, (what is good mathematics teaching).

What content should be taught

The mathematics candidates had a narrow view of mathematics. They all described mathematics as a tool for problem solving, and mentioned that problem solving was what they found most engaging about studying mathematics. In discussing the mathematics they would emphasize in their own teaching, they focused on applied mathematics or topics generally useful for other STEM disciplines. They often valued mathematics for its usefulness as a tool for other disciplines. They also discussed the difference between applied and pure or theoretical math, with all but Alex (whose STEM training was in pure mathematics) noting a preference for the former. One candidate summarized this view saying, "I like having a practical problem that I can actually solve, and having real world applications" (Reagan, p. 4). Another candidate noted that she valued using "more real world applicable" ideas in K-12 mathematics classes (Jennie, p.10). Four out of five of the mathematics candidates expressed some degree of dissatisfaction with mathematical proof; in particular they did not appreciate why proof was needed. Reagan tried to articulate the group's reaction to proving:

> The proofs in geometry seem illogical to me. Or unnecessary….I felt like a lot of the geometry proofs that I did [in her summer courses] were like, 'Well, this is pretty clear. I don't know why I'm doing a proof. It just makes sense.' (p. 22)

At the same time, the candidates noted that in their own study of mathematics they "couldn't much memorize things. I had to actually know how it works" (Gerald, p. 5) and that they enjoyed explaining math to others.

Though mathematics candidates valued applied over theoretical mathematics and viewed mathematics as a tool needed for science, they were challenged by the idea of integrating the STEM disciplines. On the surface candidates claimed that using applications of mathematics "gives a purpose for what you're learning [in mathematics class]" (Jennie, p. 13) and they acknowledged that the STEM disciplines "all just hook together in a way" (Sienna, p. 8). They were even able to mention one example of a way relate two STEM fields, though with varying specificity. Reagan, Alex, and Gerald explicitly noted using mathematics to model scientific phenomena (e.g., modeling population growth, carbon dating, and the molecular make-up of chemical compounds). All candidates spoke more generally of physics or physical science as natural or obvious way to connect science and mathematics. But when pressed to elaborate on these ideas, the candidates struggled: "I haven't really figured out all of the ways it [the STEM disciplines] hooks together" (Sienna, p. 8). Though they found it interesting to learn about STEM topics outside of their discipline, most did not see integrating the topics as a way to drive teaching practice. A mathematics candidate explained her view on integrating STEM disciplines:

> In some ways, some of the things we talked [in class] about don't directly correlate to mathematics, and so it's hard to see how I would correlate them into my mathematics classroom…. to use mathematics to discover things in scientific fields and things. I think that it's great when the two of them can be combined as often as possible, but I think that there's a point where they also need to be separated out. (Jennie, p. 11)

How content should be taught

Mathematics candidates cited *relevance* as a motivator for learning content and considered that a key facet of instructional practice. They mentioned *relevance* in three contexts, which framed their thinking about becoming teachers: relevance as an aspect of their own K-12 and undergraduate experience; relevance of their STEM-integrated program coursework; and relevance as a desired feature of their own future pedagogy. Relevance also had two different meanings: relevance as what engages or interests students and relevance as what students need to know about a topic.

All candidates mentioned former teachers who "made everything fun and relatable" (Sienna, p.3), with three candidates specifically mentioning courses that were hands-on and/or project-based. Jennie elaborated, saying one of her favorite teachers:

> would pull in things in that he knew would interest us, that also had Chemistry within them, and I think that that's really important to, high school kids, because that's how you keep their attention…that's how you keep them interested in your subject area. (p. 14)

They believed these features spurred their own interest in mathematics and science and they wanted to replicate those experiences for their students. Alex extended the notion of relevance further, stating:

> I think if you can help the kids understand, what kinds of jobs are out there…how these different jobs use math, use science, bring it together, I think it'll help them really become interested in some of these things. (p. 7)

The candidates were less certain as to how relevance played out in their program courses. Some candidates appreciated STEM integration as with Alex who explained why he enjoyed a particular lesson: "It played to the science, it played to the math, and we could all see how we [the different content areas] were all together" (p. 6). Whereas other mathematics candidates found the integration unbalanced, and this, at times, led to isolation and doubt about the relevance of integration. Reagan stated, "I don't know that that [a unit on the philosophy of science] was particularly helpful for a lot of us (p. 16). Candidates wanted instruction that was relevant for them and for their prospective students. All five stated that they would teach particular mathematics topics or concepts because, "They're going to do this in their real life" (Sienna, p. 8).

CONCLUSIONS

There were several surprising inconsistencies in the candidates' views on what, and how, mathematics should be taught. Overwhelmingly, mathematics candidates wanted to recreate for their future students the experiences that had most engaged them as students: using mathematics as a tool for problem solving. While they valued understanding the *why* behind mathematical ideas, they did not see proof as a means of explaining mathematics. While candidates valued using applications of mathematics as a way to make mathematics interesting and relevant to students, they could not meaningfully address how to use the sciences to provide applications for mathematics content. This is especially noteworthy because these candidates were ideally positioned to be aware of integrating STEM disciplines (having a strong STEM content background, being in immersed in a setting of diverse STEM expertise, and taking coursework designed to motivate their attention to integrating STEM).

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