Identifying Pre-Service Elementary Teachers Productive Knowledge Resources around Representations and Arguments in Math and Science

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Objectives

In recent years there have been increased calls for teachers of all levels to integrate and connect across STEM disciplines (e.g., Achieve, 2013; Czerniak, et al., 1999; Furner & Kumar, 2007). Intellectual boundaries between STEM topics are artificial and the sub-fields (e.g., mathematics, science, technology) blend together. This is recognized in both standards documents, which recognize the role of mathematical and computational thinking in science (Achieve, 2013), and in the professional disciplines (e.g., computational biology, mathematical physics). Furthermore, elementary school teachers tend to be generalists and are often interested in building intellectual connections out of practical necessities.

In this paper, we examine the ways in which pre-service teachers are making sense of connections between disciplines. In particular, we seek to understand teachers' existing productive resources that can strengthen their STEM instruction within and across sub-fields. Although there are many potential connections in STEM teaching, one meaningful point of contact is through a focus on the disciplinary processes or practices (Frykholm & Glasson, 2005) that are foreground in the standards (Achieve, 2013; Common Core, 2010). Although there are differences in the particular practices emphasized in each standard document, we focus on two key disciplinary connections that cross-cut STEM fields (1) generating, critiquing, comparing, and using *representations*, and (2) constructing and critiquing disciplinary *arguments*.

Despite knowing that these leverage points for integration exist, there are known challenges to overcome. Research has shown that elementary teachers often feel underprepared and anxious about teaching STEM subjects and possess fragile or underdeveloped knowledge of the content (e.g. Davis, Petish, & Smithey, 2006; Marx, et al., 1997). This is exacerbated by the limited number of STEM content and methods courses that pre-service teachers (PSTs) take as they prepare to become teachers of *multiple* subjects.

However, one might also presuppose that PSTs have existing resources about representations and arguments. For instance, individuals can have strong meta-representational knowledge, such as competence around criteria for quality and purpose of representations for various tasks (diSessa, 2004). Similarly, some work has documented student's nascent abilities in argumentation (Berland & Reiser, 2009; Engle & Conant, 2002). But there is little knowledge about PSTs knowledge resources around representations *and* arguments, especially within teaching settings where they encounter known challenges. We believe the ability to leverage existing knowledge resources has the potential to provide a large payoff in instruction. With that in mind, our goal is to examine PSTs existing pedagogical knowledge resources around representations and arguments.

Theoretical framework

Using the overlapping theoretical frameworks of Knowledge in Pieces ("KiP," diSessa, 1993) and Resource Theory (Hammer, 2000), learners knowledge systems can be conceptualized as complex systems consisting of a variety of knowledge pieces that are organized and operate at different levels across a variety of contexts (diSessa, 2002.) Early work documented intuitions, that students might activate when learning about topics in Newtonian mechanics (diSessa, 1993; Hammer & Elby, 2003). Other research has focused on not only content resources, but epistemological resources that teachers

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use for conceptualizing students approaches to learning (Elby & Hammer, 2010). Here we continue that trend by using this approach to examine PSTs resources. Based on existing research about PSTs mathematical knowledge for teaching (Ball et al., 2008; Hill & Ball, 2004) and science knowledge for teaching (Mikeska et al., 2017), we examine PSTs pedagogical knowledge resources around representations and arguments in math and science and frame our findings in terms of KiP and resource theory. Specifically, we assume that PSTs likely have many productive resources for teaching math and science that can be marshalled in a variety of situations. We purposely focus on identifying resources related to the two key disciplinary connections of representations and argumentation, which could conceivably support our larger goal of finding ways to leverage these resources in their teacher preparation.

Methods

We administered five performance assessments (PAs) to PSTs that align with a variety of math and science topics that are aligned with the relevant standards (Achieve, 2013; Common Core, 2010): 1. Comparing different strategies to solve subtraction problems; 2. Classifying examples of polygons based on a definition; 3. Analyzing graphical data of predator prey populations; 4. Predicting and then collecting data about what objects will float and sink in a tub of water; and 5. Analyzing data and generating an argument for the relationship between the length of a shadow and the position of the sun. Our performance assessments are open-ended tasks administered to PSTs in small groups that ask them to utilize their specialized content knowledge (SCK), knowledge of content and students (KCS), and knowledge of content and teaching (KCT) (Ball, Thames, & Phelps, 2008) to address a realistic classroom challenge related to a hypothetical teaching scenario involving representations and argumentation (Selling et al., 2015) (Appendix A). The performance assessments were administered in one undergraduate math content course for pre-service elementary teachers during their regular class session. We chose this course primarily because it is taken early in their undergraduate careers and therefore provides a window into PSTs knowledge resources early in their preparation. When administering the assessments, PSTs worked in small groups (2-4 individuals) of their choosing, and we collected data of eight small groups from a total of 26 individuals.

We aimed to capture the intersection of PST's SCK, KCS, and KCT through the qualitative lens of small group discussions—highlighting PST's sense-making in action. The PAs were intentionally in an open-ended format to elicit rich responses with the potential to uncover understanding and knowledge resources that would be unapparent in a multiple-choice format. Data collection consisted of audio recordings of their discussions as they worked through each PA.

For each of the five PAs we developed a unique coding scheme that varies by content topic, relative emphasis on argumentation and representation, and each includes elements of SCK, KCS, and KCT (Appendix B). The coding scheme is derived from Selling, Garcia, Ball (2016) and is formatted as an action on an object or situation. (For example, in the code *evaluating scientifically valid explanations for phenomena, events, process, or relationships*, "evaluating" is the action being performed on the object "explanations".) When coding the data, the audio was broken into small clips (1-4 minutes) based on natural breaks in discussions of PAs or changes of topic. These audio clips were then coded by two researchers. General agreement was 77% and all points of disagreement were either resolved through discussion or the code was dropped given a goal of only including data with high certainty.

Data Analysis and Results

From graphs of the frequency distribution of codes across group discussions over time for each PA (Appendix C), it is apparent that for many of the groups discussions, multiple codes were present, which suggests that in those instances, conversation may have been more on-topic with possibly more coverage of the relevant knowledge resource.

We also found that some groups of codes related to representations and argumentation co-occurred (in approximately 31% of the audio clips across all five PAs) suggesting that the PSTs use the knowledge resources of arguments and representations simultaneously. In the science PAs these instances often were focused on supporting the hypothetical student's understanding of the relationship between a representation and an argument. For example, in the predator prey PA, this often involved discussing elements of a graphical representation (patterns or data interaction) to argue for ecosystem sustainability, make predictions, or suggest possible underlying causes for population growth or decline. Interestingly, in the math performance assessments, the PSTs combine arguments and representations in a different manner. Namely, often the PSTs first analyzed arguments, either one generated by the hypothetical student or the mathematically correct argument, and then planned how to use a representation in instruction to support the hypothetical student's sensemaking.

Qualitative examples of PSTs knowledge resources at the intersection of argumentation and representations to further student sensemaking and instruction: In the science predatory-prey performance assessment we found that PSTs used knowledge resources to analyze a representation, specifically, the data within it, in ways that allow generating correct arguments that further student learning. In this scenario, PSTs analyzed a graphical representation of data of changing populations of wolves and elk over time (Figure 1) as a means for analyzing students' arguments, including possible misunderstandings, and then used that information for creating subsequent conversation prompts. In one group's discussion they first acknowledged that their students would likely recognize an apparent pattern in the data, but the PSTs also recognized the differences in y-axis scales as the elk were measured in ten-thousands and the wolves were measured in tens, would be a likely source of confusion, which they themselves also experienced when analyzing the graph. The PSTs recognized that the arguments that a student might generate from the graphical patterns may be incorrect if the students were not able to interpret the different scales. Based on that, the PSTs then suggested that the students could calculate the population of each species as a means to guide the students understanding of the representation. In turn, this might then support the students in generating a more accurate argument that could be used in a discussion to understand the relationship between the populations ("This would be a great point to open the conversation back up. And say, like, 'OK, so now that we understand this, what does this mean?' So, we know the wolves aren't going to starve. They're not killing off elk."). Summarizing, in this instance the PSTs used their knowledge resources about both arguments and representations to further instruction and student learning.

Next we present a math scenario example in which the PSTs utilize knowledge about representations and arguments to further learning and teaching objectives. In the polygon PA, students are presented with a definition of a polygon and asked to sort prepared cards into groups of polygons and non-polygons. During one discussion, a group analyzed students' arguments and determined that two students had similar arguments for a particular shape ("PST1: I like Brandt's question. He's like, "So, it looks like it could be...if you separate it." and "PST2: And Paul too. They're almost the same question."). Then to help synthesize the arguments and move the instruction forward, the PSTs suggested having the students compare their arguments with the definition of a polygon ("So we could go through the definitions. A polygon is flat. Check. Made of straight line segments. Check. And is enclosed. Check. So it is."). But then, when finding a way to address the issue of what constitutes straight lines and how using the meeting point of straight lines (an angle) could determine "straightness," a PST suggested a discussion prompt and hypothetical student responses about Figure 2 ("Then we could be like, so if it has straight line segments, what does that mean about where the segments come together? They might say, 'Those are angles.' If they know about angles. And then they could look at the examples and ask, 'are there angles?' No! Cause they're curved."). In this way, the PSTs saw strengths in student's arguments, drew on their own content knowledge, and used the definition to further the learning opportunities, all of which suggests that the PSTs were able to access relevant productive knowledge resources about representations and arguments.

Summarized Results: From the analysis we find that PSTs have a variety of productive knowledge resources related to argumentation and representations across math and science (Table 1.)

Significance

Given the significant challenges facing the preparation of PSTs, the realities of their future teaching, and a shift towards emphasizing connections between STEM disciplines, along with scientific and mathematical practices, there are questions about what existing knowledge resources PSTs may be able to leverage as they move forward in their careers. We argue that PSTs likely have many productive resources centered on two key disciplinary connections of representations and argumentation for teaching math and science that can be marshalled in their teaching. Recognizing the existence of these resources is key for being able to find ways in which teacher preparation programs can help PSTs access and capitalize upon them to improve their teaching.

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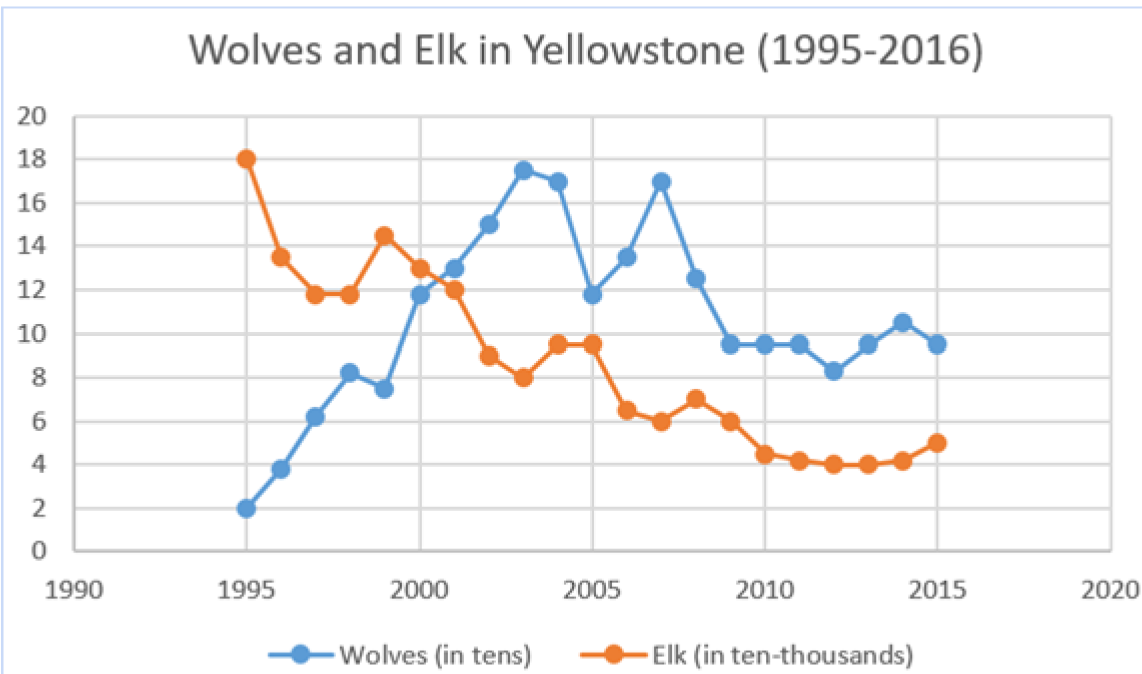

Figure 1. Graph that illustrates the numbers of wolves and elk from 1995 to 2016 inside Yellowstone National Park as was used in the predator prey performance assessment.

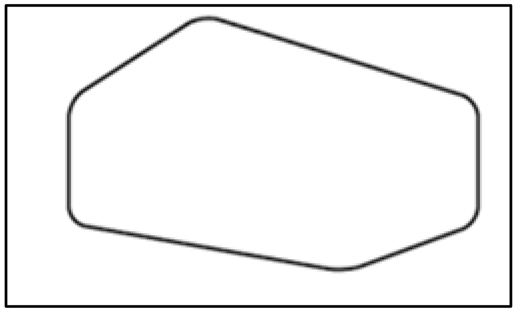

Figure 2. One of four example figures that hypothetical students were asked to sort in the polygon performance assessment.

Knowledge Resources about Argumentation	PSTs have knowledge resources about analyzing the strengths and weaknesses of a student’s arguments, a given definitions, and students reasoning and how to use that to create prompts and activities in order to further learning and teaching objectives.
	PSTs can use knowledge resources to create arguments that are mathematically and scientifically correct.
Knowledge Resources about Representations	Given different representations, PSTs have knowledge resources to analyze the representations’ sub-components, possible pitfalls and productive uses in instruction.
	PSTs have knowledge resources to analyze and generate representations to guide, empower and correct student mathematical and scientific thinking in order to further learning and teaching objectives.

Table 1. Summarized results of the PSTs knowledge resources.