Research Statement

Eli M. Silk

Executive Summary

My research is focused broadly on understanding processes of learning and development across the boundaries of Science, Technology, Engineering, and Mathematics (STEM). The central aspect of my work is trying to understand the bidirectional impacts that occur when students attempt to coordinate ideas and practices from the more basic disciplines of Science and Mathematics with related ideas and practices from the more applied disciplines of Technology and Engineering. My interests include how students come to understand the ideas and practices of one discipline in the context of another, how they come to value one discipline as being important for participating more effectively in another discipline, and how they choose make use of aspects of one discipline when problem solving in another discipline. I often take a resources perspective, which helps me to see learning as a process not only of introducing or creating new ideas, but also of activating existing ideas in situations where they may be productive and aligning them to those new situations. In addition, this perspective helps me to see the range of resources available to learners, including their own conceptual and epistemic ideas, as well as the resources present in their learning environment (e.g., time, materials, tasks, peers, teachers).

This research is valuable as it applies directly to current national efforts to increase the pool of students with the 21st century skills required to pursue careers in STEM fields (Silk & Schunn, 2008a, 2011b). Furthermore, my work has implications for theoretical understanding of learning and development as it bridges traditional boundaries of research conducted within particular STEM education disciplines (Silk, Schunn, & Strand Cary, 2009) with research in cognitive psychology (Silk & Schunn, 2011a) and in the learning sciences (Silk & Schunn, 2011c).

In my research, I employ observational (Silk, Higashi, & Schunn, 2011), design-based (Silk & Schunn, 2011c), and quasi-experimental (Silk et al., 2009) methodologies in classrooms and other organized out-of-school learning settings and then make use of qualitative and quantitative analyses. My goal is to observe intentional learning as it is happening, to be able to explain in detail the range of students' ideas and practices, to identify the features of contexts that are influencing their development, and to test out implications of those observations and explanations as instantiated in instructional designs.

Science Reasoning in Engineering Design

In many cases, science instruction in schools consists of scripted laboratory tasks that provide solutions to the cognitively challenging aspects for students and leave the underlying reasoning behind those solutions implicit. This sort of instruction is even more common in urban settings characterized by a "pedagogy of poverty" that explicitly limits opportunities for students to do the challenging work themselves (Waxman, Hwang, & Padron, 1995). At the same time, providing students more autonomy and richer contexts for engaging in science without appropriate levels of support is likely to lead to unsystematic activities (Silk & Schunn, 2006), frustration at the complexity of the task, and a focus on completing the activities rather than persisting in the hard work required of cognitive engagement. This led me to the hypothesis that the challenge of coordinating science with engineering may be primarily about both opening up opportunities for engaging in the cognitively challenging aspects of problems while constraining the focus of students' activities within those tasks on the most conceptually productive aspects.

One strand of my work has tested this hypothesis using scaffolded engineering tasks as contexts for students to learn science concepts and skills. In one study, we showed how these engineering contexts—in this case, building electrical alarm systems—can help urban middle school students develop their ability to reason using controlled experiments (Silk et al., 2009). Central in the student activity within this designed learning environment were engineering processes that align well with science reasoning, such as: (a) utilizing a process of subsystem decomposition to make salient particular conceptual issues one at a time; and (b) framing the task as needs-based so that each student can self-assess whether their solution is sufficient or further understanding is required.

In related work in this same engineering instructional context, I have investigated ways to improve science concept understanding as well. Consistent with my prior hypothesis about both opening up and constraining aspects of tasks, we investigated the effect of using contrasting cases (Schwartz & Martin, 2004) within the larger electrical alarm system task as a way to focus attention on key features that students need to account for in building more sophisticated conceptual models of the system (Silk & Schunn, 2008c). Here we showed that contrasting cases serve as an example for students in how to design and interpret controlled experimental contrasts within the context of their engineering designs. Students given the contrasting cases showed improvements in science reasoning, and those improvements in science reasoning were in turn associated with greater conceptual understanding.

Math Reasoning in Technology Problem Solving

For my dissertation research (Silk, 2011), I shifted disciplines from coordinating science with engineering, to a context in which I investigated the coordination of math reasoning with technology problem solving. In this context, middle school students learned about how to understand and control robot movements. This context led to a number of fruitful explorations. Each has been consistent with the hypothesis that successful coordination requires both expanding opportunities to engage in the cognitively challenging aspects of integrating math and robots, while helping students organize their thinking in ways that constrain the space of possible things they consider to those that are most productive for understanding and designing.

Increasingly, students' first introduction to technological problem solving is in the context of robot competitions in the upper elementary and middle school grades. In one line of research, I observed what opportunities and barriers exist to using math in these competitions settings and whether those who do choose to use math benefit from doing so (Silk et al., 2011). This observational research is valuable for establishing the base rates of math-based and non-math-based strategies, for determining which strategies are predictive of success, and for developing rich narratives of the types of problems students are challenged to solve and the solutions they come up with in response. In our case, we found that the design of the competition often favors non-math-based solution strategies that are fine-tuned to the particular challenge. As a result, only 25% of the teams chose a math-based solution strategy. Even more interestingly, we found that the success of the math-using teams was highly variable, suggesting that how a team implemented the math was important. Based on case analyses of successful and unsuccessful math-using teams, we hypothesized that when math is used fluently it can serve as a way for teams to efficiently and accurately program their robots, but otherwise can be difficult to apply and may then take away resources devoted to fine-tuning the solution.

In parallel, I was able to observe a contrasting context for learning about robots—a formal classroom setting where the math was more structured (Silk & Schunn, 2008b). In this case, we observed that math which is insufficiently motivated and that connects too many disparate ideas can be difficult to manage for students. This further supports the hypothesis that opening up the instructional tasks without simultaneously constraining them may not be effective. Building off both the competition and classroom research, I designed a new formal robotics curricula that better focused students' attention on a single—although large—math idea that more closely aligned with the particular problem students being introduced to robots were trying to solve (Silk, Higashi, Shoop, & Schunn, 2010; Silk & Schunn, 2011c). In this new instructional design students readily used math in their solutions and this math use led to gains in robot problem solving that were not evident in students who participated in robot competitions.

My research in this new instructional context led to other, related questions about the types of approaches that students used to integrate math in their robot problem solving. Students tended to frame the task in two distinct ways: (1) as a *calculational* problem (Thompson, Philipp, Thompson, & Boyd, 1994) in which their solution involved translating the context to numerical values, manipulating those values using arithmetic operations, and developing a numerical pattern that matched the data; versus (2) a *mechanistic* approach (Kaplan & Black, 2003) in which their solution involved representing their intuitive ideas about how the robot worked and using mathematical forms to be explicit about the relationships between relevant features. These distinct problem framings suggest that math, even when successfully integrated with technology problem solving, may have different purposes and lead to different results depending on how it used. Some framings may lead to developing conceptual understanding more than others (Schwartz, Martin, & Pfaffman, 2005; Schwartz & Moore, 1998). In a study using this same robot curriculum, we examined the impact of those different approaches on students' understanding as well as transfer of their experiences to more competition-like settings using similar robots and movements (Silk & Schunn, 2011a). Students in the *mechanistic* group had greater increases in robot problem solving, but also were more likely to use strategies they invented in the robot curricula on the competition-like task. Students in the *calculational* group did also use math in the robot curricula—and used math at a fairly sophisticated level—but then in the competition transfer task were more likely to revert back to the non-math-based strategies that are more common in competition solutions generally.

Future Research

Overall, my work suggests that there is value in examining the intersection of technology and engineering with science and math. There are many open questions as to how students' develop the capacity to coordinate between these disciplines when solving authentic, complex problems. My plan in future research is to better specify what successful "integration" looks like and what are typical trajectories of development. From a cognitive perspective, part of that effort will be to tease apart whether coordinating concepts and skills in the more basic disciplines of Science and Math proceeds along (1) a prerequisite, foundational path, (2) a parallel, independent path, or

(3) a coordinated, bootstrapped path with related concepts and skills in the more applied disciplines of Technology and Engineering. Since introductory robot competitions often consist of students at a range of grade levels from third grade to eighth grade, in addition to more advanced competitions for high school students, it would be possible to do cross-sectional and longitudinal studies of participating students to determine the existence of these different developmental paths. Connections to success in the competitions and to success in math and science classes in school could also be examined.

Another way to build off this work could be to examine the role of motivation and identity in influencing the trajectory of development. In my robot studies in particular, interest levels in both math and in robots may have played a large role in a students' approach to working on tasks that call for integration of those two disciplines, especially to the extent that those tasks are cognitively challenging. What motivational and identity aspects predict students' willingness to persist in the task despite the difficult challenges that they face? How does their experience in the task influence their choice to pursue more STEM experiences both out of school and in school? Further research in these robot settings may help to provide rich cases of that playing out within individuals and to explain why some robot learning environments are successful for some individuals and others aren't. In addition, investigating these ideas in other related contexts, such as makerspaces (Silk, 2012), might help to understand what are the affordances of robotics in particular versus other tasks and communities focused on integrated STEM problem solving. Overall, designed learning environments focused on STEM integration in general and robotics in particular—see the emphasis on robot competitions in the latest NSF ITEST program solicitation (National Science Foundation, 2011)—are promising contexts for expanding the depth of research in the learning sciences.

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