Research Statement – Candace Walkington

My research program is guided by the overarching question: How can abstract mathematical ideas become *grounded* (Goldstone & Son, 2005; Koedinger, Alibali, & Nathan, 2008) in concrete, everyday experiences, such that they are easier for students in grasp? Grounding is an exciting and generative area of research, as it grapples with many fundamental issues in mathematics education such as developing student motivation, confronting enormous diversity in background knowledge and experiences, and providing access to abstract, higher-level content for students who struggle to learn mathematics. As my research program shows, grounding has the potential to address many of these critically important dilemmas that face our field.

The main thrust of my work involves the emerging instructional principle of *context personalization*, or the idea that placing instruction in contexts relevant to students' interests supports learning. My research shows that personalization supports long-term retention and transfer of key concepts in algebra – especially for students who struggle with mathematics. I have also explored issues of grounding through research on contextualized problems in algebra and embodied proofs in geometry, and by examining the emergence of mathematical ideas in project-based settings. My work draws upon qualitative methods like think-aloud protocols, grounded theory, interaction analysis, multimodal analysis, and classroom observation. My research also leverages quantitative methods like regression analysis, hierarchical linear modeling, analysis of variance, and factor analysis.

Research on Context Personalization

As a researcher and teacher educator working in high-poverty urban schools, I saw firsthand how students in these settings struggled to learn mathematics, as they were taught heavily procedural skills disconnected from their lives and experiences. I became interested in researching grounding as a means to support students in making the transition from concrete to abstract forms of mathematical reasoning, by leveraging mathematical aspects of students' out-of-school interests. Algebra I represents a critical point in this transition, and has been framed as a gatekeeper to higher level mathematics (Kaput, 2000) with significant implications for equity and access (Moses & Cobb, 2001). I began a collaboration with the Pittsburgh Science of Learning Center that ultimately led to the receipt of a grant to conduct a series of studies on personalization in algebra as part of the center's *Motivation and Metacognition* research group.

Using think-alouds of students solving normal and personalized algebra story problems, my research revealed a number of novel results on the nature of personalization interventions. First, I showed that personalization can be conceptualized as a form of instructional assistance, meaning that it is most beneficial when students are struggling to learn difficult concepts (Walkington & Maull, 2011). Second, personalization supported performance by allowing learners to develop more meaningful *situation models* (Nathan, et al., 1992) of problem situations. Learners leveraged situation models of these relevant and interesting mathematical scenarios to invent informal strategies to solve problems and to avoid conceptual misspecifications of functional relationships (Walkington, Petrosino, & Sherman, under review).

The larger goal of the grant was to determine how personalization can support robust learning of algebraic concepts, in the form of long-term retention, transfer, and accelerated future learning (Koedinger, Corbett, & Perfetti, 2010). I conducted a study where 145 Algebra I students were randomly assigned to two conditions in the Cognitive Tutor Algebra software – one condition received normal story problems, while the other received personalized versions of the same problems. Analyses showed that students receiving personalization had higher levels of performance, asked for fewer hints, and spent less time solving problems (Walkington & Maull, 2011). Most importantly, after the personalization intervention had been removed, students from the experimental group were still significantly better at one particular, very important, concept – writing more complex algebraic expressions (Walkington, in preparation).

This study provided evidence that personalization supports learning - relevant contexts acted as a means of grounding for abstract algebraic relationships that would otherwise be challenging for students to represent. As an interest-based perceptual scaffold, personalization allowed learners to grasp and symbolically represent the deeper, structural characteristics of story situations, and then retain this understanding with the support removed. Personalization, as a form of grounding, seems to have great potential in allowing learners to make critical connections between concrete prior knowledge and abstract representational systems. Results also suggested that personalization is most beneficial for one group of students in particular – students who struggle with mathematics. To this end, I plan to implement personalization as an adaptive, faded scaffold for students who are having difficulty learning key mathematics concepts. Future directions also include linking the impact of personalization to learner affective states like boredom, frustration, and engagement. Finally, I plan to look at the cognitive impact of having students take an active role in personalizing their own learning, and the learning of their peers.

Research on Contextualization in Algebra

My research on algebra also more broadly examines issues of contextualization in mathematics and the role of story problems in leveraging student prior knowledge (Walkington, Sherman, & Petrosino, accepted). This research expands on the personalization studies by taking a situated perspective on learning where knowledge is understood as socially constructed and distributed across learners, teachers, resources, and the environment. My work in this area critically challenges the notion that the design of authentic mathematical learning environments that utilize prior knowledge can be accomplished without taking into account students' diverse participation practices across different social systems. This reveals an important challenge for educators and researchers attempting to design interventions that promote grounding of mathematical ideas in students' experience. My research is also exploring students' conceptions of mathematical functions presented in contextualized scenarios by developing the APOS framework (Moschkovich et al., 1993; Sfard, 1991) for early algebra (Sherman & Walkington, 2011). Ultimately, it is important for students to simultaneously view a function as both a concrete series of actions and as an abstract mathematical object, and my future work in this area will continue to examine ways in which structural reasoning can be developed from students' experiences.

Research on Embodiment as Grounding Geometric Justification

Grounding plays an important role in algebra, but has been less investigated in subsequent mathematical subjects, like high school geometry. Mathematical justification, often introduced in geometry, is a challenging practice for students to learn (Hoyles & Healy, 1999, 2007); for example, my research has shown that students may test examples rather than engaging in generalized justification (Cooper, Walkington et al., 2011). As a mathematician, I appreciate the power and conceptual beauty of mathematical proof. However, as an educator, I recognize that proof is often taught as a self-contained, abstract system detached from the experiences of learners. As geometry is a domain that is particularly rooted in the body's interactions with the physical world, I am currently examining the role of body-based action in grounding students' understanding of abstract geometric justifications.

Preliminary results (Walkington, Srisurichan, Nathan, Williams, & Alibali, 2012) suggest that justification in geometry is embodied and action-based, and that the body can serve as a critical resource not only for communicating mathematical ideas, but for constituting mathematical concepts. The body is not simply a channel through which a mentally-formulated sequence of arguments is transmitted; rather, modality and justification co-constitute each other, impacting the content and nature of mathematical proof. This research reveals the ways in which interactions with the world can ground abstract mathematical ideas by giving learners important tools for reasoning. In future work, I am interested in examining the ways in which body-based experience (real or simulated) combined with relevant contexts can synergistically provide grounding for key concepts in mathematics.

Research on Grounding in Project-Based Settings

Embedding mathematics learning in rich, applied projects where students grapple with important driving questions could be considered an ultimate form of grounding. Project-based instruction has thus been an area of great interest for me, from my time in the classroom, to my graduate experiences teaching and conducting research within the UTeach program, to my current work on the "Tangibility of Mathematics" grant at University of Wisconsin. The idea of grounding is relatively straightforward in traditional algebra or geometry – the mathematics to be learned has formal and abstract properties that may be difficult to integrate with prior knowledge, and grounding is used as a bridge. However, in project-based settings like pre-college engineering or technology-enhanced geometry classrooms, the story is different. Students must come to understand the *cohesion* of central mathematics concepts as they arise across disparate contexts (e.g., computer lab, classroom lecture, woodshop), representations (e.g., sketches, equations, designed objects), and social configurations (e.g., direct instruction, group work, presentations) (Nathan, Wolfgram, Srisurichan, Walkington, & Alibali, under review).

In engineering classrooms, the progression of project-based learning often follows an abstract to concrete progression – students first learn abstract concepts in physics or mathematics and then apply these concepts to the design and testing of devices. In a case study of a high school class participating in a project where they designed and tested model bridges, I showed how students' conceptualizations of key mathematical relationships can become *too* grounded, as they focus on concrete representations and make few connections to previously-covered mathematical formalisms (Walkington, Nathan, Wolfgram, Alibali, & Srisurichan, in press). I argued that this represents a central challenge to maintaining the cohesion of mathematical concepts in project-based lessons.

We identified three critical behaviors as central to building this cohesion across the disparate contexts that arise in project-based settings – identification, projection, and coordination (Nathan, Srisurichan, Walkington, et al., under review). When enacting *identification*, a participant explicitly labels or attends to a central mathematical concept that is being instantiated over the course of a project. Participants also use *projection*, where they make connections between current activities and future or past events, citing how key mathematical concepts are transformed across time and space. Finally, participants engage in *coordination* where they explicitly map or relate the features of different material or representational forms that instantiate the same mathematical ideas. By using these interactional moves, participants allow mathematical concepts to be simultaneously grounded and abstract, facilitating flexible understanding of how mathematics arises across shifting modalities in project-based settings. Future directions of this research include tying these moves to student learning of mathematics concepts.

Conclusion

Mathematics is a discipline firmly rooted in our interactions with the world – however it is often taught disconnected from students' experiences, especially as upper-level content becomes more abstract and complex. Grounding – whether accomplished through personalized story scenarios, body-based action, or Project-based instruction – is a powerful method to provide students with access to mathematical learning. My research program reveals both the great promise of grounding for promoting learning and access for students who struggle with mathematics, as well as the critical issues that must be grappled with when considering these approaches.