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Supporting Children's Engineering Discourse and Decision-Making with Multimedia Engineering Notebook Tools (work in progress)

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Numerous recent efforts in science education have focused on supporting the ways of talking and writing that constitute the "discourse" of science (Gee, 2004). Various groups have developed and studied templates for science notebooks, videos of productive science talk, and scaffolds for science argumentation (e.g., Crissman, Davis, Worth, Winokur, & Heller-Winokur, 2009; Fulwiler, 2007; Gallas, 1995; McNeill, 2009; Rosebery & Warren, 2008; Shepardson & Britsch, 2001; Short, Vogt, & Echevarria, 2010). An opportunity to build upon these resources for *science* discourse has arisen with the prominent inclusion of *engineering* design in the *Next Generation Science Standards* (National Research Council [NRC], 2013). As engineering emerges as a consistent part of K-12 education, there is a need for models and tools that support students' engineering design practices across all engineering curricula. In particular, students need support in developing ways of talking and writing that enable practices such as proposing possible design solutions and redesigning. Such practices require engineers to engage in reflective decision-making in communication with others (NRC, 2012).

In this work-in-progress, we are developing and studying multimedia engineering notebook tools that support urban elementary students' engagement in engineering practices, particularly those that involve reflective decision-making with fellow students. Our work is a close collaboration with elementary teacher researchers, and we are in the first phase of a three-year project. Together we are exploring the following research questions.

1. What patterns of language constitute reflective decision-making by elementary students during engineering design?
2. What linguistic resources for engaging in reflective decision-making do elementary school students bring to engineering design?
3. How do paper-based and digital engineering notebook tools support engineering processes (via students' reflective decision-making) and products (students' tangible design constructions)?

In this paper specifically, we highlight work with teacher researchers in identifying the practices and linguistic patterns associated with *reflective decision-making* in engineering planning and design. In this first phase of the project, we are currently identifying synergies and gaps between elementary students' and college-level engineers' decision-making.

Background

Because we are interested in discourse practices for teaching engineering to populations of students in low income urban communities who have the least access to quality STEM education, our theoretical framework is centered within two areas of the literature.
First, we build upon prior work that highlights the role of reflection and language in engineering design (Atman et al., 2008; Aurigemma, Chandrasekharan, Nersessian, & Newstetter, 2013) as well as prior work showing the substantial growth that occurs as engineers shift from novice to

expert practice (Atman, Adams, Mosborg, et al., 2007; Cardella, Atman, Turns, & Adams, 2008; Cross, 2004). For example, Ahmed, Wallace, and Blessing (2003) found that recently graduated engineers utilized a systematic trial-and-error approach where they implemented and evaluated each design idea through many iterations. By contrast, their experienced colleagues evaluated tentative design ideas before implementing them, thus engaging early in reflective decision-making and spending their time implementing only potentially fruitful ideas. Cross's (2003) case study of three exceptional engineering designers (as they thought out loud while designing a bicycle carrier, sewing machine, or racing car) revealed three orientations that they all shared. They all explored the problem space thoroughly and framed the problem from the perspective of their own personal experiences, they all maintained a focus on physical principles throughout their design process, and they all identified a productive tension between their own high-level problem goals and the clients' requirements for an acceptable solution. Despite these similarities among expert designers, there of course is no single engineering design method (Lawson, 1997). However, a universal feature across all engineers' practice is the creation of and reflection on representations of their work (Dym, 1994) and analysis and testing of the work they are producing (Bucciarelli, 1994). They might check that an initial conceptual design satisfies all the requirements of the problem statement, or they might develop and implement complex mathematical models, for example, of the energy consumption of each subsystem of a manufacturing device. This emphasis on analysis and testing leads to iterative redesign as another universal feature of engineering (Petroski, 1996). From problem scoping, to prototype development, to redesign and final specifications, engineers engage in reflective decision-making to determine evidence-based next steps. The literature indicates that a focus on classroom engineering discourse may uncover linguistic resources used in the negotiation of ideas that lead to reflective decisions. For example, Capobianco et al. (2011) showed that when encouraged by their teachers to reflect on and listen to classmates' recommendations, fifth and first graders critiqued each others' designs in ways that led to substantive changes in design products.

The second area of literature that our work builds upon is sociocultural/sociolinguistic learning theory, specifically the "resources perspective" which focuses on the "productive conceptual, meta-representational, linguistic, experiential, and epistemological resources that students have for advancing their understanding of scientific ideas" (Warren et al., 2001, p. 531). The resources perspective is aligned with the idea that students come to school with "funds of knowledge" from their experiences at home and in their communities (Hammond, 2001; Moll, Amanti, Neff, & Gonzalez, 1992). These funds of knowledge provide discursive resources that potentially serve as a foundation for engaging students who are typically left on the margins of school science (e.g., Barton, 2003). A key objective of the proposed study is to build upon the intellectual and linguistic resources of these urban students to develop tools for teaching design.

Methods

In the first phase of the project, we are examining students' engineering discourse for evidence of reflective decision-making. In particular, we are looking for reflective decision-making practices while students participate in planning (i.e., developing possible solutions) and redesign (i.e., iteration) aspects of engineering design. The full research team, which includes both educational researchers and classroom teachers, convenes twice a month in order to examine and analyze collected data, including field notes, video recordings, transcribed classroom conversations, and students' engineering design notebooks. These data come from elementary school classrooms as well as from college engineering classrooms. The purpose of collecting data from the college level is to enable comparisons between children's discourse and that of beginning engineering practitioners. Audio recordings and field notes from research team meetings serve as additional data sources. We are identifying patterns and themes in the corpus of data via discourse analysis (Gee, 2010) grounded in the particular analytic approach of microethnographic study of classroom cultural practices (Bloome, Carter, Christian, Otto, & Shuart-Faris, 2005). In the second phase of the project, this analytic work will assist the research team's efforts in designing multimedia engineering notebook tools that support students' engagement in reflective decision-making by building upon the identified student intellectual and linguistic resources.

In addition to analyzing video, audio, and notebook work, the research team is also assessing students' tangible engineering design solutions for design quality along three variables: functionality, novelty, and parsimony (Shah, Smith, & Vargas-Hernandez, 2003; Sobek & Jain, 2007).

Preliminary Findings

To date we have conducted initial analysis of data from three sources: (1) video of a first-year college engineering class session in which student teams designed, constructed, and tested paper towers, (2) field notes from a fourth-grade lesson in which student teams designed and constructed rubber-band powered cars, and (3) audio recordings of the research team meetings at which teachers and researchers discussed these class sessions. Preliminary analysis of transcribed class sessions and team meetings has raised two themes of ongoing interest to be investigated further in the micro-analysis.

The first theme emergent from our discourse analysis is the role of power within the design team negotiations. We find that design proposals, decisions, and suggestions for re-design are communicated via a synthesis of engineering-specific language and everyday, personal expressions, and that engineering-specific language plays a role elevating the status of students' ideas. We are exploring this theme by asking, how does the appropriation of specific everyday or discipline-specific discourses by participants shape the exchange and adoption of ideas?

The second theme that has emerged is the distribution of physical manipulation of materials with other linguistic modes as contributing to the design decisions and reflection (Aurigemma et al., 2013). In what way does physical manipulation of materials contribute or distract in shaping the discourse along with other linguistic resources? A detailed micro-analysis of transcripts from classroom engineering experience will allow our research team to explore which intersections of multiple resources (everyday and disciplinary language, physical manipulation) result in design changes or reflections.

Discussion and Conclusion

The intended contributions of this work include advancing educators' knowledge of how to identify and build upon intellectual and linguistic resources that students bring to engineering design processes. We also hope to empower educators to support young students' development of a reflective stance toward engineering design, in preparation for a society that increasingly demands technological literacy of its citizens.

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