Designing Computer-Based Guidance to Support Teacher and Student Practices in Engineering and Modeling Projects

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Dissertation Defense

Linking Document

Nationally, there have been concurrent calls to increase the use of mathematical modeling (e.g., NGA, 2010) and to increase the use of engineering design (e.g., NRC, 2012) in K-12 classrooms. Mathematical modeling is an iterative "process that uses mathematics to represent, analyze, make predictions or otherwise provide insight into real-world phenomena" (Bliss & Libertini, 2016, p.8). Modeling is firmly grounded in a real-world context and is used to better understand or make predictions about that context by creating abstract mathematical representations of the real-world context (Cirillo, Pelesko, Felton-Koestler, & Rubel, 2016). Engineering design is also an iterative process that is grounded in a real-world context; however, engineering design typically takes the insights developed from mathematical modeling to build prototype designs, test them, and refine them not in an abstract mathematical sense, but within the real-world context itself (e.g., Burghardt & Hacker, 2004). While mathematical modeling and engineering design are distinct, they have much in common and complement each other. These practices have been found to be important for students' understanding and self-efficacy of both science and mathematics (e.g., Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006; Plant, Baylor, Doerr, & Rosenberg-Kima, 2009), and may be particularly engaging for students typically underrepresented in science or mathematics (e.g., Han, Capraro, & Capraro, 2014; Cirillo, Bartell, & Wager, 2016). Supporting these student practices involves designing projects that guide students to use these practices in their learning and also supporting teachers to facilitate these practices in their classrooms.

Research in teacher education highlights the importance of supporting core teaching practices (e.g., Ball & Forzani, 2009; Grossman, Hammerness, & McDonald, 2009). For teachers engaging their students in engineering design or mathematical modeling projects, it is particularly important that they are supported with the core practices of *eliciting*, *noticing* and *responding* to student ideas.

Eliciting student ideas (Franke et al., 2009; Linn & Eylon, 2011; Lesh et al., 2000) involves helping students articulate their existing ideas about a concept or phenomenon. Learners do not come to class as a blank slate, but instead have a rich repertoire of ideas from prior instruction or everyday experience (Hammer & Elby, 2003; Minstrell, 1992; Pfundt & Duit, 1991). From a constructivist perspective, it is important to leverage students' existing ideas as a starting point for instruction and activities (NRC, 2000). However, to do so, it is important for teachers to pose questions or challenges that *elicit* the different ideas that students have. Teacher questions play a critical role in eliciting students' ideas (Franke et al., 2009), whether these questions are asked within teacher-student dialogue, or within the design of the instructional materials provided to students during a design or modeling project.

Noticing student ideas, whether expressed explicitly in their dialogue or written explanations, or implicitly in their actions, is the practice of noticing important ideas and connecting them to broader pedagogical ideas and classroom contexts (van Es & Sherin, 2002). It is not enough for teachers only to pose questions to elicit students' ideas, but they must also be able to recognize the kinds of ideas present in students' responses. For example, if a teacher asked students to describe how changing the radius of a circle impacted its circumference, the students might describe a variety of ideas that are different from the normative $C = 2\pi r$ relationship. If a student says, "in a circle the radius doesn't change size," the teacher might focus on how this student's idea is different from their idea and dismiss it. Alternatively, the teacher might recognize that this alternative student idea is valid and consider how to build upon this idea in a way that reaches the intended learning goal. Many teachers struggle to notice the nuance of students' mathematical ideas (Sherin, Jacobs, & Philipp, 2011), or the diversity of design practices used by students (Purzer, Moore, Baker, & Berland, 2014), making it difficult for teachers to respond effectively.

Responding to student ideas involves teachers prioritizing which student ideas to respond to (Jacobs, Lamb, & Philipp, 2010) and how to format the response to align with research-based formative feedback practices (Shute, 2008; Hattie & Timperley, 2007). Responding typically occurs while in classrooms, requiring frequent, in-the-moment decision making, and even when teachers are able to notice student ideas, they do not necessarily respond to these ideas effectively (Jacobs et al., 2010). For example, even having noticed that the student statement "in a circle the radius doesn't change size" could be considered valid, the teacher might not know how to resolve the apparent paradox that radius is a constant in the student idea, but a variable in the teacher's original question, and might therefore dismiss the student idea anyway.

Since teaching practices of eliciting, noticing and responding to student ideas are both complex and in need of support, this dissertation describes three studies that look at the design of technology that can guide student and teacher practice. The first study examines the design of a web-based learning environment to guide students through a project that *elicits* from students their engineering design and mathematical modeling practices together. The second study seeks to support the *noticing* of engineering design practices by leveraging the log data created by students as they use software to complete science-based engineering design challenges. This noticing can then be used to guide students with their practice directly, or to help teachers guide students. Finally, the third study seeks to support the *responding* practice of teachers whose students are engaged with a mathematical modeling project by providing teachers with automated guidance while they are responding. Descriptions of each of these studies are summarized in more detail below.

Paper 1. *Supporting Students' Mathematical Modeling and Informed Engineering Design in Geometry Classrooms: A Design-Based Approach*

Paper 1 examines the design of a web-based learning environment to guide students through a project that *elicits* their engineering design practices and mathematical modeling practices. Teachers are known to face challenges implementing projects that are intended to promote these practices with their students, and therefore need to be supported. While mathematical modeling and engineering design are both seen as a means to promote deeper, more integrated, and more applied student understanding, there has also been little focus on how to encourage students to use them both together in K-12 classrooms. This study aims to explore how to design projects that incorporate both mathematical modeling and engineering design synergistically. We present two cycles of a design-based research study that uses a web-based, learning environment to guide students through an engineering design project. In the first cycle, students used mathematical models in their designs, and in the second cycle students created mathematical models from testing prototype designs. We examined how the different elements of the design of the projects resulted in a more connected understanding of geometry, and supported mathematical modeling and engineering design in K-12 classrooms. We used pretest and posttest data, embedded assessments, learning environment log-data, student explanations and artifacts, as well as classroom observations and video, to support our analysis.

This paper was a significantly revised version of my qualifying paper. Since proposing this work, I have analyzed the data, written-up the results, discussion and limitations sections. I have also reworked some of the front matter to make the paper more cohesive and made revisions suggested by dissertation committee members during the proposal defense. I plan to submit this paper to a journal in the Fall. My role in this paper has been to design the engineering design and mathematical modeling project with guidance from Jennie Chiu. I was also supported by Jennie and James Hong with the implementation of the study and with the analysis of the data collected. Jennie Chiu has also assisted with framing the argument and editing multiple drafts of the paper including the qualifying paper.

Paper 2. *Using Evidence-Centered Design to Develop Automated Noticing of Students' Engineering Design Practices*

Paper 2 describes the early stages of designing automated *noticing* of student engineering design practices. Teachers need support noticing the engineering design practices of each student so that they are better able to respond to the students about these practices. This study proposes to leverage the log data collected while students are using Energy3D—a computer-aided design (CAD) and simulation software specifically designed for K-12 students to construct buildings and analyze their energy efficiency (Xie, Schimpf, Chao, Nourian, & Massicotte, 2018). Drawing upon the Evidence-Centered Design framework (e.g., Mislevy Haertel, Risconcente, Rutstein, & Ziker, 2017) to make inferences about student performance, we: (1) used machine learning data analytic techniques to notice patterns of student design practices in the log data; (2) triangulated assumptions of the log data analysis with video of students designing in Energy3D; and (3) investigated alignment between the video and the log data analysis to explore the validity of inferences of the machine learning analytic techniques. By exploring the validity of the log data analyses, we worked towards developing automated ways to capture students' design behaviors in the moment. We hope that this work will eventually be used to help provide automated guidance to teachers to support their noticing practice, and to students to support their engineering design practice.

The data for this study was collected in the Spring semester of 2018 and pilot development of the analysis was presented at the ICLS conference in the Summer of 2018. Significant revisions to the analysis have been made since proposing this work, and the methods, results, discussion and implications sections have been added. I plan to submit this paper to a journal in the Fall. My role in this paper has been to run the study in classrooms with assistance from my advisor and dissertation committee chair Jennie Chiu. Dissertation committee member Mark Floryan advised me on numerous iterations of the analysis and Jennie Chiu has assisted with framing the argument and editing drafts of the paper including earlier revisions submitted for the ICLS conference.

Paper 3. *The Teacher Responding Tool: Scaffolding the high-leverage teacher practice of responding to student ideas in mathematics classrooms.*

Paper 3 introduces the Teacher Responding Tool (TRT), which we designed and tested with four high school geometry teachers whose students were participating in a mathematical modeling project. *Responding* to the mathematical ideas of students is a core practice, yet complex. Teachers need support to develop effective ways to respond to students' ideas. The TRT leverages natural language processing technology to provide teachers with automated, student-specific recommendations for how to respond to the mathematical ideas within their students' written explanations. By examining the teachers' interactions with the TRT, their think-aloud data, and their post-project interviews, we found that the recommendations helped teachers notice nuances in the mathematical ideas of their students, and that the TRT scaffolded responding for teachers without simplifying the complexity of the practice.

This paper has been accepted for publication with the journal *Computers & Education*. Since the proposal, this paper has revised based on committee members' feedback, submitted to the journal, and further revised based on reviewer comments. My role in this paper was building and designing the TRT (including learning the technical skills necessary such as Python, NLP, and client- and server-side web-design), running both the pilot and the main study in the school, analyzing the data. Jennie Chiu assisted with framing the argument and editing drafts of the paper. James Hong, a fellow Curry Ph.D. student and third author, assisted in ensuring that the teacher responses were reliably coded. Vidhya Sankaranarayanan, a Curry Master's student and fourth author, assisted in writing the feedback recommendations.

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