Modeling and Model-Eliciting Activities (MEAs) as Foundational to Future Engineering Curricula

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Abstract*: This paper reports on research and theory-building efforts associated with models and modeling in undergraduate engineering education. The presentation focuses on a collaboration comprising a seven-university scale-up project funded by the US National Science Foundation's (NSF's) Course, Curriculum and Laboratory Improvement (CCLI) Program. The CCLI funding includes separate linked grants to the University of Pittsburgh, Purdue University, the US Air Force Academy, California Polytechnic University at San Luis Obispo, the Colorado School of Mines, Pepperdine University, and the University of Minnesota. Additionally, Makerere University in Kampala Uganda and a K12 school in Kasana are partnered with this project to develop and implement MEAs in those venues.The project seeks to enhance the complex reasoning and problem solving competencies. The collaborators are testing a form of problem-based learning, called model-eliciting activities, or MEAs, in undergraduate engineering curriculum.*

Introduction

This paper reports on research and theory-building efforts associated with models and modeling in undergraduate engineering education. The presentation focuses on a collaboration comprising a seven-university scale-up project funded by the US National Science Foundation's (NSF's) Course, Curriculum and Laboratory Improvement (CCLI) Program. The CCLI funding includes separate linked grants to the University of Pittsburgh, Purdue University, the US Air Force Academy, California Polytechnic University at San Luis Obispo, the Colorado School of Mines, Pepperdine University, and the University of Minnesota (Shuman & Besterfield-Sacre, 2007). Additionally, Makerere University in Kampala Uganda and a K12 school in Kasana are partnered with this project to develop and implement MEAs in those venues.The project seeks to enhance the complex reasoning and problem solving competencies. The collaborators are testing a form of problem-based learning, called model-eliciting activities, or MEAs, in undergraduate engineering curriculum (Diefes-Dux, Moore, Zawojewski, & Imbrie, 2004; Hamilton, Lesh, & Lester, 2008; Lesh & Harel, 2003).

One objective of the paper is to relate the work of the seven partners towards efforts to build a theory around personalized learning communities. A second objective will focus on models and modeling in engineering learning. The paper will present curriculum extensions in the MEA construct that have been made through our research trajectory of modeling activities, particularly the use of MEAs to elicit misconceptions, to aid in ethics education, and to help students integrate traditional models in novel ways to solve problems. It will also compare and contrast problem-based learning (PBL) and modeling. Our MEA approach intersects PBL in some important areas, yet departs sharply from it in others, especially with MEA's focus on creating an effective model to resolve a general class of problems as typified by the problem at hand.

Theoretical Framework

An initial premise of this curriculum research and development is that the conceptual models – and especially mathematical models - that students possess, express, test and refine in group settings are central to the quest for systems thinking and complex reasoning in engineering. Emphasizing models that students build and manipulate in turn leads to highlighting the role of elicitation – creating scenarios that expose conceptual models and allow them to be expanded.

This work rests heavily on the notion that because students engage in and form deep tacit insights about the complex systems they face in the world every day, the research-informed wisdom that teaching should match prior knowledge (Bransford, 2000; Clark & Mayer, 2003) can go farther. This principle suggests that teaching should elicit and leverage not only factual knowledge but the systems thinking that youngsters already exercise intuitively, often in hazy or unclear ways. Model-elicitation as an instructional tool requires model representation by students; translating conceptual structures to representations – that is, the expression of systems thinking - can expose patchy and weak content structures that can then be refined, stabilized and expanded (Hjalmarson, Cardella, & Adams, 2007). The focus of elicitation is relatively agnostic towards the philosophy of constructivism (R. Lesh & Doerr, 2003), stressing not so much individuals creating new conceptual structures as much as revealing and revising existing ones as they attempt to solve problems that are meaningful or consequential to them. The three remaining papers present data and analysis around model-eliciting activities.

A central theme is that a focus on elicitation of models that students possess and build as a pathway to expanding systems thinking is a promising approach to a broad, sublime goal of designing personalized learning communities. The theoretical and empirical arguments behind that somewhat non-intuitive conjecture is an important contribution of the paper. The paper will briefly outline one way to view personalized learning communities, invoking multiple theoretical and practical frameworks and then drawing connections to those characteristics from different principles related to the use of model-eliciting activities.

Model-Eliciting Activities (MEAs)

This paper gives a more systematic introduction to the specifics of model-eliciting activities, and positions MEAs in the context of related literatures. The many flavors of modeling in contemporary education research collectively form a suite of approaches for rethinking and "re-mixing" curriculum for future learning environments, seeking to depart from the traditional and persistent tendency of schools to function primarily as didactic dispensers of declarative and procedural knowledge (Weigel, James, & Gardner, 2009). Across multiple definitions or interpretations, modeling emphasizes the connected knowledge forms, the adaptation of large ideas to new contexts, just-in-time learning, and complex reasoning in collaborative arrangements. Emphasis on modeling has a well-established lineage in the computer-supported collaborative learning community (e.g., Hmelo, Holton, & Kolodner, 2000; Lesh, Middleton, Caylor, & Gupta, 2008; Roschelle, Tatar, Shechtman, & Knudsen, 2008). Mathematics education researchers have similarly formulated multiple frameworks to feature modeling as central to the acquisition, use, and growth of mathematical ideas (English, Fox, &

Watters, 2005; Swee Fong & Lee, 2009). The model-eliciting activity or MEA strand that is central to this symposium has previously been presented as the basis of efforts advocating modeling as a foundation for future mathematics curricula (Lesh, Hamilton, & Kaput, 2007).

The MEA approach involves the use of 30-50 minute case study problems that middle, high school and college students solve in groups of three to five. Early MEA research efforts to expose student conceptual models by eliciting them was shown to have the unplanned result of producing high problem-solving performance from youngsters whose prior performance was uneven or weak (Lesh & Yoon, 2004). Among the design characteristics refined over ten years of research (Lesh, Hoover, Hole, Kelly, & Post, 2000) was the constraint that scenarios represent meaningful contexts that would engage students in realistic problems for which testable models or solutions might be found.

A critical element involves what has become crystallized as six principles for model-eliciting or thought-revealing activities, principles that were developed to guide the design of activities which focused on models as products of students' problem solving. Such activities have been used in multiple K-12 settings to situate mathematics and science in authentic contexts such as engineering. Multitier design research has emerged as a methodology for investigating design, implementation and revision of modeling activities. It relies on the use of multiple tiers in the education research enterprise (e.g., researchers, teachers, students) who are designing innovations or models in parallel while relying on data from the other tiers.

Results from the Scale-Up MEA Research

The paper will briefly outline MEA implementation in undergraduate engineering disciplines including environmental bioengineering, chemical, civil, industrial and mechanical engineering as part of the scale-up curriculum project at the NSF-funded consortium of schools mentioned in the opening section.

The critical research question in these group implementations of MEAs always focuses on student models. The question is always: what are the student models ? The paper shows how this question is addressed and explain what constitutes the student models in solving a particular problem, the model characteristics and stability, and then how models evolve during the period of solving the MEA scenarios through adaptive cycles of expressing, testing and revising the models during collaborative problem-solving. The paper traces this "life of a model" and suggests a shift in orientation in instruction towards more emphasis on model development and the self-regulatory skills associated with it.

Unlike problem-based learning approaches, MEA research emphasizes the evolution of student conceptual systems in contrast to the structure of problems, a contrast that is introduced here and explored more fully in the discussant panel.

Extensions

The final portion of the paper will focus on important pedagogical initiatives relating to a model-eliciting activity approach. Specifically, we describe how MEAs can be used to identify misconceptions and improve conceptual learning (C-MEAs), how an ethical component can be introduced to better sensitize students to the types of issues they might face as practicing engineers (E-MEAs) and how a laboratory component enables students to conduct experiments in order to enhance modeling and problem solving skills.

The paper presents examples of MEAs in the form of case studies in each of these areas of misconceptions, ethics, and laboratory uses of modeling activities. The paper highlights assessment and repair of misconceptions: The problem is widespread through science and mathematics disciplines with nearly 7000 reported studies of student misconception in the literature. Prior research by Miller et al in engineering student misconceptions of thermal science topics show that senior-level chemical and mechanical engineering students retain a significant number of robust misconceptions even after completing courses in fluid mechanics, heat transfer, and thermodynamics (Miller et al., 2006). Over 40% consistently cannot distinguish between the rate and amount of heat transfer between two bodies at different temperatures and approximately 50% cannot distinguish between the quantity and quality of energy as described by the second law of thermodynamics. Nearly 30% cannot logically distinguish between temperature and energy in simple engineering systems and processes. This paper highlights the role that elicitiation can plan as a strategy to expose and begin to repair misconceptions, with case study interview transcripts. It also reflects on broader and more diverse implementations of the MEA approach.

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