AC 2010-1501: SPECIAL SESSION: MODEL-ELICITING ACTIVITIES IN ENGINEERING: A FOCUS ON MODEL BUILDING

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MEAs In Engineering: A Focus On Model Building

Abstract

This paper addresses the importance of models and modeling in engineering education reform. It focuses specifically on model-eliciting activities, or MEAs, as research and curriculum tools to develop complex reasoning skills, nurture transference and generalizability of problem-solving, and build collaborative skills emphasized in reform literature. Modeling as a key strategy to engineering education carries risk that exclusively didactic and sequential approaches do not, but it appears that much of this risk can be mitigated.

Introduction

The word curriculum has two related lineages from the original Latin term *currere*. One refers to the rut in the ground that wheelbarrows would follow in ancient agrarian cultures. The rut guides, but is inflexible and uni-directional. Another involves a more literal meaning of *currere*, to run. This implies a sense of dynamism and motion [1]. Curriculum development traditionally has largely involved following a pedagogical, instructional and representational scheme as it can be used to render a structured notion of disciplinary content. Ideas build upon each other in a relatively invariant hierarchy, they are treated as one-off in the sense that students have or have not been exposed to them. Context, intuition, and adaptive problem-solving do not occupy the same importance in learning a curriculum that they occupy in day-to-day living [2]. The aim of a curriculum usually is to take students through a body of content knowledge. The notion of a rut that a wheelbarrow follows is apt, for better or worse, relative to traditional engineering curriculum models, with prescribed beginning, end and intermediate steps.

Modeling

Recent theorizing that consolidates important trendlines in learning sciences, engineering education research, social software, and educational technology has given rise to a theory of personalized learning communities [3]. While notions about personalizing education has often focused on technology, important research strands have focused on areas that are not intrinsically technological, including the value of eliciting or exposing student conceptual systems as an operational starting place for acquiring new knowledge – in contrast to imparting predetermined concepts as the operational starting point. Indeed, any approach to knowledge development that focuses on conceptual systems rather than a predetermined chain of new ideas contrasts sharply with typical curricula.

Student conceptual systems as a starting point for operationalizing curriculum has a certain natural symmetry with everyday life. In everyday life students continually participate in various complex dynamic systems [4, 5], where constructs such as feedback loops, self-modifying effects, intuition, optimizing, constraining, and aggregating all play crucial roles that are largely neglected in traditional curriculum. Life rarely occurs or can be observed as a series of single variable causes of single variable effects. For the purpose of this paper and symposium, we treat a focus on student conceptual systems as a focus on student models, and modeling to be a process of creating representations of problematic phenomena or scenarios as a means to solve those situations. The ascendant education research and reform movements that promote systems thinking [6] at all levels of schooling include diverse strands that explicitly focus on modeling in the manner that we use the term. Another way to look at modeling is to create structured representations of complex systems for the purpose of exploring a domain of knowledge or interpreting those systems [7].

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 [8]. Across multiple definitions or interpretations, modeling emphasizes **connected knowledge forms**, **adaptation of large ideas to new contexts**, **just-in-time learning**, and **complex reasoning in collaborative arrangements**. An orientation around models and modeling is often referred to as a Models and Modeling Perspective (MMP) (http://modelsandmodeling.net).

Emphasis on modeling has a well-established history in the computer-supported collaborative learning literature [9-12]. In science education, various curriculum projects [13] exemplify this trend with the development of replacement modules across multiple areas of the high school curriculum. Multiple new modeling oriented pedagogical frameworks have arisen from increased attention towards enabling learners to experience science curriculum in a manner more closely resembling both scientific practice and scientific phenomena [14]. Mathematics education researchers have similarly formulated multiple frameworks to feature modeling as central to the acquisition, use, and growth of mathematical ideas [15, 16]. One strand useful for this discussion has focused specifically on exposing and clarifying the conceptual models that youngsters possess,

Table 1: Types of New Emphases That Emerge in MMP Curriculum Approach and in MEAs

- Feedback loops
- Self-modifying effects
- Mathematical and scientific interpretative systems
- Intuition
- Affect and belief systems
- Optimizing
- Constraining

test and revise as part of group problem-solving settings. This strand, referred to as *model-eliciting activities* or MEAs [17] is the basis for efforts that advocate modeling as a foundation for future mathematics curricula [18].

The MEA approach involves the use of 30-50 minute case study problems that middle school, 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 [5] Among the design characteristics refined over ten years of research [19] was the constraint that scenarios represent meaningful contexts that would engage students in realistic problems for which testable models or solutions might be found. MEAs are a class of problems that simulate authentic, real-world and consequential situations that small teams of 3-5 students work to solve over one or two class periods. While these baseline elements are common to the general literature on problem-based learning [20-23], MEAs have a different design focus. MEA practice grew as a way for education researchers to observe the development of student problem-solving competencies and the growth of mathematical cognition [24]. Part of that evolution entailed altering assumptions about problem-solving as a research-domain. The main question that an MEA entails for any student at any time is - *what is the model?*

Some of the MEAs most commonly used in education and research presentations introducing a models and modeling perspective appear include the Volleyball Problem, the Summer Jobs Problem, and Big Foot [7]. The Paper Airplane problem is an example of an MEA that has been used with both middle school students and for the core freshman engineering program at Purdue University. Moore, Diefes Dux and Imbrie review four MEAs in one of Purdue University introductory courses [25]. Gainsburg examined the connection between modeling activities of structural engineers and those of mathematics students participating in MEAs [26]. A higher level problem for engineering students involves the Quantifying Aluminum Crystal Size MEA and is outlined in depth in [27, 28]. A fuller treatment of MEAs, the terminology of models and modeling, and their application appears at [7] . MEAs have been the subject of numerous NSF grants focused at the level of middle school mathematics. The MMP/MEA approach was the research focus of a recent exploratory grant involving undergraduates, focusing on enhancing and assessing complex reasoning skills, by NSF Human and Social Dynamics Program [29]. This NSF project led directly to the development of a theory of personalized learning communities underlying the educational paradigm shifts sought by this proposal and contributed substantially to the volume Foundations for the Future in Mathematics Education [30]. Although MMP represents an approach to research on cognition, in recent years, the approach has garnered important student achievement successes [31] as it has moved to deployment of MEAs as an instructional tool.

Table 2: Eleven Design Principles for Personalized Learning Communities [3]

- Modeling & Systems Thinking As Driver For
1. Elicitation
2. Consequentiality
3. Adaptivity
4. Sightlines
5. Individualization
6. Connection
7. Self-regulation
8. Hybrids
9. Generativity
10. Bandwidth

As noted above, it has been used across the Purdue University freshman engineering program. Additionally, the MMP/MEA approach is the subject of a current Phase III scale-up Course, Curriculum and Laboratory Improvement (CCLI) collaborative grant by NSF in undergraduate engineering education, hosted by the University of Pittsburgh [32] the University of Minnesota [33], Purdue University [34], the US Air Force Academy [35], California Polytechnic State University at San Luis Obispo [36], and the California School of Mines [33]. Members of the collaborative seek to build and test cyber-mediated curriculum modules that are designed around scenarios that elicit or expose the models engineering students possess, that enable them to test those models, and in so doing to clarify and to expand them. Research in MEAs, as noted, has contributed heavily to development of a theory of personalized learning communities [3]. The eleven design principles of this theory (Table 2) interact in ways best expressed through the language and metaphors of complex systems theory.

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