AC 2011-311: EXPLORING SENIOR ENGINEERING STUDENTS' CONCEPTIONS OF MODELING

Adam R. Carberry, Arizona State University

Adam R. Carberry is a Postdoctoral Research Associate in the College of Technology and Innovation, Department of Engineering at Arizona State University. He earned a B.S. in Materials Science Engineering from Alfred University, and received his M.S. and Ph.D., both from Tufts University, in Chemistry and Engineering Education respectively. His research interests include conceptions of modeling in engineering, engineering epistemological beliefs, and engineering service-learning.

Ann F. McKenna, Arizona State University

Ann McKenna is an Associate Professor in the Department of Engineering in the College of Technology and Innovation at Arizona State University (ASU). Prior to joining ASU she served as a program officer at the National Science Foundation in the Division of Undergraduate Education and was on the faculty of the Segal Design Institute and Department of Mechanical Engineering at Northwestern University. Dr. McKenna's research focuses on understanding the cognitive and social processes of design, design teaching and learning, the role of adaptive expertise in design and innovation, teaching approaches of engineering faculty, and the diffusion and impact of curricular innovations. Dr. McKenna received her B.S. and M.S. degrees in Mechanical Engineering from Drexel University and Ph.D. from the University of California at Berkeley.

Robert A. Linsenmeier, Northwestern University
Jennifer Cole, Northwestern University

Jennifer Cole is the Assistant Chair in Chemical and Biological Engineering in the Robert R. McCormick School of Engineering and Applied Science at Northwestern University. Dr. Cole's primary teaching is in capstone design, and her research interest are in engineering design education.

Exploring Senior Engineering Students' Conceptions of Modeling

Abstract

Modeling is a pervasive feature of engineering that is rarely explicitly taught to engineering learners. The implicit inclusion of modeling often results in conceptions of models being primarily descriptive, originating from everyday and coursework use. A broader understanding of modeling is achieved when students are given opportunities to learn about the predictive nature of some modeling applications. A significant shift was observed between pre and post-surveys of senior engineering students taught a modeling intervention. Descriptive-centric conceptions remained prevalent with an additional focus on predictive mathematical models.

Introduction

Many courses in an engineering curriculum focus on teaching students "engineering fundamentals." Engineering fundamentals can include many different disciplinary topics, but one underlying emphasis is to develop analytic skills that are rooted in basic mathematical and scientific principles. Typical engineering courses engage students in deriving, using, and applying theories, equations, and models in a variety of problem solving contexts.

Models are taught in the engineering curriculum to help students connect a design with the real world.[1] The modeling process provides students with an understanding of how to develop purposeful representations of engineering concepts and solutions. Starfield, Smith, and Bleloch suggest that there are two general categories of engineering models: descriptive and predictive.[2] Descriptive models represent what is expected, while predictive models represent theoretical behaviors. Each category is important to engineering, but is not always given equal attention in the engineering curriculum. This can lead to an underdeveloped understanding of what models truly represent.

This issue is further complicated by what Maki & Thompson note are the different context specific uses of the term model.[3] In everyday use, modeling references a display version or miniaturization of something (e.g. fashion models or toy modeling kits). Engineering students are likely to come to an engineering program with this descriptive-centric notion of a model, which neglects mathematical, theoretical/conceptual, and logic models.

The following study investigates the range of senior students' conceptions of models and modeling for the purpose of identifying their ability to flexibly respond and adaptively apply appropriate models in the context of engineering design.

Theoretical Background

We frame our study using the adaptive expertise model. According to Schwartz, Bransford, and Sears, an adaptive expert is someone who not only has deep subject matter knowledge, but also can efficiently apply his or her knowledge in an innovative manner.[4] Our study analyzes adaptive expertise as it applies to how one flexibly uses knowledge of modeling. Modeling know-how falls under the banner of "computational adaptive expertise" or CADEX,[5] which concentrates on the development of analytical and computational knowledge. Many engineering courses teach these topics without explicitly acknowledging how analytical techniques serve as representations of a physical phenomenon. This approach omits an important step in the development of a robust fluency.

Research Methods

Participants

Senior biomedical engineering students enrolled in a capstone design course at a large Midwest university were solicited to participate in the study. Students in this course were specifically chosen because the course was experimenting with a new intervention designed to improve student modeling expertise.

The course was taken by 76 students, of which 48 responded to every component of the study – 63% response rate. Participation in the study was voluntary even though data sources were included as part of the course. The final cohort of 48 students had 15 females and 33 males.

Data Collection

At the beginning of the course, students were asked to answer a series of open-ended questions regarding their conceptions of modeling in design. This paper focuses on the results obtained from the question: *Describe different ways to model a design solution or idea.* The question was designed to identify their general conceptions of modeling prior to the course's new modeling intervention.

The modeling intervention consisted of a series of modeling tasks that aligned with the mathematical modeling process described by Gainsburg – identify the real-world phenomenon, simplify or idealize the phenomenon, express the idealized phenomenon mathematically, perform the mathematical manipulations, interpret the mathematical solution in real-world terms, and test the interpretation against reality.[6] Note: A detailed description of the activity development and implementation strategy have been published in previous ASEE proceedings.[7, 8] The tasks focused on the design of a phototherapy device used to treat neonatal jaundice. Students were instructed over the course of the intervention to advise a hypothetical design team in:

- deciding what should be modeled
- identifying how models could help the solution
- sketching the system
- identifying relevant parameters and variables
- proposing and creating a mathematical approach to model the system
- listing assumptions
- discussing the relevance of the model to the real world
- interpreting and verifying data produced by the model

The intervention was implemented as the course material in conjunction with the students' senior capstone design work. The general pedagogical approach taken with the activities was to allow the students to attempt the activities followed by a discussion/lecture about the ideal processes. An added reflection component was implemented midway through the course based on instructor feedback that suggested students were unclear about the purpose of the activities. The activity simply asked the students to write a short reflection on why the modeling intervention was being included in the course and in what ways modeling might help them with their own projects. This added reflection allowed us to uncover students' evolving conceptions, as well as how to modify the implementation to make it clearer.

Post-conceptions were later recorded approximately one month after the end of the intervention and prior to the start of the new term to identify changes that may or may not have occurred from the intervention.

Data Analysis

An open-coding approach was taken to identify emergent categories in the data. A single rater first read each student's response to determine a set of categories compiled into a rubric. The rubric was then used to code each student's response. A second rater then used the rubric to test its validity. The second rater repeated a two-step process consisting of 1) coding 10% of the responses using the rubric, and 2) consulting the first rater's codes, until agreement was reached. Changes to the rubric were made to establish 100 percent inter-rater reliability between the two raters.

Codes

Seven codes of interest emerged from the data: physical representations, theoretical models, computer-aided drawings, computer simulations, written descriptions, mathematical models, and the design process. Physical representations included statements regarding a tangible artifact including prototypes, mockups, artwork (e.g. drawings, sketches), systematic diagrams, and charts or graphs. Theoretical models represent untested ideas that should work based on what is known about the real world. The two computer-related codes represent computer versions of the first two codes. Computer-aided drawings refer to artwork that has been transformed into a computer representation, while computer simulations conceptualize theoretical ideas. These codes were separated because of the increased use of computers in engineering courses. Written descriptions are ideas in the form of words, while mathematical models are ideas represented by mathematical equations and calculations. The final code, design process, represents when a student assumes that the entirety of the design process is equivalent to modeling.

Results

The number of students referring to each category for the pre and post-survey are displayed in Table 1. Responses were coded by assigning a value of one when a code was present and zero if a code was not. Students consistently focused on descriptive models – physical representations, computer-aided drawings, and written descriptions – with major emphasis on prototypes, mockups, and artwork. Few students in the pre-survey referred to predictive models – computer simulations, mathematical models, and theoretical models. A shift from pre to post in the reference to mathematical models was evident.

A paired-samples t-test was conducted to compare pre and post-intervention responses. A significant difference in the number of students between pre and post-surveys who reported computer-aided design drawings [t (47) = 2.480, p (2-tailed) $\leq$ 0.05], written descriptions [t (47)

= 3.066, *p* (2-tailed) ≤ 0.01], mathematical models [*t* (47) = -13.364, *p* (2-tailed) ≤ 0.001], and the engineering design process [*t* (47) = 2.591, *p* (2-tailed) ≤ 0.05] as models was seen. Each category went down from pre to post except mathematical models. These results show that students reported mathematical models far more often in the post-survey than they did in the pre-survey and that computer-aided design drawings, written descriptions, and the engineering design process were reported significantly less in the post-survey than the pre-survey.

Table 1: Number of students identifying each category as a component of modeling (percent of total sample, N = 48). p values are for pre- post- paired t-tests.

Category	Pre	Post	*p*
Physical Representations	45 (94%)	41 (85%)	n.s.
Computer-aided Drawings	21 (58%)	11 (38%)	≤ 0.05
Computer Simulations	13 (27%)	8 (17%)	n.s.
Written Descriptions	9 (19%)	1 (2%)	≤ 0.01
Mathematical Models	9 (19%)	47 (98%)	≤ 0.001
Theoretical Models	5 (10%)	7 (15%)	n.s.
Design Process	6 (13%)	0 (0%)	≤ 0.05

The remaining categories – physical representations [*t* (47) = 1.273, *p* (2-tailed) = 0.21], computer simulations [*t* (47) = 1.401, *p* (2-tailed) = 0.17], and conceptual/theoretical models [*t* (47) = -0.628, *p* (2-tailed) = 0.53] – were consistently cited between pre and post-survey.

Discussion and Implications

Modeling is a crucial step in the engineering design process; however, our initial findings suggest that students often do not have very nuanced conceptions of the full power and use of models. The survey results collected at the beginning of the course identified an overwhelmingly descriptive notion of modeling by the sample of students. Of even greater concern was the thirteen percent of the student sample actually listing the steps of the design process as being equivalent to modeling. We believe that the physical nature of modeling shown in the pre-survey is more than just semantics. We believe and suggest that these results are in large part due to student coursework experiences. This suggestion reflects not just what is present in the curriculum but rather, what is absent or tacit.

When an explicit modeling intervention was introduced to these students, a shift occurred in their conceptions of modeling. No students in the post-survey identified the engineering design process as modeling. We assume that the students realized that modeling is a tool used throughout the design process rather than the process itself. Descriptive models remained highly referenced between pre and post-surveys, with mathematical modeling becoming far more prevalent. The significant increase in citing mathematical models was probably highly influenced by the mathematical nature of the intervention; however, the results suggest that the mathematically-based activities positively impacted the student's connection of predictive models to modeling without diminishing the descriptive forms of modeling.

We did see a significant decrease in post responses in the computer-aided design drawings and written descriptions categories. We hypothesize that the newness of the mathematical modeling activity impacted the focus of the students' responses and believe that these previously stated modeling forms are still present.

The added reflection implemented midway through the course also suggested that the pedagogical approach could be improved to mitigate potential frustration or confusion about the purpose of the activities. Approximately 38 percent of the students expressed a dislike of the intervention and a belief that it was irrelevant to their senior design course. It could be that the introduction of mathematical modeling concepts seemed out of place in a design-focused course, and this caused frustration among some of the students. Even so, 75 percent of the students viewed the activities as being included to help them learn how to model and approach design problems. The frustration with the intervention is likely due to the 23 percent of students who were highly concerned with the intervention measuring their knowledge of modeling and hence impacting their grade. The established culture focused on grades may explain the students' preoccupation with how they were being evaluated. The problem can be mitigated by altering the grading of the activities or by implementing the activities through an alternative pedagogical approach.

Overall, our findings suggest that when modeling is made explicit to students, they appear to grasp the variety of modeling types. These results suggest that modeling needs to be made more explicit to engineering students at all stages and that explicit modeling interventions can be used to help make predictive models become more highly associated with what is conceived as modeling.

Conclusions and Future Work

Modeling is an important part of engineering and the design process. Our study sheds light on the nuances of students' conceptions of modeling in the context of a senior design course. Our findings indicate that students describe multiple ways to model a design solution and that most students use descriptive-centric explanations. However, when presented with an activity that explicitly embeds detailed steps of mathematically modeling in the context of design, student responses include increased mention of the prescriptive power of modeling.

While our work has provided useful insights, additional studies are needed to further investigate the modeling conceptions of engineering students at all levels in all disciplines. This type of cross disciplinary and multiple year data can inform how modeling might be taught throughout the engineering curriculum in order for students to be prepared to fluently use this aspect of CADEX in the process of innovation. Explication of modeling depends highly on the current curriculum used at a given institution. In some instances the changes may simply be for analysis-focused courses to be more explicit about how modeling is used in the context of setting up a problem and deriving a solution. Or, it may be necessary to embed modeling as a core component of design-focused courses. Changes in the way modeling is taught will undoubtedly improve the way that students perceive modeling and increase their modeling expertise.

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