Change in student understanding of modeling during first year engineering courses

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Abstract

All engineers must be able to apply and create models to be effective problem solvers, critical thinkers, and innovative designers. To be more successful in their studies and careers, students need a foundational knowledge about models. An adaptable approach can help students develop their modeling skills across a variety of modeling types, including physical models, mathematical models, logical models, and computational models. Physical models (e.g., prototypes) are the most common type of models that engineering students identify and discuss during the design process. There is a need to explicitly focus on varying types of models, model application, and model development in the engineering curriculum, especially on mathematical and computational models.

This NSF project proposes two approaches to creating a holistic modeling environment for learning at two universities. These universities require different levels of revision to the existing first-year engineering courses or programs. The proposed approaches change to a unified language and discussion around modeling with the intent of contextualizing modeling as a fundamental tool within engineering. To evaluate student learning on modeling in engineering, we conducted pre and post surveys across three different first-year engineering courses at these two universities with different student demographics. The comparison between the pre and post surveys highlighted student learning on engineering modeling based on different teaching and curriculum change approaches.

Introduction

Through it is rarely explicitly taught, modeling is fundamental for many core concepts, throughout undergraduate engineering education [1]. There are many benefits to explicitly teaching modeling, particularly in the first years of an engineering program [1-3]. Furthermore, there are some well-developed pedagogies that demonstrate the successes of doing this approach. Model-eliciting activities (MEAs) are an impactful example of a pedagogical approach used in first-year engineering to teach mathematical modeling skills [3]. However, there is still a significant need for more meaningful ways of explicitly teach modeling throughout the engineering curricula, especially for first-year engineering students [1, 4].

There has been an extensive amount of research around modeling interventions within the Computational Adaptive Expertise (CADEX) [2, 5] and Models and Modeling Perspective (M&MP) [6] frameworks that have been proven successful. For instance, Carberry, McKenna, Linsenmeier, and Cole [7] conducted research within the CADEX framework and found that explicit modeling interventions caused a significant shift in the modeling conceptions of senior engineering students. In addition, to gain a greater understanding of modeling conceptions, Carberry and McKenna [1] expanded their research within the CADEX framework, noting that when students were taught an explicit mathematical module, they were more likely to discuss mathematical and predictive models. Hence, research efforts within the M&MP have focused around a mathematical modeling intervention called model-eliciting activities (MEAs) [3]. Some of this research has focused on how students develop mathematical model solutions to MEAs (e.g., [8, 9]), MEA implementation strategies within engineering courses (e.g., [10, 11]), and the improvement of MEA implementation strategies in large first-year engineering (e.g., [12]) and upper division courses (e.g., [13, 14]).

Problem solving, design, and introductory computer programming are examples of some fundamental course concepts that have been integrated into most first-year engineering courses [4, 15, 16]. Even though, all three of these concepts involve modeling, they may not be explicitly discussed or demonstrated. Because mathematical modeling is essential to solving and designing engineering problems in the workforce, it is necessary to teach it more explicitly [4]. Teaching students how to develop an algorithmic solution (a type of model) is fundamental to programming, although sometimes there is greater focus on syntax [16]. Most engineering education studies on computer programming focus on paired programming (e.g., [17]), extreme programming (XP) (e.g., [18]), or active learning teaching pedagogies [19]. However, this study specifically focuses on modeling development in first-year programming courses.

Research Purpose and Questions

In this study, engineering modeling instructions were integrated into three different courses at two different universities. To evaluate student learning during the semester, pre and post surveys were administered at the beginning and end of the semester. This study aims to answer the following question:

- To what extent, first year engineering students benefit from exposure to engineering modeling instructions and assignments?

Methods

Setting and Participants

In Fall 2019, participants from two different universities were selected; one university is classified as a public school, while the other is a private school. The public school was a mid-size school in the west coast serving Hispanic students; while the private school was also medium sized but only served STEM and business students. The participants selected for purposes of this study consisted of 23 students enrolled in an introductory engineering course at the public school as well as 596 students enrolled in multiple sections of two introductory engineering courses at the private school. Both groups of students had different engineering backgrounds; their demographics can be found in Table 1. Students from the public school were mostly Asian and then Hispanic, while students from the private school were predominately White.

At the public school, two hands-on projects integrated in the course were designed to introduce engineering modeling, specifically physical and computational modeling. Thus, changes to the curriculum was more limited than the private school where two courses were redesigned to incorporate modeling concepts in the syllabus.

Table 1 – Participants demographic

University	Ethnicity				Gender		
	Asian	Hispanic	White	Other	Female	Male	N/A
Public School	16	4	1	2	5	18	0
Private School (Course 1)	34	27	223	75	99	257	3
Private School (Course 2)	16	15	166	40	34	196	7

Data Collection and Analysis

The survey was administered online to all students via Qualtrics. The survey asked students questions on definition of engineering modeling, types of models and their differences. Students demographics information were also collected. The pre-survey was administered at the beginning of the semester before student exposure to the modeling materials and the post survey was administered at the end of the semester. Table 2 shows number of participants in pre and post surveys in each course.

The data was exported from Qualtrics and quantitatively analyzed. Based on students' responses, new variables were defined and calculated. These variables which included the length of student response to various questions provided insights into student improvement of understanding during the semester. Test of equality of variance and t-tests were conducted to find any significant differences among these variables for per and post surveys. In addition, to provide context to student responses, word clouds were created from the survey questions.

Table 2 – Number of participants in surveys

University	Pre-Survey	Post-Survey
Public School	23	22
Private School, Course 1	359	201
Private School, Course 2	237	147

Results and Discussion

In the public school, students provided longer responses to open ended questions at the end of the semester when compared to the beginning of the semester. The difference in response length for all 3 questions was significant. At minimum, this confirms students are more capable of answering questions related to engineering modeling after being exposed to the course materials. This can also be an indication of improved understanding of the concept. Table 3 summarizes the results for 3 of questions.

The results of the private school were mixed. In course 1 there was no significant difference between pre and post response length, while in course 2 this difference was significant. Student demographics is one factor for the difference between the private and public school. However, further investigation is needed to determine the root cause for these differences and between the two courses at the private university.

Table 3 – Public School - Average length of student responses in characters

Question	Pre Length	Post Length	T-test p-value
What is a model in science, technology, engineering, and mathematics (STEM) fields?	71	122	< 0.01
List different types of models that you can think of.	37	59	< 0.05
Describe each different type of model you listed.	140	258	< 0.001

Table 4 – Private School, Course 1 - Average length of student responses in characters

Question	Pre Length	Post Length	T-test p-value
What is a model in science, technology, engineering, and mathematics (STEM) fields?	92	85	> 0.05
List different types of models that you can think of.	45	46	> 0.05
Describe each different type of model you listed.	203	203	> 0.05

Table 5 – Private School, Course 2 - Average length of student responses in characters

Question	Pre Length	Post Length	T-test p-value
What is a model in science, technology, engineering, and mathematics (STEM) fields?	73	102	< 0.001
List different types of models that you can think of.	40	51	< 0.01
Describe each different type of model you listed.	189	274	< 0.001

To provide better insight in student responses, word cloud representations were created (Table 6). Student responses in the post survey has more words related to type of models such as mathematical and physical compared to student responses in the pre-surveys. This suggests students were more aware of different types of models at the end of the semesters. It also aligns with previous findings that students wrote longer responses in the post surveys.

Conclusions

In this study, we did the first step of analyzing student survey data on engineering modeling concepts. The surveys were administered at the beginning and end of the semester of 3 first-year engineering courses at two different universities. These 3 courses were redesigned to incorporate modeling instructions. The results suggest students were more equipped to answer modeling related questions at the end of the semester. In addition, they provided longer responses and more specific words related to modeling types at the end of the semester. Further analysis is needed to understand the extent of their knowledge gain during the semester.

Acknowledgements

This work was made possible by a grant from the National Science Foundation (IUSE 1827406). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

Table 6 – Word cloud representation of student responses.

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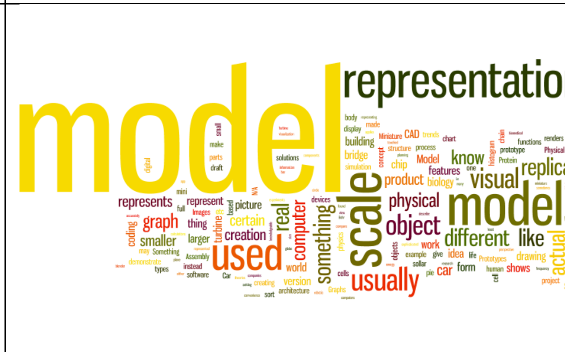
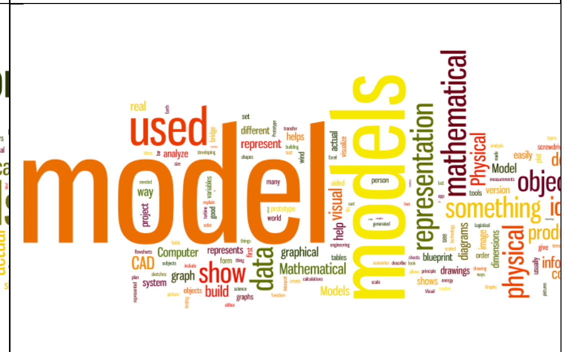
<tr><td>Public School</td><td>
</td><td>
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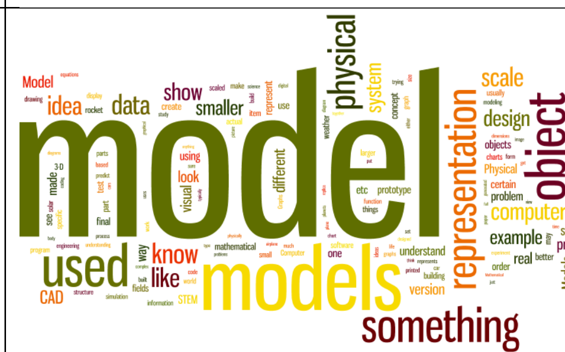
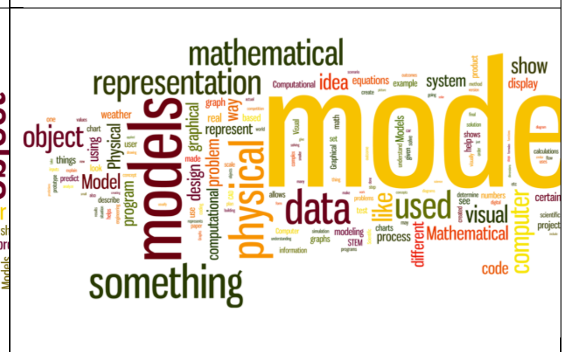
<tr><td>Private School Course 1</td><td>
</td><td>
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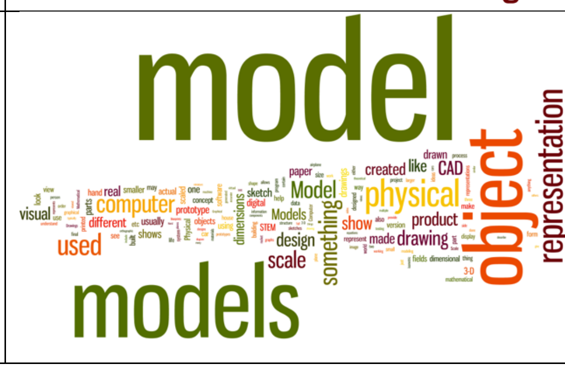
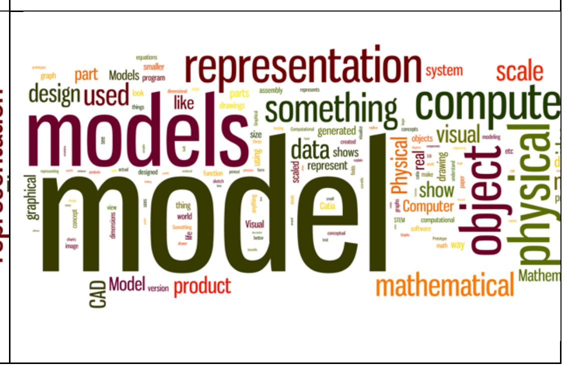
<tr><td>Private School Course 2</td><td>
</td><td>
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References

[1] A. R. Carberry and A. F. McKenna, "Exploring student conceptions of modeling and modeling uses in engineering design," *Journal of Engineering Education,* vol. 103, no. 1, pp. 77-91, 2014.

[2] A. McKenna, R. Linsenmeier, and M. Glucksberg, "Characterizing computational adaptive expertise," in *2008 ASEE Annual Conference and Exposition*, 2008.

[3] J. S. Zawojewski, H. A. Diefes-Dux, and K. J. Bowman, *Models and modeling in engineering education: Designing experiences for all students*. Rotterdam, the Netherlands: Sense Publishers, 2008.

[4] J. Gainsburg, "Learning to model in engineering," *Mathematical Thinking and Learning,* vol. 15, no. 4, pp. 259-290, 2013.

[5] A. F. McKenna, "Adaptive expertise and knowledge fluency in design and innovation," in *Cambridge handbook of engineering education research*: Cambridge University Press, 2015.

[6] R. Lesh, H. M. Doerr, G. Carmona, and M. Hjalmarson, "Beyond constructivism," *Mathematical thinking and learning,* vol. 5, no. 2-3, pp. 211-233, 2003.
[7] A. R. Carberry, A. F. McKenna, R. A. Linsenmeier, and J. Cole, "Exploring senior engineering students' conceptions of modeling," in *118th ASEE Annual Conference and Exposition*, 2011.
[8] H. A. Diefes-Dux, M. A. Hjalmarson, and J. S. Zawojewski, "Student Team Solutions to an Open-Ended Mathematical Modeling Problem: Gaining Insights for Educational Improvement," *Journal of Engineering Education,* vol. 102, no. 1, pp. 179-216, 2013.
[9] H. A. Diefes-Dux, K. Bowman, J. S. Zawojewski, and M. Hjalmarson, "Quantifying aluminum crystal size part 1: The model-eliciting activity," *Journal of STEM Education: Innovations and Research,* vol. 7, no. 1/2, p. 51, 2006.
[10] H. A. Diefes-Dux, M. A. Hjalmarson, T. K. Miller, and R. Lesh, "Chapter 2: Model-eliciting activities for engineering education," *Models and modeling in engineering education: Designing experiences for all students,* pp. 17-35, 2008.
[11] E. Hamilton, R. Lesh, F. Lester, and M. Brilleslyper, "Model-Eliciting Activities (MEAs) as a Bridge between Engineering Education Research and Mathematics Education Research," *Advances in Engineering Education,* vol. 1, no. 2, p. n2, 2008.
[12] H. A. Diefes-Dux and P. Imbrie, "Chapter 4: Modeling activities in a first-year engineering course," *Models and modeling in engineering education: Designing experiences for all students,* pp. 37-92, 2008.
[13] R. M. Clark, L. J. Shuman, and M. Besterfield-Sacre, "In-Depth Use of Modeling in Engineering Coursework to Enhance Problem Solving," in *Modeling Students' Mathematical Modeling Competencies*: Springer, 2010, pp. 173-188.
[14] T. P. Yildirim, L. Shuman, M. Besterfield-Sacre, and T. Yildirim, "Model eliciting activities: assessing engineering student problem solving and skill integration processes," *International Journal of Engineering Education,* vol. 26, no. 4, pp. 831-845, 2010.
[15] A. El-ZEin, T. Langrish, and N. Balaam, "Blended Teaching and Learning of Computer Programming Skills in Engineering Curricula," *Advances in Engineering Education,* vol. 1, no. 3, p. n3, 2009.
[16] H. Fangohr, "A comparison of C, MATLAB, and Python as teaching languages in engineering," in *International Conference on Computational Science*, 2004: Springer, pp. 1210-1217.
[17] C. McDowell, L. Werner, H. E. Bullock, and J. Fernald, "The impact of pair programming on student performance, perception and persistence," in *Software Engineering, 2003. Proceedings. 25th International Conference on*, 2003: IEEE, pp. 602-607.
[18] L. Williams and R. Upchurch, "Extreme programming for software engineering education?," in *Frontiers in Education Conference, 2001. 31st Annual*, 2001, vol. 1: IEEE, pp. T2D-12.
[19] J. McNeil, A. Thompson, and N. Hawkins, "A Comparison of Students Learning Programming with Online Modules, Instruction, and Team Activities " presented at the 2018 ASEE Annual Conference & Exposition Salt Lake City, Utah, 2018. [Online]. Available: https://peer.asee.org/29665.
[20] H. A. Diefes-Dux, J. S. Zawojewski, and M. A. Hjalmarson, "Using educational research in the design of evaluation tools for open-ended problems," *International Journal of Engineering Education,* vol. 26, no. 4, p. 807, 2010.