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Work in Progress: Designing Modeling-based Learning Experiences Within a Capstone Engineering Course

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Introduction

Computational modeling and simulation is a skillset that both academics and industry professionals desire to see in graduating engineers [1]. Additionally, there have been national calls to increase computation within STEM education at all levels [2]. However, currently there are multiple barriers for entry to getting computational modeling experiences into engineering education such as lack of time within courses and a bloated engineering curriculum [3]. In the fall of 2018, a designed modeling-based learning experience, intended to be inserted into already existing curriculum, was piloted in a senior level process design engineering course. This study looks at how students experienced the first iteration of the designed intervention. The research presented here intends to investigate the following research questions: *(1) How can modeling-based learning experiences be designed to supplement a capstone design course? (2) What are students perceived overall advantages of the modeling-based learning experience over traditional instruction?*

Methodology and Research Setting

This study uses design-based research in order to achieve the primary goal of creating effective modeling-based learning experiences within engineering courses. Wang and Hannafin [4] define design-based research as the continuous iteration of a learning design in tandem with educators in order to design instructional environments and activities that are embedded within inseparable context. This method of research differs from other methods in that the instructional context and the instructional intervention are impossible to separate [5]. Thus, an advantage of design-based research is that interventions are studied within their naturalistic setting [6].

Being within a naturalistic setting means that researchers should approach design-based research with the intent of transforming the educational process within a specific context [6]. In this paper, the context is a senior-level capstone course focused on food and pharmaceutical process engineering. The class size was approximately sixty students that met twice a week for a lecture period and twice a week for a lab period. The class had more females than males and the sample was representative of the class as a whole. The course consisted of in-class lecture delivered through discussion of instructor notes. In-class assignments mainly consisted of individual homework, individual design tasks, group projects, and test/quizzes. Lab periods were typically used for either additional lecturing or working on course assignments and projects. This paper reports on the first iteration of the designed intervention.

For this study, students were given assessments of discipline specific and programming content as well as surveys both before and after the designed intervention. Open-ended surveys were designed to capture student experiences with perceived benefits, challenges, and strategies for overcoming encountered challenges. The pre-survey and pre-test were given the first day of the designed intervention and the post-survey and post-test were given in class following the final part of the designed intervention. There were approximately four weeks in between to accomplish the modeling tasks.

Intervention Design

In light of this course structure, our research aims to design modeling-based learning experiences that can be used as a template within multiple different engineering courses and contexts. To do so, we rely on three bodies of literature to inform both the learning and pedagogical design.

Modeling-based learning. The body of literature around modeling-based learning asserts that modeling activities should be broken up into four primary steps: *collection of observations and experiences*, *construction of the model*, *evaluation of the model*, and *revision of the model* [7]. Altogether these four phases allow students to draw on their own experiences, construct a model based on these experiences, evaluate their constructed model, and then revise their construction based on their evaluation.

Productive failure. The pedagogy for our design was informed mainly through productive failure [8], [9]. Kapur and Bielaczyc [8] breaks productive failure into two phases: *generation and exploration of multiple representations and solution methods (RSMs)* and *consolidation and knowledge assembly*. In the first phase, instructors should give students problems that are complex and require multiple assumptions. Students should work collaboratively with little input from the instructor, promoting potential failure. In the second phase, students should compare their solutions with peer and expert solutions, understanding why some solutions are better than others.

Model-eliciting activities. Model-eliciting activities (MEA) are well studied in engineering education [10], [11]. MEAs gave our activity a structured format for the problem design. The structure of MEA activities are based on six principles [10], [12]: *the model construction principle, the reality principle, the generalizability principle, the self-assessment principle, the construct documentation principle,* and *the effective prototype principle*. Altogether, these six principles guide the structure of the activity within our modeling-based learning experience.

Final design. All three of these bodies of literature inform our final learning design, pulling together pedagogical and learning theories while structuring the actual activity into four unique phases. Figure 1 shows how the alignment of these bodies of literature produced the final design.

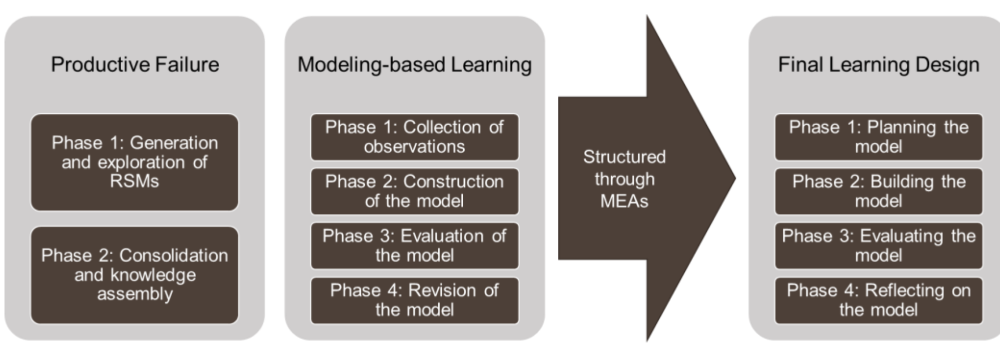

Figure 1. Alignment of theory and practices to produce our final learning design.

The final modeling-based learning experience design consists of four phases. First is *Planning the Model*, where students work together to pull from their experiences and observations of the phenomenon within a group to create and explore different modeling pathways. In this step students develop and document a plan for their model using different mathematical and computational pathways. The *Planning the Model* step occurs largely prior to instruction in the course, giving the students full opportunity to explore different ways to solve the problem. Second is *Building the Model,* where students actually create one of their modeling solution pathways individually. During the *Building the Model* step, students program the model and document their thinking process through a final report and in-code comments. In the third step, *Evaluating the Model*, students meet with their team and other teams to compare solutions in order to identify key differences in how the problem could be solved, documenting the evaluation process. Finally in the *Reflecting on the Model* phase students have an opportunity to review how they solved the problem and what they would do in future iterations.

Preliminary Results and Discussion

The intervention was launched in the fall of 2018 with interesting results. Figures 2 and 3 report on student experiences during the modeling-based learning experience as derived from open-ended post-surveys given to the students after the intervention (n=37).

Students reported high levels of benefit to the *Building the Model* and *Evaluating the Model* phases of the learning design as seen in Figure 2. When explaining why, students reported that these phases were where they obtained actual experience modeling and getting to see other solutions. For example, one student wrote of the *Evaluating the Model* phase: *"Seeing other groups code was great for getting ideas on how to improve mine and do future projects."*

In the *Planning the Model* phase, students felt there was not enough instruction prior to creating their plan. For example one student wrote: *"The initial time we spent in class to plan out steps gave some help, but I didn't really understand the problem until building."*

The phase that was reported least beneficial was the *Reflecting on the Model* phase, where students felt that this phase overlapped with *Evaluation of the Model*. One student wrote: *"I think I saw a lot of what's bad/good during the evaluation part."*

Additionally, Figure 3 shows that students reported during the open-ended post-survey that the biggest benefits to this type of activity were application of lecture material, the hands-on nature of the activity, and the deeper understanding required to apply classrom

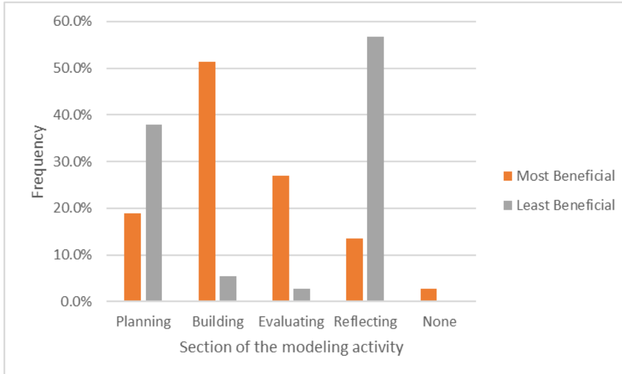

Figure 2. Student feedback on most/least beneficial phase of design. Students could report more than one.

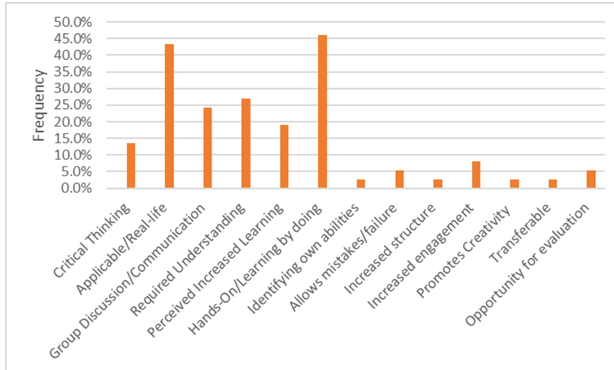

Figure 3. Reported benefits of the learning design over traditional lecture format. Students could report more than one benefit.

learnings. One example of a student reporting the needed understanding for the intervention was a student who wrote: *"You must fully grasp the concepts before being able to use them. So you're forced to truly understand/put more effort in."*

It is interesting that *Building the Model* and *Evaluating the Model* are percieved to be the most beneficial, in that students during these processes may be pushed into cognitive dissonance as their own mental models come into conflict with created computational models. In *Building the Model*, the students original plan may come into conflict with their realization of what is possible during the construction process. Likewise, during the *Evaluating the Model* phase, what students may have percieved as the best solution may come into conflict with what they observe in peer solutions. This interaction between one's mental model and reality during model-based reasoning may lead to learning gains [13]. However, more work is needed to conclude on the matter.

Conclusions and Future Work

The overarching goal of the research is to design a modeling-based learning experience that can be integrated across curricula. Although students generally gave positive feedback for the intervention, there is need for changes to the design of the intervention prior to fall of 2019.

Designing modeling-based learning experiences: The results show that students found both the *Building the Model* and *Evaluating the Model* phases most beneficial. The fourth phase, *Reflecting on the Model*, will need modification to more clearly separate it from the *Evaluating the Model* phase. Additionally, *Planning of the Model*, will need revision to scaffold students more clearly towards correct thinking. By implementing and continuously improving the learning design, we intend to understand how the changes we are making effect student experiences and learning outcomes. This is accomplished by looking longitudinally from semester to semester to understand how both self-reported and performance metrics change from year to year through both descriptive and inferential statistics. Additionally, we intend to take the learnings from this design and implement them into both junior and sophomore level engineering courses. This type of spiral curriculum, with modeling included at every point in the engineering process, may be the best way to incorporate these types of learning experiences [3].

Perceived advantages of the modeling-based learning experience: Students reported that the most advantageous aspects to the modeling-based learning experience were the hands-on nature of the activity, the application of course material, and the deeper understanding required to apply classroom learnings. However, there is continued analysis for the current data, including using thematic analysis to look at student-reported challenges during the activity and strategies students used to overcome these challenges. From there, we can perform cluster analysis to look at how students clustered together as far as their shared experiences during the activity and how those clusters mapped to learning outcomes. This will allow us to understand what reported benefits and challenges align with learning through the modeling experience.

Acknowledgements

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