Exploring How Students Learn Estimation Using a Modelling-based Learning Environment

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Abstract: Estimation is an important class of problems that engineering undergraduates must learn to solve. However, teaching-learning of estimation is under emphasized in the current engineering curriculum and in learning sciences research. In this work, we report on the evaluation of the first cycle of a design-based research (DBR) project to design a technology-enhanced learning environment (TELE) for estimation. The TELE includes a progressive higher order modelling-based structuring of the estimation process, a problem system simulator and metacognitive scaffolds. From a lab study we identified the role of these pedagogical features for doing and learning estimation and changes needed to the design.

Introduction

Engineers routinely make estimates of physical quantities such as power before they begin designing or making (Linder, 1999). In order to estimate a quantity, say power, a solver needs to make a simplified model, i.e., an equation relating power to parameters that significantly impact its value in the given real-world system (Linder, 1999). This is challenging for students because they must apply conceptual knowledge to a real-world system, identify the parameters that will dominate power requirements, make assumptions, quantify inefficiences and make judgements regarding numerical values (Linder, 1999). Thus estimation is an ill-structured problem, very different from the well-structured problems which remain the emphasis of engineering curricula (Linder, 1999). Research has found a marked difference between the estimation performance of expert engineers and graduating engineering students (Linder, 1999). Thus, there is a need to explicitly train engineering students in estimation problem solving. While several researchers (Mahajan, 2014; Linder, 1999) have offered guidelines for learning estimation, these guidelines have not been empirically validated for their effectiveness for learning estimation. This is the motivation for our DBR project to design a TELE for estimation.

Design of the learning environment

The main goal of our TELE is to provide learners a structured approach to reduce the complexities of a real-world problem system and create an equation. It has been found that causal model progression (Sun, 2013), serves as a scaffold to learners in creating quantitative models (equations). So we employed a progressively higher order modelling-based structure (Resier, 2004) to scaffold learners estimation process and get them to build models using appropriate affordances and scaffolds at each stage (Sun, 2013), such as simulations for qualitative modelling (Lindgren & Schwartz, 2009). Research shows that learners must be scaffolded in order to articulate and reflect on their problem solving (Kim & Hannafin, 2011), and question prompts (Ge & Land, 2004) are one way to do so. So we incorporated several question prompts to trigger learners' metacognitive processes. Our TELE is called **M**odelling-based **E**s**t**ima**t**ion **L**earning **E**nvironment (MEttLE) and learners solve an estimation problem by doing five tasks in a non-prescribed sequence (Figure 1): three stages of modelling (functional, qualitative and quantitative), at the end of which they have a simplified equation connecting the quantity to be estimated to the parameters that significantly impact it. There are affordances (such as a problem system simulator) and prompts available for learners to create these simplified models. Then they choose values for parameters, calculate and evaluate the estimate. At each stage, learners are prompted to evaluate and revise their developing models and plan the rest of the estimation. Finally, they reflect on their estimation process. The details of the pedagogical features of MEttLE are described in another paper (Kothiyal & Murthy, 2017).

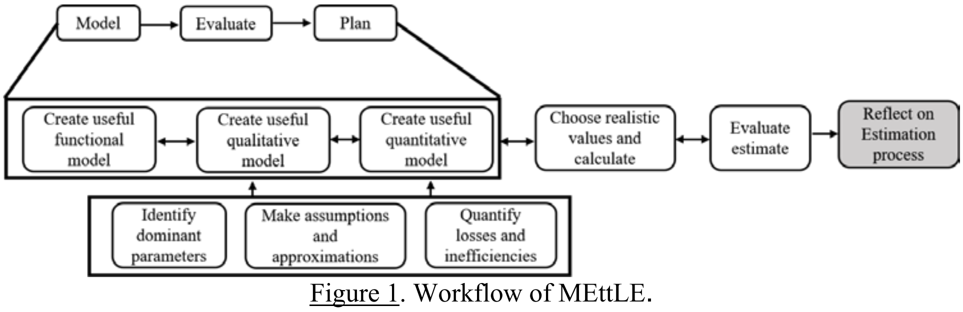

Figure 1. Workflow of MEttLE.

Methods

Broadly, we use DBR to design, evaluate and refine our TELE. Our research goal for the evaluation of the first cycle was to investigate how the pedagogical design of MEttLE supported learners doing of estimation. We performed a lab study and participants were six second year mechanical engineering students selected by convenience sampling. We collected qualitative, multimodal data and applied interaction analysis (Jordan & Henderson, 1995). We used their screen captures and video recordings to create detailed transcripts with annotations of the on and off screen actions done by learners during estimation, along with their explanations of their actions given during the interview. From this transcript, we identified the interaction patterns of learners in MEttLE and then the roles of various features in MEttLE on learners' estimation process.

Findings and discussion

The results showed that learners were able to apply the structured, progressively higher-order modelling-based process in MEttLE and use the modelling affordances and question prompts in order to create and refine models, and obtain estimates correct to the order-of-magnitude. Even though we had no post-test, learners reported during the post-interview that the three-phased modelling-based process was useful and applicable to other similar problems. Further we found that MEttLE supported a diverse set of productive actions which helped learners create models and solve the estimation problem. Finally, we found that the simulator served as a good tool for visualization and qualitative understanding of the problem system (Lindgren & Schwartz, 2009) which scaffolded learners when they lacked conceptual knowledge to build the qualitative models.

We found that the manner in which we structured the estimation process into a set of five tasks, each with two or three sub-tasks, each with a specific goal mentioned in the focus question, scaffolded learners in doing estimation and helped them abstract out the estimation process. As S3 reported, *"I didn't do it before, but you should know the concept what you are actually doing, you should know that before you actually solve the problem, and you should first analyse it qualitatively, like the relationships and all, that's actually one of the most important things to do and if we just look at it as a problem and just go through the quantitative part, that way I don't think it'll be as beneficial as it was today."* Learners followed the path of functional modelling, qualitative modelling, quantitative modelling, calculation and evaluation. If they made errors during modelling, they iterated between the sub-tasks and tasks until they obtained a reasonable estimate. This helped them recognized the utility of the progressively higher-order modelling-based process. Further, since there were five tasks only, all of them to be done in some order, this was a productive constraint that helped learners recognize the sequence that would be useful in solving the problem. This structure (Sun, 2013; Reiser, 2004), along with the reflection, gave learners an estimation process which they perceive to be useful to apply in future problems.

A significant gap that we observed in learners estimation after working in MEttLE was that they were unable to do estimation practices such as identifying dominant parameters, quantifying inefficiencies, making assumptions and reasoning about numerical values. While these practices take time to develop (Linder, 1999; Mahajan, 2014), learners' responses to the question prompts suggest that they need further scaffolds for these practices. Specifically, learners need to understand how to use conceptual knowledge in real-world conditions to make decisions. For this we will introduce guidance regarding expert practice at appropriate points in the pedagogy. This formative evaluation of MEttLE highlights the ways in which the pedagogical features lead to the doing and learning of estimation and what changes are needed to the design to further improve learning.

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