Board 65: Changing Homework Achievement with Mechanix Pedagogy

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Dr. Julie S. Linsey is an Associate Professor in the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technological. Dr. Linsey received her Ph.D. in Mechanical Engineering at The University of Texas. Her research area is design cognition including systematic methods and tools for innovative design with a particular focus on concept generation and design-by-analogy. Her research seeks to understand designers' cognitive processes with the goal of creating better tools and approaches to enhance engineering design. She has authored over 100 technical publications including twenty-three journal papers, five book chapters, and she holds two patents.

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Director of the Sketch Recognition Lab and Professor in the Department of Computer Science and Engineering at Texas A&M University, Dr. Hammond is an international leader in sketch recognition, haptics, intelligent fabrics, SmartPhone development, and computer human interaction research. Dr. Hammond's publications on the subjects are widely cited and have well over a thousand citations, with Dr. Hammond having an h-index of 23, an h10-index of 65, and multiple papers with over 200 citations each. Her research has been funded by NSF, DARPA, Google, and many others, totaling over 9 million dollars in peer reviewed funding. She holds a PhD in Computer Science and FTO (Finance Technology Option) from MIT, and four degrees from Columbia University: an M.S in Anthropology, an M.S. in Computer Science,

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Changing Homework Achievement with Mechanix Pedagogy

Abstract

Introductory engineering courses at large universities often number over a hundred students, while online classes can have even larger enrollments, significantly constraining instructors' ability to differentiate instruction or reteach challenging material. Especially in the case of large enrollment classes, homework assignments often evaluates if students have comprehended a concept through multiple-choice questions, which marking answers as right or wrong with little feedback, or by using online text-only systems. In these scenarios, however, the feedback is often a binary type (right or wrong) with limited constructive feedback to scaffold learning. Set in this context, there is a growing concern amongst engineering educators that student lacks critical sketching skills and the ability to idealize a real-world system as a free body diagram(FBD). A sketch-recognition based tutoring system can allow learners to hand-draw solutions just as they would with pencil and paper, while also providing iterative real-time personalized feedback. Sketch recognition algorithms use artificial intelligence to identify the shapes, their relationships, and other features of the sketched student drawing. Other AI algorithms then determine if and why a student's work is incorrect, enabling the tutoring system to return immediate and iterative personalized feedback facilitating student learning that is otherwise not possible in large classes. Preliminary results using Mechanix, a sketch-based statics tutoring system built at Texas A&M University suggest that a sketch-based tutoring system increases homework motivation in struggling students and is as effective as paper-and-pencil-based homework for teaching method of joints truss analysis. In focus groups, students believed the system enhanced their learning and increased engagement. This project will assess a range of engineering education research questions as well as have a broader impact through its positive impact on at-risk students. To observe the effectiveness of this system for this project, it has been implemented into various courses at three universities, with two additional universities planning to use the system within the next year. Student knowledge is measured using Concept Inventories based in both Physics and Statics, common exam questions, and assignments turned in for class.

Keywords: FBD, sketch, algorithms, Mechanix, engineering, education.

Introduction

In large classes, professors often assess whether students have mastered the concept with conventional methods, but the feedback is mostly binary in nature (right or wrong) and not constructive, which compounds with a rising concern among engineering educators that students are losing both critical skills of the sketched diagram and creating accurate, simplified free-body diagram (FBD). Also, binary feedback tends not to help scaffold learning. Feedback helps learners identify misconceptions and guides the learner to a more accurate conception of the

topic[1]. A sketch-recognition based tutoring system allows students to hand-draw solutions, while also providing iterative real-time personalized feedback.

An advantage of having a freehand sketch-based interface for learning truss analysis and FBDs (Free Body Diagrams) is that it takes the focus off of learning the simulation tool and puts the focus back on learning the concepts behind truss systems. Often, in engineering, physics, and mathematics education, too much time is spent learning how to use the software tools. Students can thus become experts of a software tool while failing to understand the concepts behind the software. It is additionally concerning that there is a lack of emphasis and exposure to freehand technical sketching like drawing FBDs. This situation may create a deficient circumstance where students become less capable and comfortable with graphical communication skills [2, 3].

The main problem with this sketching deficiency for engineering students is the impact on the learned design process. This problem can manifest in several ways. For one, a correlation between freehand sketching and regulated thinking reflects students' understanding of an underlying conceptual structure [4]. This link is especially important for engineers, as complex systems often must be sketched in order to offload working memory and sketching is a standard communication tool. With sketch interface systems, less emphasis is placed on the tool, and more emphasis is placed on the fundamentals of learning. Tools change over time, but the fundamentals do not. Our goal is to produce engineers who understand fundamental concepts, independent of any software tool. Sketches not only return to the fundamental concepts but they also significantly reduce any learning curve associated with traditional toolbar-based, WIMP (Window, Icon, Menu, Pointing Device) programs. This ease of use is important for students in a classroom, but likely even more so to distance education students who often have to teach themselves how to use the software tool. Sketching has other proven advantages to engineering education as well. First, research has shown that the closer a training tool matches a real-world scenario, the more a student learns [5]. Second, engineers and architects prefer the lost art of sketching to computer-aided design (CAD) software tools [6, 7, 8]. Since sketching is the favored method of problem-solving for many professional engineers, building a tool that uses sketching should increase the transference of skills from the classroom to the real world.

Background

In teaching science and engineering, the coordination of visual and verbal is also essential. According to the Dual Coding Theory of cognition [9, 10], the coordination of verbal and nonverbal information helps people to learn because there are separate mutual cognitive channels toward each kind of representation. The observed sketching utilizes two nonverbal channels [9] which were visual learning via the real sketches and kinesthetic learning via the method of sketching. This union will theoretically maximize education. According to the Select-Organize-Integrate model of multi-media learning [11], learners should be actively involved in the method for maximum understanding.

Formative feedback is given to learners amid the learning process and facilities learning, allowing them to adjust their thinking and consider their misconceptions [12]. Homework problems can serve as opportunities for formative feedback. In contrast, summative feedback occurs at the end of the learning process, typically in the form of a final exam. Unfortunately, within higher education, instructors' ability to provide frequent and timely formative feedback is substantially limited due to factors such as class size [13]. Therefore tools, such as Mechanix, can help provide formative feedback by guiding students within the problem-solving process.

While the research on the timing of feedback is complex and often contradictory, a meta-analysis of studies comparing immediate and delayed feedback [14], concluded the overall superiority of the immediate feedback. When feedback is delayed, students may have moved onto new content, and the feedback may be irrelevant to them. The benefit of immediate feedback has been found across many populations, including our target population of undergraduate college students [13].

Mechanix

Mechanix is a sketch-based tutoring system developed at Texas A&M University for engineering students. In addition to allowing allow students to hand-drawn solutions with planar truss and free body diagrams, precisely as they would by pencil and paper, it also examines the student's work against a hand-drawn answer entered by the instructor. Mechanix then delivers instant feedback to the student and saves instructor time, both of which are otherwise not possible in large classes.

Currently, Mechanix can review two different varieties of static homework problems: 1) Free-form free body diagrams, 2) Planar truss problems solved via the method of joints. They have been tested in a classroom situation. Additionally, Mechanix has three distinctive interfaces: 1) the student interface, where the student answers the problem 2) the instructor question creation interface, and 3) the instructor review mode, where the instructor reviews the existing solutions.

Impact of Mechanix on Student Learning

Prior implementation of Mechanix into the engineering curriculum of courses at Texas A&M University (TAMU) in College Station, TX, LeTourneau University (LETU) (a small, private, teaching-focused university) in Longview, TX, Georgia Institute of Technology (GT) in Atlanta, GA, Lovejoy High School in Lucas TX, Cedar Ridge High School in Round Rock, TX, and Judson Early College Academy in Universal City, TX demonstrated its effectiveness for teaching concepts, providing immediate feedback, and saving grading resources [15-29].

While requiring significantly less teacher overhead, Mechanix had similar learning outcomes to traditional paper and pencil homework and the WinTruss software [18-20, 26]. Mechanix was as useful for student learning but provided automatic grading and instant feedback to the students. In Spring 2011 at TAMU, there was a significant increase in homework grades for students using Mechanix. This situation was unique because that section had a high percentage of students who

were at risk for leaving engineering because they either failed ENGR 111 the first time (typically about 25% of the class), were transfer students, were from high schools that did not prepare them well for college so they could not take the ENGR 111 class in fall semester, or were out of sequence for some other reason. Formally testing the impact on at-risk students is one goal of the current project. From the focus groups, it was clear that the students enjoyed the instant feedback from Mechanix and believed it to be a useful tool for learning. One interesting outcome from the TAMU Fall 2012 implementation was that there might be a difference for mastery-oriented versus task-oriented students.

This project will assess the following engineering education research questions:

• Prior research suggests that a sketch-recognition based tutoring system improves homework motivation for at-risk students. Is this the case, if so why, and how does this correlate with physics preparation, majors, gender, and minority status?

• Prior research has shown that a sketch-based tutoring system is at least as capable as paper-and-pencil techniques in controlled comparisons. If more problems are assigned, does learning increase beyond paper-and-pencil, without increasing teacher overhead?

• How can collated visualizations of student submissions and system provided feedback aid with the instructor in quickly identifying student difficulties?

Additionally, this project will also advance the field of computer science through the development of:

• Enhanced AI algorithms that support a full range of problems.

• Novel HTML5-supported client and server-side sketch recognition algorithms are increasing recognition accuracy and speed.

• Real-time visualization algorithms that merge a classroom of student sketched data for the instructor to ascertain student comprehension and specific difficulties immediately.

Research Plan

A sketch-recognition statics tutoring system (Mechanix) will be evaluated in five different courses across five different universities: Introduction to Aerospace Engineering at TAMU, Statics at GT, Statics at LETU, Structural Analysis at Texas State (TXST), and Mechanical Design 1 at San Jose State University (SJSU). Students from over ten different majors will participate in the studies, including Aerospace, Mechanical, Nuclear, Civil, Biomedical, Environmental, and General Engineering along with Industrial Design, Civil Engineering Technology, Construction Science and Management, and Computer Science. At each school, test (Mechanix) and control (paper) scenarios will be performed by the same instructor. In large sections (over 100), we will call for student volunteers to participate, and then these students will be randomly assigned to the control or test scenarios. The other students in the class will be allowed to use Mechanix or not as they wish. In classes with small sections (around 20 students), if the teacher is teaching two or more sections, one section will be randomly assigned to be the test and the other the control, or alternate semesters will be used.

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