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Changing Homework Achievement with Mechanix Pedagogy: A Recap

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Abstract

It is challenging to effectively educate in large classes with students from a multitude of backgrounds. Many introductory engineering courses in universities have hundreds of students, and some online classes are even larger. Instructors in these circumstances often turn to online homework systems, which help greatly reduce the grading burden; however, they come at the cost of reducing the quality of feedback that students receive. Since online systems typically can only automatically grade multiple choice or numeric answer questions, students predominately do not receive feedback on the critical skill of sketching free-body diagrams (FBD).

An online, sketch-recognition based tutoring system called Mechanix requires students to draw free-body diagrams for introductory statics courses in addition to grading their final answers. Students receive feedback about their diagrams that would otherwise be difficult for instructors to provide in large classes. Additionally, Mechanix can grade open-ended truss design problems with an indeterminate number of solutions.

Mechanix has been in use for over six semesters at five different universities by over 1000 students to study its effectiveness. Students used Mechanix for one to three homework assignments covering free-body diagrams, static truss analysis, and truss design for an open-ended problem. Preliminary results suggest the system increases homework engagement and effort for students who are struggling and is as effective as other homework systems for teaching statics. Focus groups showed students enjoyed using Mechanix and that it helped their learning process.

Introduction & Background

Free body diagrams are a core concept in engineering and physics. They are critical to the field of mechanics and often taught in the first physics course a student takes. Understanding how to draw free body diagrams is essential for a student's success in several fields of engineering. Free body diagrams help increase learning by decreasing a problem's cognitive load [1]. Although students need thorough feedback [2] in order to learn properly and not form misconceptions, many introductory classes are quite large and often have hundreds of students in a single class. This situation makes grading a large burden and providing effective feedback in a timely manner difficult. Many instructors turn to web-based homework systems to help students get the feedback they need without as much reliance on the instructor [3].

The use of online homework systems makes it difficult to provide feedback on students' free body diagrams. Online systems typically only check for a final answer and have no way of inputting diagrams. While some instructors require students to upload their diagrams as part of the homework process, the diagrams often receive a low level of feedback or untimely feedback due to the burden of grading hundreds of diagrams. We propose an online system named

Mechanix which requires students to draw their free body diagrams in a browser and helps students receive immediate feedback about their diagram.

There are other systems for physics tutoring such as the Free-Body Diagram Assistant [4], Andes physics tutoring system [5], and Conceptual Helper [6]. These systems do not use hand-drawn diagrams, but instead use computer-aided drawing tools to create diagrams. These tools can be cumbersome to use at times and also have their own learning curves. There are also sketch-based systems such as Newton's Pen [7], [8] which requires some specific hardware, or COGSketch [9], which grades sketches based on geometric relationships such as "above" or "below". The goal of Mechanix is to provide feedback on free body diagrams for statics classes without the need for any specific hardware.

Development of Mechanix

Mechanix was developed as a web application so it can be easily used by students on almost any device. Students hand-draw diagrams using a stylus, mouse, or finger. Mechanix utilizes sketch recognition algorithms to recognize the student's diagram as the first step of every problem. An example of the interface is shown in Figure 1.

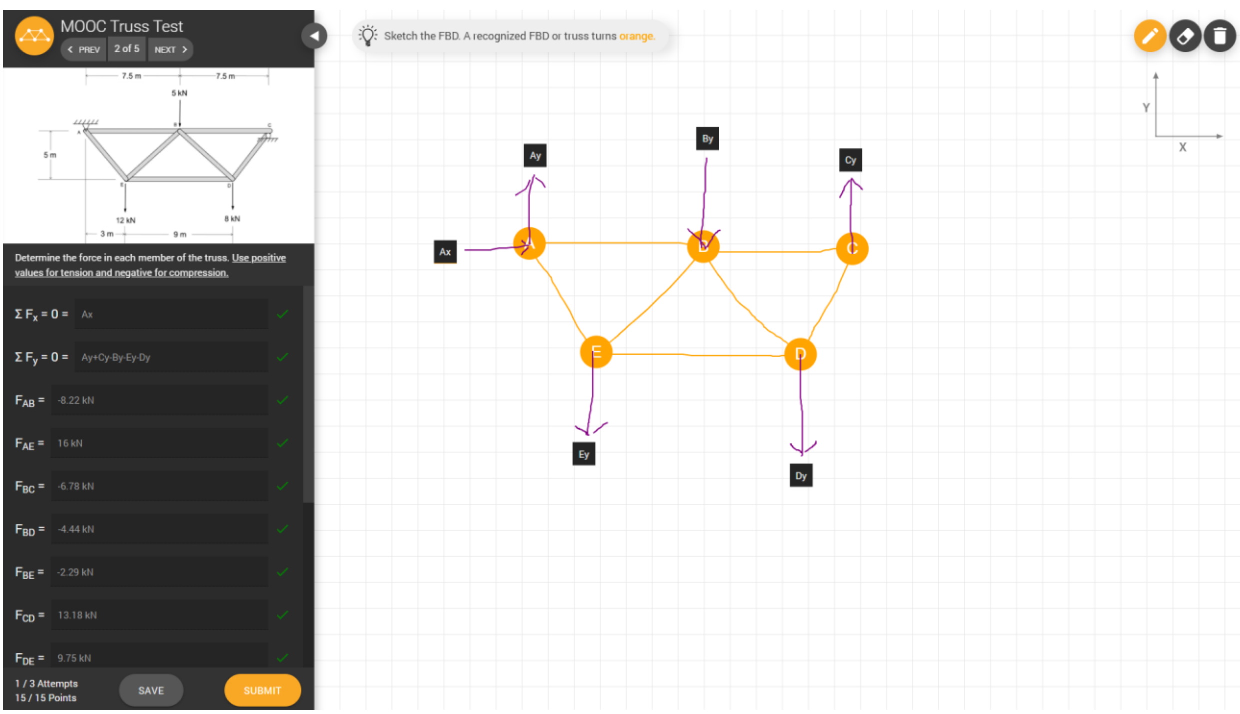

Figure 1: Example of the Mechanix interface while solving a problem

Mechanix requires an instructor diagram to be drawn as the comparison point for student diagrams. Multiple sketch recognition algorithms are used to recognize different parts of the sketch as the student completes the problem. The student draws the body first and then any forces acting on the body. Diagonal forces are automatically broken into their component forces along the cartesian axes. Students may label their forces anything the want, and a corresponding input box will be added in the side panel.

The answer inputs allow free text entry for the students. Any answer with units expects the student to input units. The student may input any unit as long as it is the same type of unit (e.g. kilonewton, newton, and pounds force are all units of force, but pascals is a unit of pressure). There are also some provided inputs for summation of forces. These require students to use their assigned force names to write the sum of forces equations in terms of variables. Once the student submits their answer, they receive feedback about if their answers are correct as well as guidance on some mistakes such as having too many forces, forgetting units, or flipping a sign. The answer checker takes the direction the student draws each force into account when checking the validity of their answer, so a student may put an equal but opposite force as an accepted answer.

Mechanix also includes support of open-ended truss design problems. This creative design mode gives students a set of constraints for designing a 2D truss bridge. The typical constraints are an acceptable range for the length of the bridge, a maximum tension and compression force each truss member can support, and a minimum total load requirement. The students must draw their design and then Mechanix displays inputs for each angle and beam length. While students fill in their dimensions, Mechanix automatically fills in missing dimensions, as possible, based on the lengths and angles given. Once submitted, Mechanix takes the student's inputs and solves the truss described for all internal forces. Feedback is then provided if the truss does not meet any of the requirements. A more in-depth explanation of how Mechanix works is provided in [10].

Research Design

Mechanix has been used by over 1000 students across five universities over a six-semester period. This group includes students in an Aerospace Engineering statics class at Texas A&M University, Mechanical Engineering statics classes at Georgia Institute of Technology and LeTourneau University, a Construction Science structural analysis class at Texas State University, and a Mechanical Engineering dynamics class at San Jose State University.

The students were assigned surveys to assess baseline knowledge during the first week of classes. The students took a statics concept inventory [11], an abbreviated force concept inventory [12], engineering design self-efficacy survey [13], and a demographic information survey. In the dynamics class, students also completed an abbreviated dynamics concept inventory [14]. At the end of the semester, students once again completed the statics concept inventory, force concept inventory, and engineering design self-efficacy survey.

During the semester, students were randomly assigned to either the experimental group or control group. The experimental group used Mechanix for one to three homework assignments during the semester while the control group used the usual homework system for the class. The homework assignments consisted of general free body diagram problems, method of joints truss analysis problems, method of sections truss analysis problems, and an open-ended truss design problem. For the open-ended design problem, students were tasked with designing a bridge to meet certain requirements. Students were also given a common exam problem across the universities as another method for gauging student learning.

Results

Mechanix has been used for six semesters across five universities by over 1000 students. Student homework scores were analyzed to determine if Mechanix had any effects on student homework success. Overall, students who used Mechanix performed similarly to the students who did not use Mechanix when limited to three graded attempts. In at least one instance, students using Mechanix performed significantly better than those not using Mechanix, and students using Mechanix never performed worse than those not using Mechanix. A more in-depth analysis can be found in [15].

The open-ended truss design problem was also analyzed to determine how students performed compared to students completing the assessment on paper. Students in the Mechanix group submitted more design iterations and their solutions trended towards higher total loads than the control group [16]. Focus groups with students revealed that students found Mechanix fairly easy to use, felt it allowed them to iterate quickly, and enjoyed the challenge of the design problem [17]. This type of problem is time consuming to grade for paper submissions, and the teaching assistants grading these control problems actually used Mechanix to check the loads of the paper submissions.

Conclusions

Overall, we have found Mechanix to be a helpful tool in the classroom to help reduce the burden of grading while providing feedback on student free body diagrams. As such, instructors using this system are able to provide students with feedback based upon scaffolded learning theories and have their homework assignments automatically graded for approximately the same amount of effort needed to set up a homework assignment in any online homework system. Further, Mechanix allows instructors to assign and grade open-ended problems, which would normally require a significant amount of grading time due to the possibility of each submission being unique, with a similar amount of effort required for problems with a single solution. Students and instructors both seem to enjoy using Mechanix and students perform at least as well on Mechanix as other homework systems with the added requirement of drawing their free body diagrams.

Acknowledgements

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