AC 2012-4854: MECHANIX: THE DEVELOPMENT OF A SKETCH RECOGNITION TRUSS TUTORING SYSTEM

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Mechanix: The Development of a Sketch Recognition Truss Tutoring System

Abstract

Mechanix is a sketch recognition tool that provides an efficient means for engineering students to learn how to draw truss free-body diagrams (FBDs) and solve truss problems. The system allows for students to sketch these FBDs, as they normally would by hand, into a tablet computer; a mouse can also be used for regular computer monitors. Mechanix is able to provide immediate and intelligent feedback to the students; it tells them if they are missing any components of the FBD. The program is also able to tell students whether their solved reaction forces or member forces are correct or not without actually providing the answers. Mechanix also has a checklist feature which appears in the same window as the program, it guides the students through the problem and automatically updates as the student progresses and solves each part of the truss problem.

This paper presents a study to evaluate the effectiveness and advantages of using Mechanix in the classroom as a supplement to traditional teaching and learning methods. Freshman engineering classes were recruited for this experiment and were divided into an experimental group (students who used Mechanix in class and for their assignments) and a control group (students who were not exposed to Mechanix). The learning gains between these two groups were evaluated using a series of quantitative formal assessments which include concept inventories and homework, quiz, and exam grades. Qualitative data was also collected through focus groups for both groups to gather the students' impressions of the programs for the experimental group and general teaching styles for the control group.

Due to some issues with the server that runs Mechanix, the students were not able to properly use Mechanix during the in-class evaluations. We believe that this caused the results to show that there was no change in the homework and concept inventory scores between both groups for the current evaluation. However, the results show that Mechanix is a capable tool for enhancing students learning and performance in exams. The focus group discussion showed that the students really liked the program; they mostly appreciated the instant feedback and they said that Mechanix motivated them to move on to more problems when they saw that they had successfully solved the previous ones.

Introduction

The Mechanix software is an innovative and efficient computer-based educational tool developed to teach engineering students the fundamentals of truss mechanics and design. It provides a visual aid for students to solve problems and it is able to guide (tutor) them through the process of solving a truss design by providing immediate and intelligent feedback and guidance.

The objective of this project is to evaluate and improve on the Mechanix program while measuring its effectiveness for student learning. This will be done through both quantitative and qualitative means with freshmen students at Texas A&M University. An experiment will analyze the effects of Mechanix on both short-term impact and longer-term retention measured through homework assignments, exam questions and pre/post concept inventories. Results from the most recent and third overall evaluation of Mechanix, as well as plans for future evaluations, are presented.

Prior FBD and Truss Software

There are other statics tutoring programs that already exist; these tools help students to solve their problems step-by-step and provide them with feedback about their steps. At the same time, none of them offer an opportunity for students to solve the problem completely by themselves; all of them provide the students with partial solutions and ask them to determine some missing values, force directions, or calculate the failure point. They also provide feedback whether the students' answer for the missing part is correct or not. None (but Newton's Pen[1]) evaluate the student's sketch of a FBD. Some of the existing software are discussed below.

The Andes physics tutoring system [2] was designed with similar goals to Mechanix. The Andes interface mimics pen and paper homework while providing extra features like immediate feedback. Similar to Mechanix, Andes was intended as a drop-in replacement for pen and paper homework to support the current physics curriculum. Andes is not a sketching application; instead, students use a palette of tools to place graphical objects on the screen with the mouse. Once a graphical object is placed, the student is prompted with a dialog they must fill out to provide extra information about the object. Mechanix improves on the Andes system by letting users draw shapes instead of selecting them from a palette and dragging them around with a mouse. The Open Learning Initiative offers problems in which students are asked to identify the various parts whose free body diagrams are to be created, but offers no interface for the student to create the FBD. Mechanix also allows students to add metadata to shapes at their own pace instead of prompting them each time a new shape has been drawn.

WinTruss [3] allows students to draw trusses using a set of pallet tools and it solves for forces in the members and shows truss deformation under a load. At the same time, Mechanix offers an interface for the students to draw their own free body diagrams, place the forces and couples or reaction forces at the required locations and solve the problems completely by themselves as they do on paper. As in other tools, it also provides feedback on students' answers so that it maximizes their learning experience. Instructors also control how much feedback and guidance is provided by Mechanix.

The VaNTH ERC Free Body Diagram (FBD) Assistant [4] provides instant feedback to students practicing free body diagram and statics problems. The FBD Assistant was designed to be integrated into the courseware suite at Vanderbilt University, which makes it very easy for professors to incorporate into the curriculum. The FBD Assistant, like Andes, provides a tool- and dialog-based diagram creation environment that the student must first learn how to use before they can attempt to solve a problem. The goal of Mechanix's sketch recognition design is so that students do not need to learn how to use the software; they can focus on learning the engineering concepts required to solve the problems.

Newton's Pen has a very similar approach to Mechanix in that it allows the student to make a sketch in order to solve statics problems. This software relies on a particular digital pen and input technology, constraining the user to draw the sketches in a very particular way and order. Mechanix, on the other hand, offers true free sketching, meaning that its recognition capabilities is independent of the order in which the student draws the component of the sketch solution.

Mechanix

Mechanix is a sketch recognition program developed at Texas A&M University. With Mechanix, students are able to directly sketch a truss free-body diagram (FBD) onto a computer tablet using a smart pen; they can also sketch the FBD with a mouse and a standard computer monitor. Mechanix features two operating modes: the Instructor mode and the Student mode. When the students use the program, they are operating in the Student mode. As the student sketches the FBD into the program, Mechanix is able to automatically detect and label the nodes of the truss as the instructor entered it. The student then draws an axis and proceeds to solve the problem as he/she would by hand, i.e. labeling the FBD with input and reaction forces, etc. The student's ability to draw their own sketch mimics the procedure that is taken when drawing a sketch on paper, which is the traditional way of solving truss problems, this makes it is easier for the student to transition back and forth between Mechanix and traditional truss solving methods. Figure 1 shows a student using Mechanix.

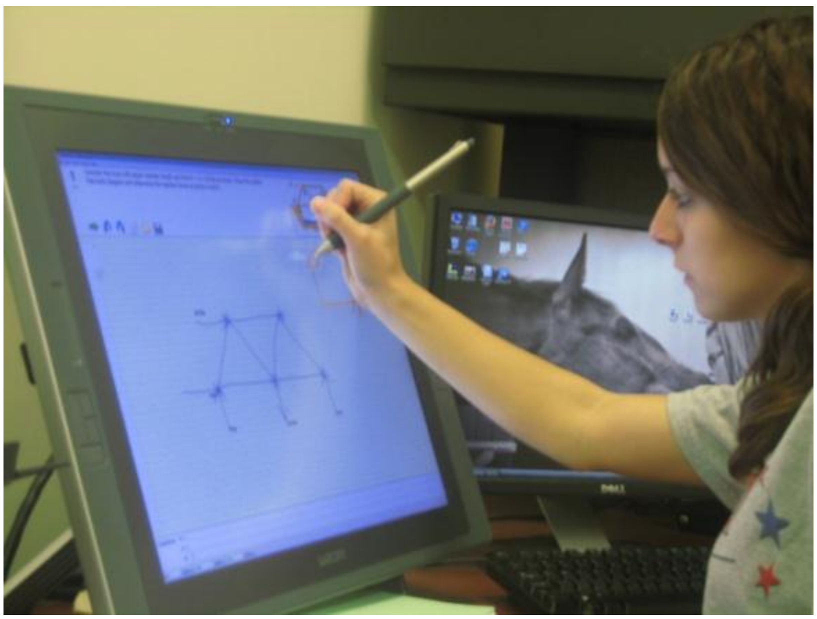

Figure 1: A Student Sketches a Truss FBD into the Mechanix Program

Mechanix also provides instant feedback to the students through a checklist window (Figure 2) that appears with each problem, and dropdown feedback messages. The instant feedback feature of Mechanix is one of its most important and outstanding features. The checklist acts as a guide for the student and provides a list of steps to follow to solve the problem. Figure 2 also shows an example of the view in Student mode as the student is solving the problem. The student can click on the large green checkmark in the upper right of the Mechanix screen to check whether his/her answer is correct. As shown, the student has incorrectly labeled the input force at node C (11 lbs instead of 10 lbs) and Mechanix has alerted the student in the checklist and also in the dropdown feedback message which is in orange at the top of the screen. Mechanix does not provide the answers to the students, but it is able to tell them if their answers are correct or incorrect.

With these hints/messages, the student can correct his/her mistakes. After the appropriate corrections are made, the student can continue solving the problem by labeling the reaction forces at nodes A and E. As the student labels these reaction forces, input boxes at the bottom of the Mechanix window appear where the student can enter the force value and select units. Figure 2 shows the answer boxes for the reaction forces, the student can also enter the force summation and moment equations at the bottom of Mechanix window and shows a message that tells the student that the force values have not been entered. After the student has solved and entered the values for the reactions forces, the solution can be checked again by clicking on the submit button (green checkmark). Figure 3 is the screen that the student sees when the problem has been successfully and correctly solved.

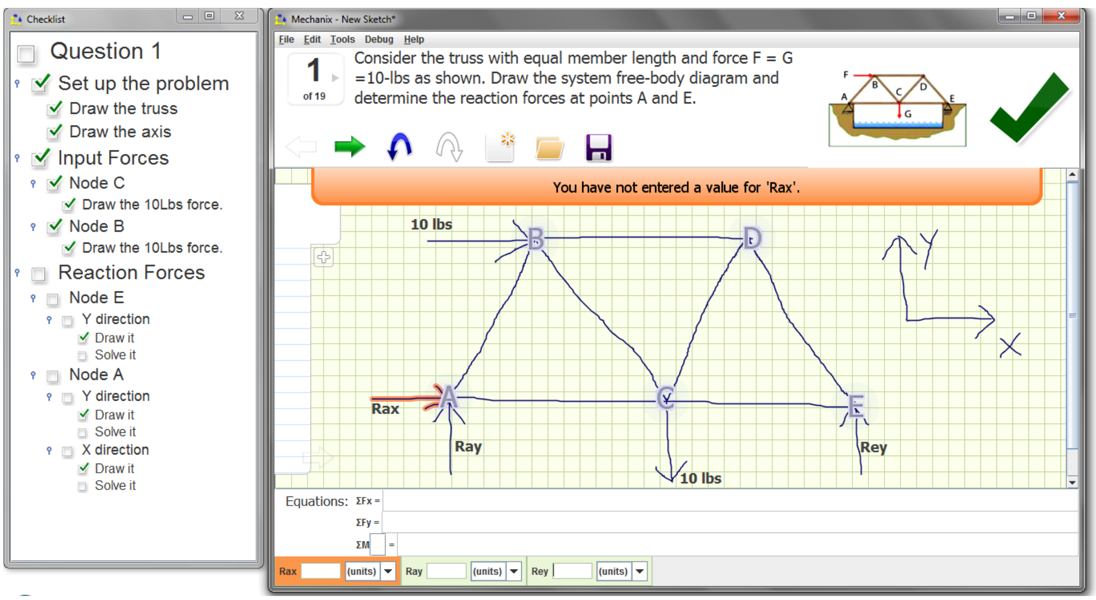

Figure 2: Sample Problem in Mechanix showing the Checklist window, the Dropdown Feedback Message and where students can enter their solutions to the truss problem

An advantage of Mechanix over existing statics tutoring software is that each time the student checks their answers by clicking the submit button, Mechanix saves the submitted drawing and also the feedback message generated by the system at that point in time. This is very helpful to both the student and the instructor, because when the instructor goes to grade the assignment, they can tell what aspects of the problem the student is having trouble with. If a lot of students seem to have trouble with the same concepts, the instructor is able to go to class and spend more time explaining that particular concept. The instructor can also create a completely new problem set without the need of any programming skill, he/she will use an interface similar to that of the student, there they can input the text and images of the problem set, draw the expected sketch, and fill in the correct solution values. Giving the instructor the tools they need to review the students' progress and create new content based on that the overall system provides a means to optimize instructional needs of the classroom.

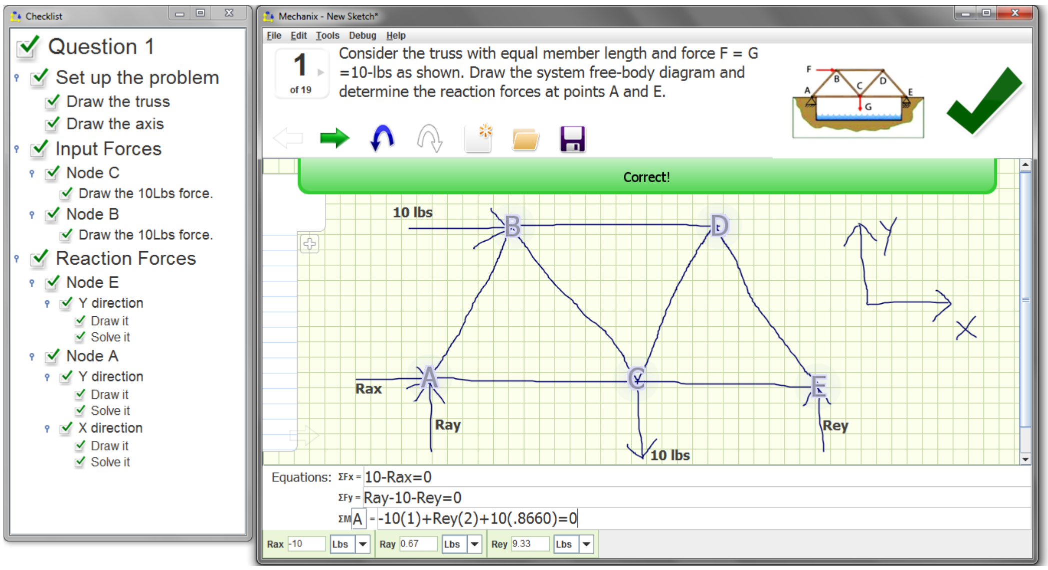

Figure 3: Correctly Solved Problem in Mechanix

Method

Evaluation of the truss module of Mechanix occurred by testing the program within an authentic classroom setting. Short-term and long-term learning gains were measured with homework, exam questions, and concept inventories. Students were recruited from the same class with the same instructor. Additionally, the collection of qualitative data in the form of a focus group supplemented quantitative results and provided for more thorough intepretation. In this section, the current evaluation of Mechanix is discussed.

Participants

Recruitment occurred from an undergraduate engineering class typically populated by freshman students (age 18-19). This engineering class introduces students to Newton's laws, statistics, basic graphics skills and CAD tools, and lasts for 2 hours each class period. Students were recruited from two sections of this course: an honors section and a regular section. Current class sizes are 70-100 per section with 5-7 sections per semester. Students were informed that they were participating in a study to evaluate a particular teaching technique; however, they did not receive information about the individual techniques. The students were randomly assigned to the two conditions, a control and a Mechanix condition. Thirty-six students from the honors section (which is a smaller class) and 86 students from the regular section were recruited. These students received extra credit for their participation.

Research Conditions

The students were randomly assigned to two conditions: (1) traditional condition (control) which included students that were not exposed to Mechanix to use for their homework and to study for exams and (2) a Mechanix condition which included students who were exposed to Mechanix and used the program to submit their homework and to study. For the honors section, 17 out of the 36 recruited students were assigned to the Mechanix condition and 19 were in the traditional condition; for the regular section, 41 students were assigned to the Mechanix condition and the remaining 45 students were in the traditional condition.

Evaluation

The same instructor presented lecture materials for both sections to eliminate teacher effects, and all students were assigned the same homework problem sets and exams. For both sections, the in-class evaluation sessions occurred three times; all students started class together and learned course related materials for the first hour from a traditional lecture. For the second hour the students in the different condition were split up. For the honors section, the students in the traditional condition remained in the classroom with a teaching assistant (TA) while the students in the Mechanix condition were moved to another classroom in the same building where the Mechanix program had already been setup on the computers there. For the regular section, the Mechanix students remained in the classroom, while the students in the traditional condition were moved to another room. The Mechanix students also had a TA available to them. Graduate students from the Computer Science department who helped to create Mechanix were also on hand to help students in the Mechanix condition with any issues that they might encounter while running and using the program.

The students in the traditional condition worked individually on their homework during this time. The students wrote their answers while manually drawing necessary diagrams for the solution. They received no immediate feedback or guidance from the TA. Their work was collected at the end of each session, graded and returned to them in about a week.

In the Mechanix condition, instead of using the traditional method to solve their homework problems, the students used Mechanix. They drew their solutions with the sketch software on tablet monitors and received immediate feedback for accuracy through the program. To maintain equal lengths of intervention, these students had time for training to use the software. The first ten minutes of the first meeting time was used to explain how to use the program. The software captured and recorded each student’s attempts, feedback, and solutions as they worked through the process towards a solution. The students in the Mechanix condition were also given the option of turning in their homework by hand if they did not want to use the program.

It is important to mention that during evaluation sessions the Mechanix program encountered some server issues during the second evaluation. During this time, the server crashed and the students were unable to use Mechanix or submit all of their homework with the program. For this session , the students submitted a few problems through Mechanix and the rest traditionally, by hand.

Measures

Open-Ended Exam Problems. On the first exam which occurred after the Mechanix in-class sessions, one open-ended problem was created to measure long term learning gains. Much research indicates that the benefits of visual-aided learning differ when being measured in short and long term learning conditions [5].

Standardized Concept Inventories. Two standardized measures, Force Concept Inventory [6] and the Statics Concept Inventory [7], served as both a pre- and post-test to measure learning gains. Both inventories cover a broad range of topics on concepts relevant to trusses. Only results from relevant topics on each inventory are shown in the results section.

Focus Group
Three weeks after the last Mechanix in-class evaluation session, a focus group was conducted to fully explore the students' perspectives on the program. Students were invited to participate in a focus group which discussed their experiences in using the sketch software program.

Results

The analyzed data from the homework, exams and concept inventories are presented in this section; findings from the focus groups and our interpretation of information collected are also presented. Because of the server problem that was encountered during the evaluations, not all of the Mechanix students were able to complete their entire homework with Mechanix; therefore the data was also analyzed for the students who completed at least 50% of their homework on Mechanix (this group is denoted as Mechanix – 50% in the plots).

Homework Results

Five homework sets were assigned; the first two homework sets were submitted the traditional way (on paper) by all groups. The last three homework sets were completed when the students had been assigned to their experimental groups. Generally, there was no significant difference on homework grades between the groups (Figure 4 shows the results of the homework scores for the regular section, the honors section showed similar results). This is somewhat surprising given that the Mechanix group receives feedback. Previous evaluations of Mechanix [8] show that students in the Mechanix condition performed significantly better in the homework than students in the traditional condition. The inconsistency between these results is likely due to the server problems that were experienced by the students.

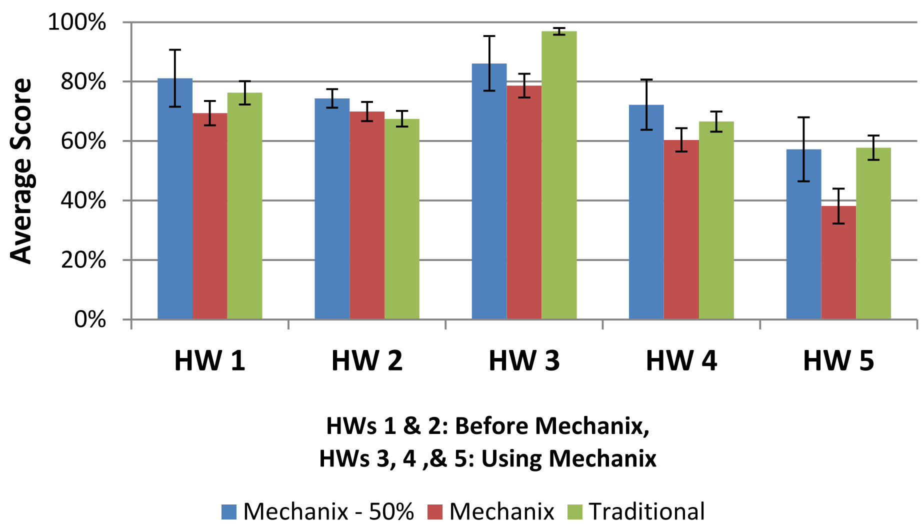

Figure 4: Homework Results for students in the Regular Section

Open-Ended Exam Problem Results

The open-ended exam problem result is shown in Figure 5; the problem was scored out of a possible 20 points and was based on finding the external and internal reaction forces of a truss. For the honors sections, we can see that the students in the Mechanix – 50% group performed significantly better than the students in both the Mechanix and traditional condition. For the traditional section, this trend is the same, the students in the Mechanix – 50% group performed significantly better than both of the other groups. Comparing the Mechanix and Traditional groups alone for both sections shows no significant difference in their performance. These results show that the students most exposed to Mechanix had more learning gains; which were evident in the performance in the open-ended exam question. This shows that Mechanix has the potential to improve students' performance in truss and FBD related problems.

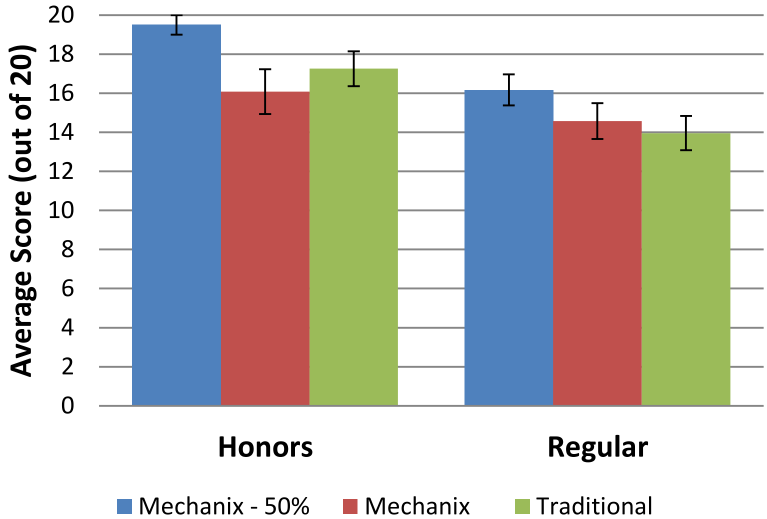

Figure 5: Results for Open-Ended Exam Problem for both Class Sections

Force Concepts Inventory Results

The Force Concept Inventory consisted of 30 questions that were designed to access students' knowledge of Newtonian concepts (these include: kinematics, first, second and third law, superposition principles and force types).

From Figure 6 and Figure 7 we can see that though there is no significant improvement in the students' scores from the pre to post test when we compare the three groups.

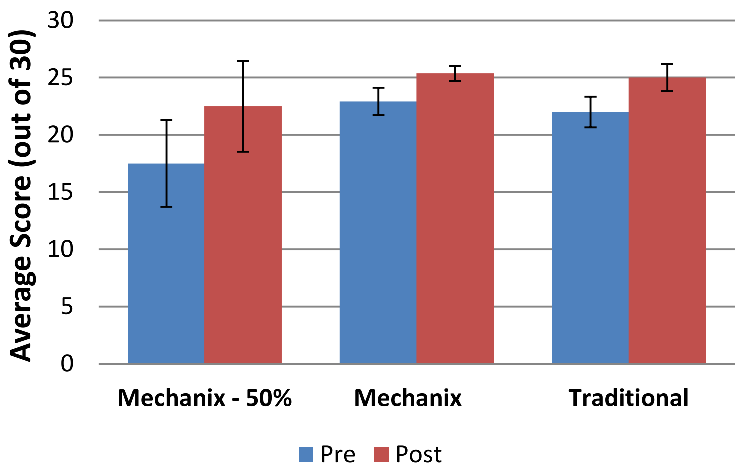

Figure 6: Pre- and post-Force Concepts Inventory Results for the Honors Section

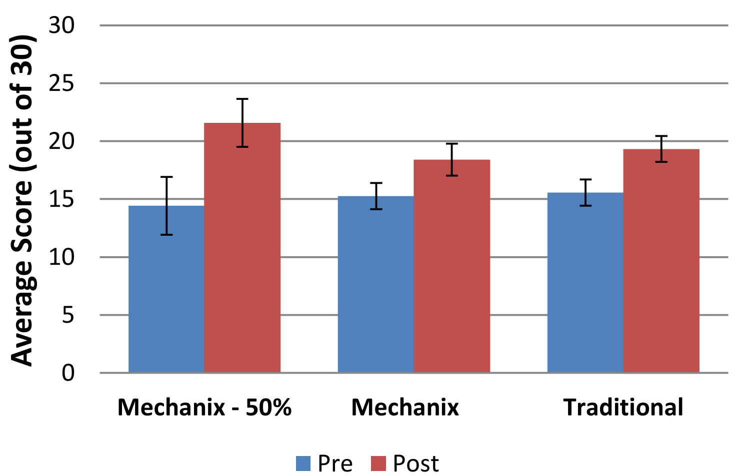

Figure 7: Pre- and post-Force Concepts Inventory Results for the Regular Section

Statics Concepts Inventory Results

The Statics Concepts Inventory questions were designed to probe the students' ability to use fundamental engineering statics concepts in isolation and to identify typical student conceptual errors [7]. The students were tested on the same questions at the beginning and at the end of the semester (pre- and post-). Figure 8 and Figure 9 show the percentage increase in performance for all three groups for the honors and regular sections respectively.

To measure Mechanix's influences on this data, we will take a closer look at the performance of the students on each particular type of problem and compare that to concepts that Mechanix can improve or measure which are the FBD, Roller and Slot Concepts. Figure 8 shows us that for the Mechanix students in the honors section, there is no significant improvement in their performance and understanding of these concepts, when we compare the Mechanix – 50% student and the Mechanix students to the students in the Traditional condition. For the students in the regular section, we can see from Figure 9 that the Mechanix – 50% students improved significantly compared to the other students only for the FBD concept questions; there was no improvement for the other concepts.

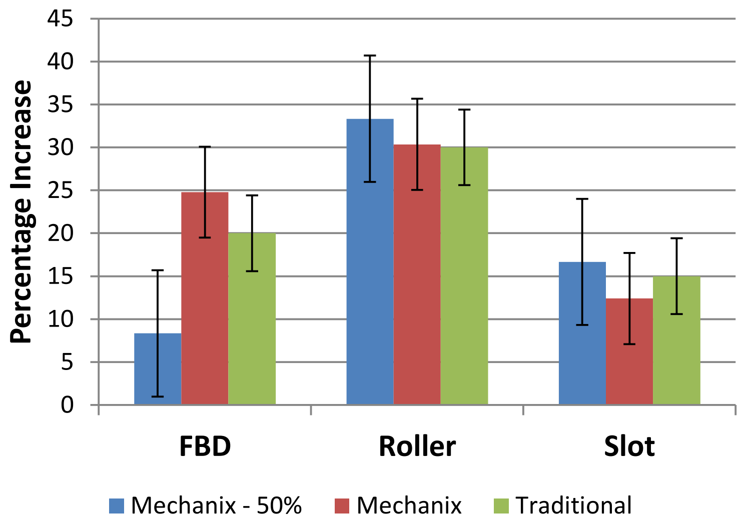

Figure 8: Percentage Increase in Performance of Students in the Honors Section for the FBD, Roller and Slot Concepts

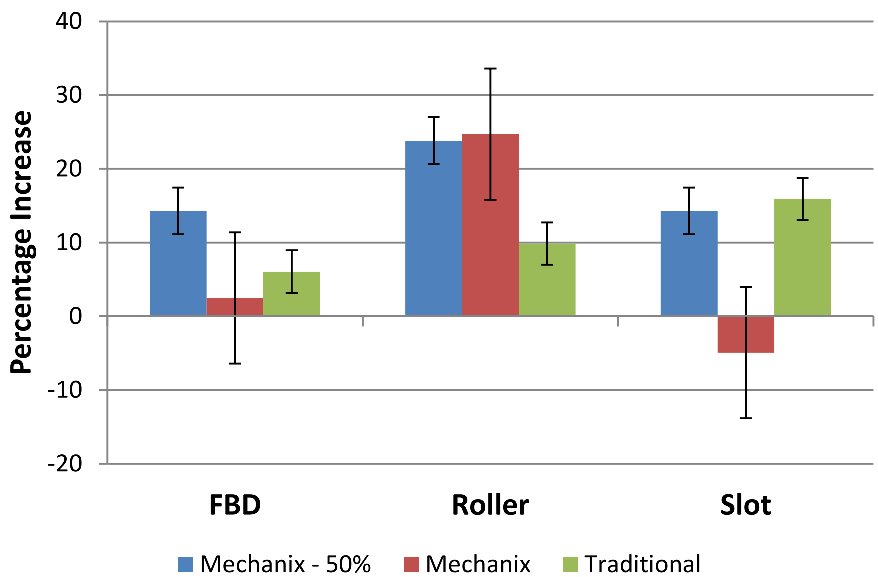

Figure 9: Percentage Increase in Performance of Students in the Regular Section for the FBD, Roller and Slot Concepts

Focus Group

The purpose of the focus group was to gather the students' initial impression of using Mechanix for truss diagrams and homework assignments, the focus group was aimed at diagnosing potential problems that the students encountered while using the program for future improvements on the program. Three separate focus groups were done on back-to-back days, and a total of 27 students attended. Attendance was voluntary and the students received extra credit for their participation. There was also a focus group done for students in the traditional condition, this allowed them to also earn extra credit, the aim of this focus group was to gather the students' opinion about the overall class. The data for the Mechanix focus groups is presented in this section.

The facilitator presented questions to students and encouraged discussion; the results of these discussions are presented below:

1. What did you feel was the purpose of the Mechanix software?

Most students understood that Mechanix is a program that helps with homework and allows you to receive your results back quickly. They said that it was a "teach as you go" program and that they appreciated that Mechanix was interactive and showed them what steps to take as well as provided them with immediate feedback when they made mistakes. They said that it sort of forces them to review their mistakes because not all of them would normally do so when they received their handwritten homework back; they liked that Mechanix gave them an incentive to correct their mistakes now. Some students said that they first saw Mechanix as a learning tool, but because of the recognition and server issues that they experienced while using the program, they now saw it as a homework checker.

Our Interpretation: There was an overall appreciation for the fact that Mechanix provided them with feedback in real-time. They felt that it was progressive and moving towards a more interactive, electronic, instant feedback model in education. We understand that they had some frustrations with using the program because of the server issues which caused it to crash. This issue has been successfully resolved and should not cause any problems for future evaluations.

2. How does the experience of solving problems on Mechanix compare with solving them on paper?

The students were really impressed by the truss recgonition capabilities of Mechanix. They however said that the arrow recognition for the axes was a little frustrating and that they had to draw their arrows a few times for the program to recognize it. Most students did not have any trouble with the truss itself being recognized. Some students said that they preferred using paper to using Mechanix because of some of the problems they had with the program, i.e server problems. Some students said that they would like to see Mechanix be able to help them with internal force calculations and not just the reaction forces, they said they had to do the internal forces by hand and would like to be able to do everything in Mechanix. They liked that truss and arrows had different colors.

Our Interpretation: The students would enjoy using Mechanix more if the arrow recognition was improved. This is currently being addressed and after the focus group we decided to recruit students to help us draw various arroes so that the programmers could get a better understanding of how different students, including right and left-handed studetns, draw their arrows. The students received payment for their help with the arrow study. The arrow recognition is being worked on and should be ready in time for future evaluations.

3. What benefits and/or hinderances did Mechanix provide for learning trusses

The students said that Mechanix helped them to remember to draw all the components of the truss; they said that Mechanix helped them to learn the proper way to set-up the program and the correct step-by-step procedure for solving a truss. A few students said that Mechanix was the reason that they remembered to draw axes while solving trusses, this helped them in their physics classes. The students expressed that the newness of the program made it fun to use and it encourage them to get the right answers. They said that it encourages them to move on to the next program when they see that they have got the previous one right. They said that the checklist was very helpful. The students also mentioned that they would like to see more help resources such as online forums and a video tutorial tied in to the program. They did mention that the program was easy to use and had a very low learning curve. As for hindrances with using the program, some students said that they sometimes had some trouble saving their work and would have to start over again if they closed the program.

Our Interpretation: The students showed a lot of interest in using Mechanix and it helped them to learn how to solve trusses, it also encouraged them and gave them an incentive to move on to new problems. The hinderances with using the program, especially the not being able to save issue, is server related and is being addressed.

4. How did they find the feedback? What was most useful?

The students really appreciated the instant feedback that they received. They said that it will be more helpful to them if Mechanix showed them all the errors or problems with their truss all at once instead of one at a time.

Our Interpretation: The students liked the feedback they received but would like more thoroughness. This is something that we will work on for future versions.

Conclusions

Results from the open-ended exam problem, show that Mechanix is a tool that has a great potential to increase students' learning and understanding of FBD and truss problems. Though the statics and force concepts inventories show that the students in the Mechanix experimental condition did not perform significantly higher or improve their learning, we believe that this is due to the fact that the students encountered a few issues during the evaluation period. We believe that the problems with the server crashing caused the data that we collected to not be as robust as previous evaluations of Mechanix.

Previous evaluations on Mechanix as seen in Atilola, et al. [8] show that Mechanix is a tool that improves homework scores significantly. Data from Atilola et al [9] also shows that statics and force concepts performance is also increased for Mechanix students in FBD, roller and slot concepts. These previous evaluations were done in an environment where Mechanix had very few issues or bugs.

The focus groups were very helpful in learning the students' impression of the program. The students mostly appreciated the instant feedback that they received for their homework problems; they said that Mechanix made them want to do more problems because they knew instantly that they were solving the problems successfully. There were some concerns about the program not properly recognizing their arrows, but this issue is currently being addressed.

Future evaluations of Mechanix will occur on the Texas A&M campus as well as other college campuses outside Texas A&M system.

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