



Mechanix: Evaluating the Effectiveness of a Sketch Recognition Truss Tutoring Program against other Truss Programs

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Abstract

Mechanix is a sketch recognition program that was developed at Texas A&M University. Mechanix provides an efficient and effective means for engineering students to learn how to draw truss free-body diagrams (FBDs) and solve truss problems. The Mechanix interface allows for students to sketch these FBDs, as they normally would by hand, into a tablet computer; a mouse can also be used with a regular computer monitor. Mechanix is able to provide immediate and intelligent feedback to the students, and 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. A recent and exciting feature of Mechanix is the creative design mode which allows students to solve open-ended truss problems; an instructor can give their students specific minimum requirements for a truss/bridge, and the student uses Mechanix to solve and create this truss. The creative design feature of Mechanix can check if the students' truss is structurally sound, and if it meets the minimum requirements stated by the instructor.

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. Mechanix is also tested alongside an established and popular truss program, WinTruss, to see how learning gains differ and what advantages Mechanix offers over other truss analysis software. Freshman engineering classes were recruited for this experiment and were divided into three conditions: a control condition (students who were not exposed to Mechanix or WinTruss and did their assignments on paper), a Mechanix condition (students who used Mechanix in class and for their assignments), and a WinTruss condition (students who used the WinTruss program for their assignments). The learning gains among these three groups were evaluated using a series of quantitative formal assessments which include a statics concepts inventory, homework sets, quizzes, exam grades and truss/bridge creative design solutions. Qualitative data was also collected through focus groups for all three conditions to gather the students' impressions of the programs for the experimental group and general teaching styles for the control group. Results from previous evaluations show Mechanix highly engages students and helps them learn basic truss mechanics. This evaluation will be compared with previous evaluations to show that Mechanix continues to be a great tool for enhancing student learning.

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. In this experiment, Mechanix is also measured against another truss software, WinTruss¹. This software tool uses a palette (WinTruss is discussed in more detail in the next section). Adding WinTruss as an experimental condition will indicate the value of free sketch recognition and more in-depth feedback on student learning. Results from the most recent 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 Pen²) evaluate the student's sketch of a FBD. Some of the existing software is discussed below.

The Andes physics tutoring system³ 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.

The VaNTH ERC Free Body Diagram (FBD) Assistant⁴ 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.

WinTruss 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. Unlike WinTruss, 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. WinTruss does not purely provide feedback, instead it solves the truss that the student creates and provides the values for the reaction and member forces. Mechanix does not give away the answer to the students, rather it lets them know if their inputted answer is correct or not, by providing this feedback, it maximizes the students' learning experience. Instructors also control how much feedback and guidance is provided by Mechanix.

Mechanix

Mechanix is a sketch recognition program developed at Texas A&M University through collaboration among the Mechanical Engineering, Computer Science and Education departments. With Mechanix, students are able to directly sketch a truss free-body diagram (FBD) onto a computer tablet; they can also sketch the FBD with a mouse and a standard computer monitor. 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.

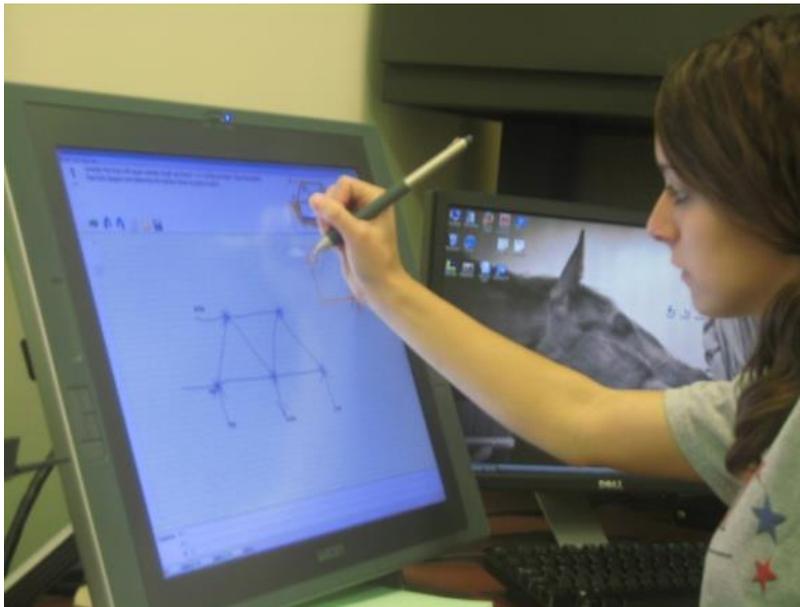


Figure 1: A Student Sketches a Truss FBD into the Mechanix Program

Mechanix also provides instant feedback to the students through a dropdown feedback message bar that appears when a student asks for feedback by clicking on the green check mark (this also

serves as the submit button) at the upper right-hand corner of the Mechanics window (see Figure 2). The dropdown feedback message bar will indicate and display if the student has made a mistake in their solution and what exactly the error is, in this case, the message bar is bright orange. When the student has successfully solved the problem the message bar will display as such and will be green in color.

The instant feedback feature of Mechanics is one of its most important and outstanding features. Figure 2 also shows an example of the view as the student is solving the problem; here the student has asked for feedback by clicking on the green checkmark. As shown, the student has forgotten to label the input force at node C as 1 kN and Mechanics has alerted the student with the dropdown feedback message which is in orange at the top of the screen. Mechanics 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 Mechanics 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 Mechanics 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 asking for feedback or submitting the solutions. Figure 3 is the screen that the student sees when the problem has been successfully and correctly solved.

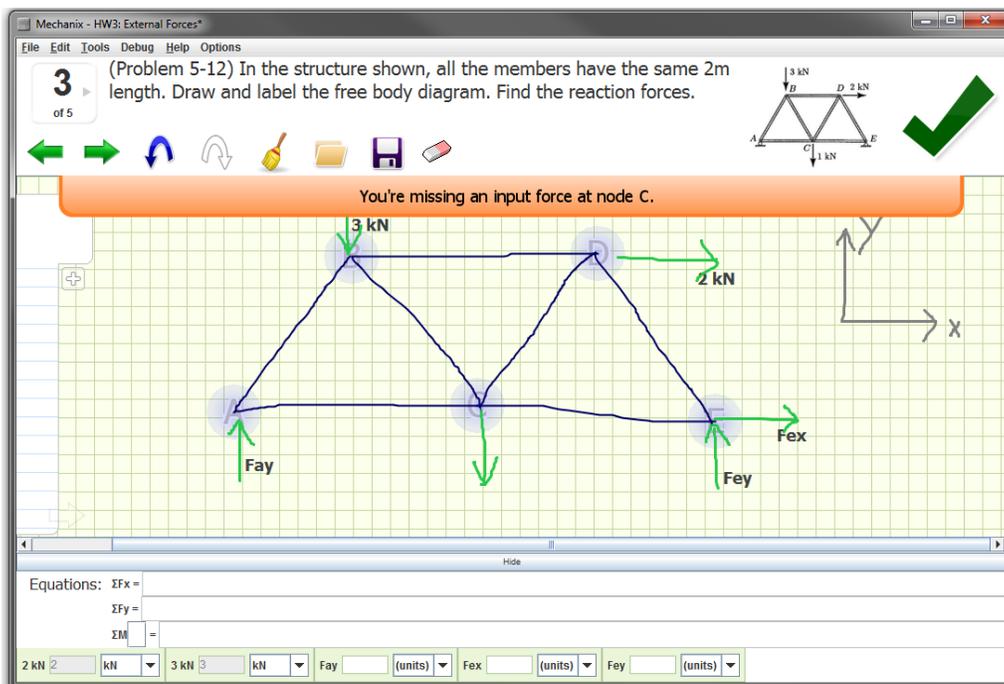


Figure 2: Sample Problem in Mechanics showing the Dropdown Feedback Message Bar and where students can enter their solutions to the truss problem

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. Only the student's last click on the green check mark or submit button is counted as the student's final solution. 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.

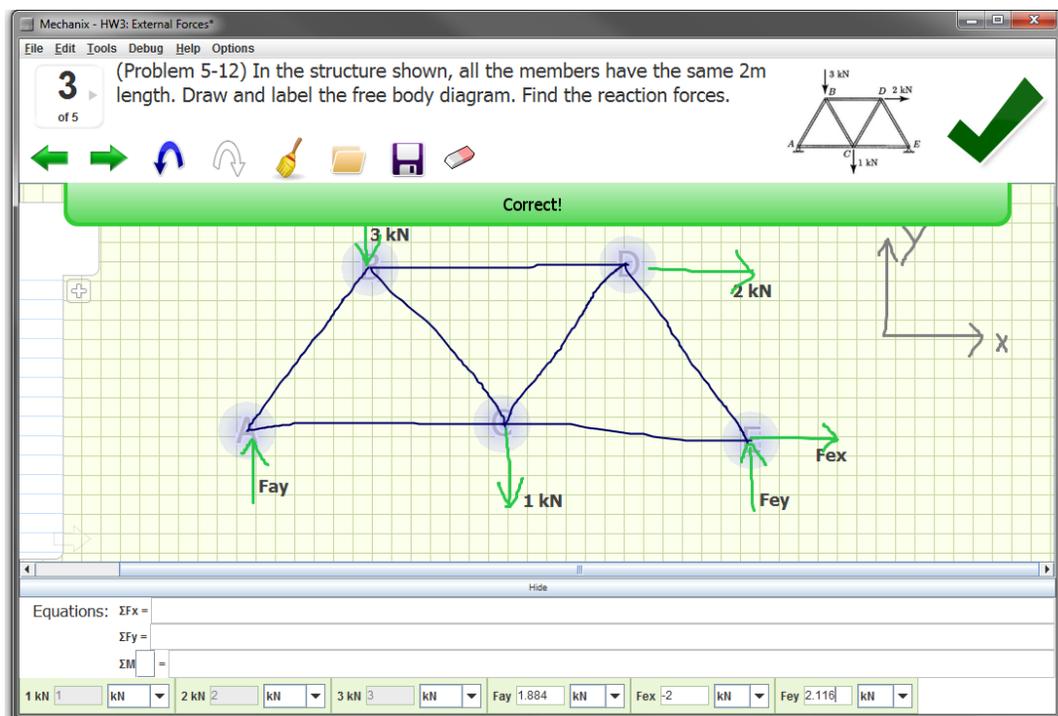


Figure 3: Correctly Solved Problem in Mechanix

Method

Evaluation of Mechanix occurred by testing the program within an authentic classroom setting. Short-term and long-term learning gains were measured with homework, quizzes, exam questions, and standardized 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 a more thorough interpretation. 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 the same class taught by one instructor. 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, participation was voluntary and the students did not have to participate if they did not want to. The class consisted of 65 students in total and 49 students signed up for the experiment. For this class, students are already randomly assigned into teams of three or four in which they work together on homework and class projects. The students that signed up for the experiment were randomly assigned to three conditions by their teams: a control condition, a Mechanics condition, and a WinTruss condition. Assigning the students to conditions by their teams helped to eliminate students in the same team being assigned to different conditions, this way there was no cross contamination of data; each team was asked to not discuss the experiments with other teams in the class who were not in their assigned condition. The students who volunteered for the experiment received extra credit for their participation.

Research Conditions

The students were randomly assigned to three conditions: (1) a control condition which included students that were not exposed to Mechanics or WinTruss; they submitted their homework and studied for quizzes and exams the traditional way: on paper, (2) a Mechanics condition which included students who were only exposed to Mechanics and used the program to submit their homework and to study, and (3) a WinTruss condition where students were only exposed to WinTruss which they used to assist them with their homework and with their studying. For this experiment there were 18 students in the Control condition, 20 in the Mechanics condition and 11 in the WinTruss 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. There were three in-class evaluation sessions that occurred; 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 conditions were split up. The students in the Control condition were taken to another classroom with no computers; mechanical engineering graduate students accompanied them. The students in the Mechanics condition remained in the classroom with tablet computer monitors, the instructor and mechanical and computer science graduate students stayed with them, and the students in the WinTruss condition were taken to a classroom with computers which already had the WinTruss program installed on them, this condition also had graduate mechanical and computer science students with them. The computer science graduate students were students who helped to create the program; they were available for any trouble shooting or

software/computer related issues. The mechanical engineering graduate students were students who were experts in Mechanics and or WinTruss, who were proficient in statics and who had also helped to design the Mechanics program

The students in the Condition worked individually on their homework during this time. The students wrote their answers while manually drawing necessary diagrams for the solution. They received limited feedback and guidance from the graduate students monitoring them.

In the Mechanics condition, instead of using the traditional method to solve their homework problems, the students used Mechanics. They were first given a tutorial on how Mechanics worked, and then they proceeded to use the program. They drew their solutions on tablet monitors and received immediate feedback for accuracy through the program. Mechanics captured and recorded each student's attempts, feedback, and solutions as they worked through the process towards a solution. The students in the Mechanics condition were also given the option of turning in their homework by hand if they did not want to use the program. Students in this condition were given a link to download Mechanics so that they could use it at on their personal computers on- or off-campus.

The students in the WinTruss program were also given a tutorial on how the program worked. They then worked through their homework problems using WinTruss. They were also given access to the program so that they could use it on their personal computers on- or off-campus.

Measures

1. *Homework Scores:* All students submitted three sets of homework related to trusses: (1) a truss FBD homework set, (2) an external forces truss homework set, and (3) an internal forces truss homework set. The scores from these three homework sets are analyzed and compared across the three experimental conditions.
2. *Class Quizzes.* Two quizzes were given to the students (an FBD quiz and a member forces quiz); the results of these quizzes are compared and presented.
3. *Multiple Choice Quiz.* A multiple choice quiz consisting of 10 questions pertaining to trusses and statics from prior exams for the course was given to the students. The questions were not created by the instructor but were taken from a database of past final exams questions for that course. There was a pre-quiz and a post-quiz which were given before and after the in-class sessions to measure learning gains related to a particular intervention method.
4. *Standardized Concept Inventories.* A Statics Concept Inventory ⁵, served as both a pre- and post-test to measure learning gains. Only questions relevant to trusses were selected for this inventory. There were 9 questions in all.
5. *Open-Ended Exam Problems.* On the final exam of the course which occurred at the end of the semester and after the Mechanics in-class sessions, one open-ended truss 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 ⁶.

Focus Group

After the in-class sessions were completed, focus groups were conducted to fully explore the students' perspectives on Mechanics and WinTruss. Students were invited to participate in a focus group which discussed their experiences in using the two programs; there were separate focus groups for each condition. The students in the Control condition (and those who did not volunteer to be in the experiment) were also invited to participate in a focus group to discuss their thoughts and impressions about the course as a whole. Students were offered extra credit on their final exam for participating in the focus groups.

Results

The analyzed data from the homework, quizzes, concept inventory and exams are presented in this section; findings from the focus groups and our interpretation of information collected are also presented.

Homework Results

Three homework sets were assigned; the students in the Mechanics condition submitted their homework online through Mechanics and students in the Control and WinTruss conditions submitted their homework by hand. From Figure 4, we see that there are no clear or fixed consistencies among the group for the three homework sets. For Homework 1, the Mechanics condition scored significantly less than the other two conditions, for Homework 2, there are no significant differences among all three conditions and in Homework 3, the WinTruss condition scored significantly higher than the other two.

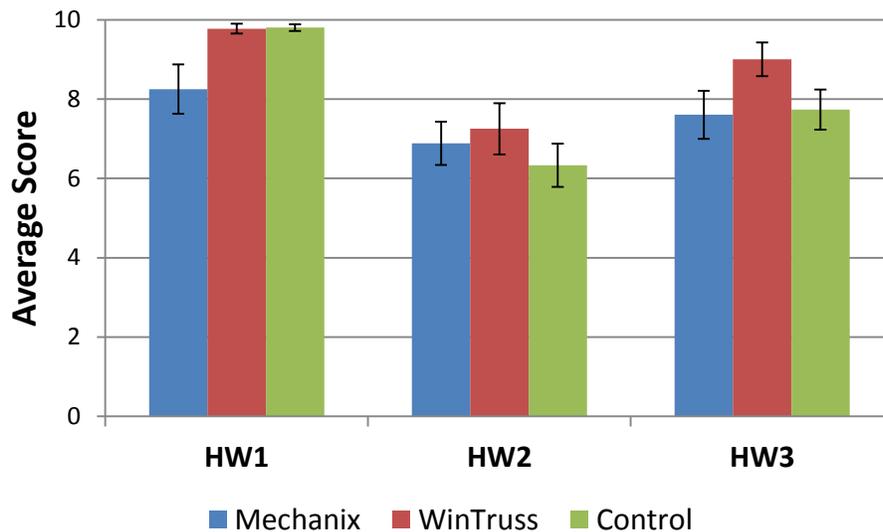


Figure 4: Homework Results for students in all Three Conditions

Class Quiz Results

The results of the FBD and member force quizzes are shown in Figure 5 and Figure 6. Each of these quizzes had a maximum score of 10 points.

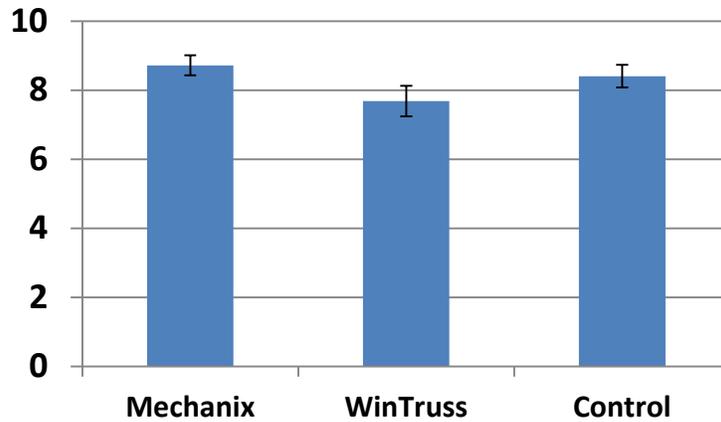


Figure 5: FBD Quiz Results

For the FBD quiz, the Mechanix condition scores higher than all other conditions; there is a significant difference when compared to the WinTruss condition, but no significant difference when compared to the Control condition. Looking at the member force quiz in Figure 6, there are no significant differences when we compare the any of the conditions to each other.

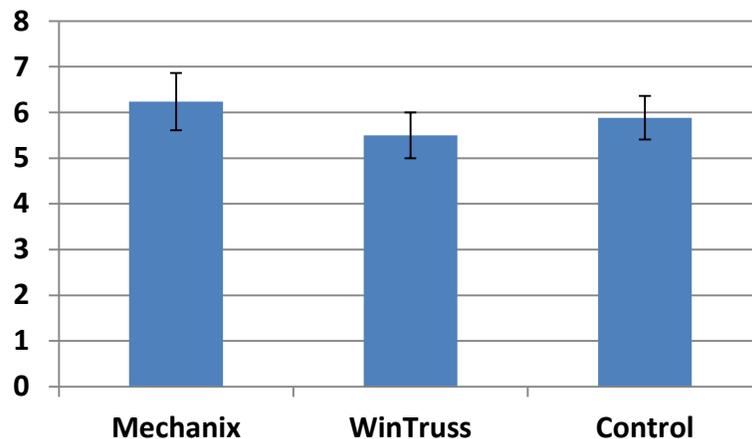


Figure 6: Member Force Quiz Results

Multiple Choice Quiz

The pre- and post-results of the multiple choice quiz are shown in Figure 7. For all three conditions there is a significant increase in the post quiz scores compared to the pre quiz scores; however, when the post-quiz scores of the three conditions are compared, there are no significant differences.

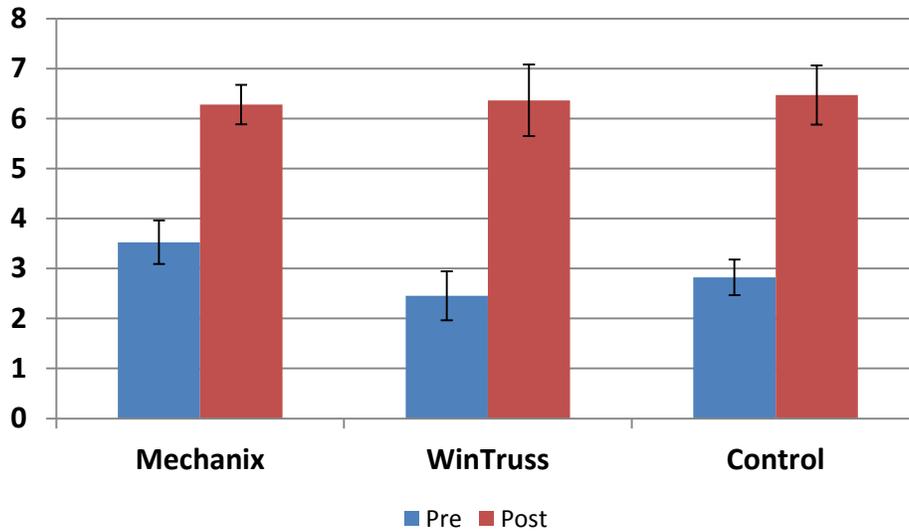


Figure 7: Multiple Choice Quiz Results

Statics Concept Inventory Quiz

The results of the pre and post statics inventory quiz are presented in Figure 8. There is a significant difference in the pre and post scores for the Mechanics condition, the other conditions do not have any significant differences when comparing the pre and post scores.

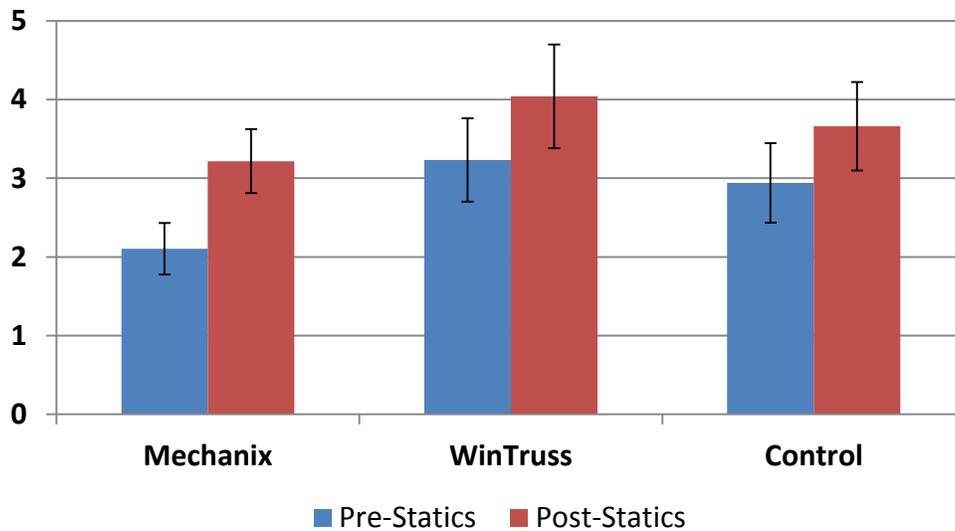


Figure 8: Statics Inventory Quiz Results

Open-Ended Exam Problem Results

The open-ended exam problem result is shown in Figure 9; the problem was scored out of a possible 25 points and was based on drawing the FBD of a truss and finding the external and

internal reaction forces of a truss. The results show that there is no significant difference in the scores when we compare the Mechanics condition to both the WinTruss and Control conditions.

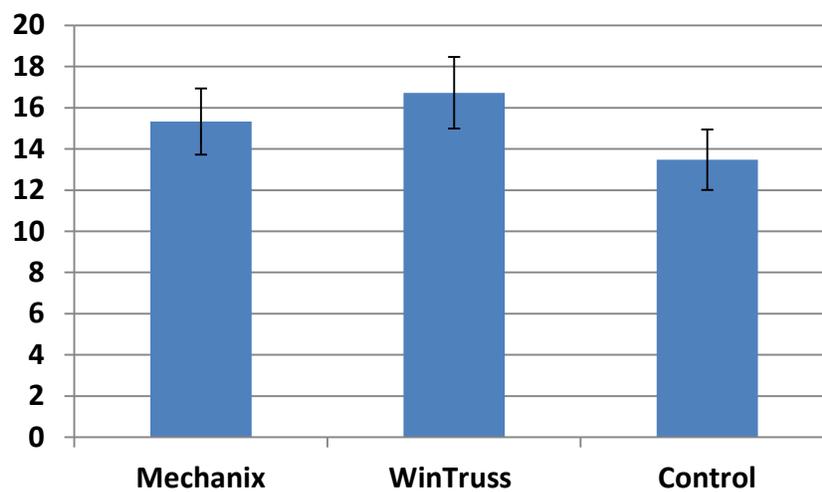


Figure 9: Open-ended Exam Results

Focus Group

The purpose of the focus group was to gather the students' impressions of the Mechanics and WinTruss programs for truss diagrams and homework assignments, the focus group was also aimed at diagnosing potential problems that the students encountered while using Mechanics, this information is useful for future improvements on the program.

For the students in the WinTruss condition and/or focus group, their time was broken up into two segments, in the first segment they discussed questions regarding their experience with WinTruss and in the second segment, they were given a tutorial where they were shown Mechanics and allowed to use it to solve a few truss problems; this way they could directly compare their experiences using WinTruss as opposed to using Mechanics.

Attendance for the focus groups was voluntary and the students received extra credit for their participation. The data for the Mechanics and WinTruss focus groups are presented in this section.

Mechanics Focus Group

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

1. What was it like using Mechanics for the first time?

Most students reported that it took some time initially and wasn't immediately clear how to use all the functions. The most successful users spent about half an hour playing around with the program first and then dived into actually doing the work. The least successful users tried to solve

the problems while learning the program simultaneously. The students reported that first time they solved a problem with Mechanix, it took about 90% of their attention to use the program; however, after they had learned to use it, it was very quick and easy for them to use it (only about 10% – 20% of their attention). Others reported that they switched back and forth between paper and Mechanix and used Mechanix as an input checker.

Our Interpretation: Mechanix has a very quick learning curve and with little practice, students become proficient in it.

2. What was the most beneficial thing about using Mechanix.

The students unanimously agreed that the instant feedback was the most beneficial part of Mechanix. They appreciated the non-delay/on-demand type of feedback for learning. The students reported that the feedback was specific and easy to interpret. They also expressed that they would like the feedback to tell them all the mistakes that they had made all at once, instead of one at a time; this way they can fix all their mistakes at one time, which limits the amount of times they ask for feedback.

Our Interpretation: The feedback that Mechanix gives is very well liked and beneficial to their learning. The amount of feedback given at once may need to be increased.

3. What was the most frustrating thing about using Mechanix.

The students mentioned that encountered a few bugs while using Mechanix. The bugs that were stated were: sometimes losing work and having to start from scratch, axes were not recognize.

Our Interpretation: Mechanix has some bugs that need to be addressed. It is important to note that the amount of bugs in Mechanix has drastically decreased from the previous experiment carried out last year.

WinTruss Focus Group

The students in the WinTruss focus group stated that the benefits of using WinTruss were that since WinTruss gave them the correct answers, they had an assurance that their submitted homework answers were correct. They said that WinTruss was reliable and that if they were clueless as to how to solve a problem, they could just put it in WinTruss, get the answers and then work backwards to show their work when they submitted their homework.

According to the students, the cons of WinTruss were that it took a long time (about 3+ minutes) to setup the problem in WinTruss, i.e. draw the truss, label nodes, add input forces, etc, while it would only take about 30 seconds to draw on paper. They stated that WinTruss did not teach anything on the conceptual level, that changing the letters associated with a node was very time consuming, making the truss member lengths correct was time consuming, and that the process of using WinTruss and taking an exam were not very similar.

Comparing WinTruss to Mechanix

After the students in the WinTruss had been shown how to use Mechanix and had some time to solve a truss problem, they were asked to compare their experiences using WinTruss compared to using Mechanix.

The students stated that they really liked how they could draw the truss quickly in Mechanix and how it automatically recognized and labelled the nodes. They said that drawing the truss in Mechanix was a lot faster than in WinTruss. They liked the Mechanix interface better and appreciated the similarity to drawing on a piece of paper. A few claimed that Mechanix was “better for teaching purposes” because it did not directly give you the solutions like WinTruss did but instead guided them to the solutions with feedback messages and hints. They liked how they were able to get step-by-step feedback by asking for it. There were some students who stated that they liked WinTruss better for the sole reason that it gave them the correct answer right away. It appeared that those who supported WinTruss were interested in a quick and easy way to get the solution, so they could apply this to their written homework (and solve to reach this solution without the aid of the software) and it also appeared that those who supported Mechanix were interested in a more efficient and complete learning tool, so they could solve the problems step-by-step and learn from their mistakes.

There seemed to be an overall impression that Mechanix would be preferred in a learning environment.

Conclusions

Results from the homework and class and multiple choice quizzes, and the open-ended exam problem show that there were no significant differences when comparing the learning gains among the three experiment conditions. The statics concept inventory quiz shows that there is a significant difference in the performance of the student in the Mechanix condition compared to WinTruss and Control conditions; this suggests that there were learning gains for the students in the Mechanix condition compared to the other two.

The focus groups show that the students were very excited to use Mechanix and very much appreciated the instant feedback. Data from the focus group also show that Mechanix has a quick learning curve, which is what it was designed to be. Data from comparing Mechanix to WinTruss from the WinTruss focus group show that the majority of the students prefer Mechanix to WinTruss, especially for the ease of drawing and labeling the truss. They stated that Mechanix was “better for teaching purposes”.

Overall, the results from this experiment show that Mechanix has the potential to enhance student learning compared to students who use other truss software or no truss software at all. Students who used both Mechanix and WinTruss preferred Mechanix.

Future evaluations of Mechanix will occur on the Texas A&M and Georgia Institute of Technology campuses.

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