# AC 2012-4935: AUTOMATIC IDENTIFICATION OF STUDENT MISCONCEPTIONS AND ERRORS FOR TRUSS ANALYSIS

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# Automatic Identification of Student Misconceptions and Errors for Truss Analysis


## Abstract

The use of concept inventories in mechanics education has great potential to identify areas where interventions are either working or not working for particular concepts. Concept inventories are validated measures and easy to implement. Where intended interventions are not working, there is potential for enhancing student learning. This process of implementing concept inventories to quickly measure the effectiveness of a teaching intervention is shown through a case study with Mechanix. Mechanix is a sketch recognition tool that tutors students on drawing free-body diagrams (FBDs) and truss problems. It is being developed at Texas A&M University. Students sketch their answers on tablet computers as they would normally on paper or with a mouse and a standard computer monitor. This provides a system with a low learning curve. Mechanix is able to provide immediate and intelligent feedback to the students; it tells them if they are missing any components of the FBD and if their answers are correct. The program tells the students whether their solved reaction forces or member forces are correct or not without actually providing the answers.

The concept inventories indicate the concepts that Mechanix is already more effective at teaching than tradition lecture only. Since Mechanix captures the students answers in real-time, their errors and misconceptions can easily be identified and corrected if appropriate feedback is built into Mechanix. Mechanix is still in development and its feedback system can be further refined to more precisely target the concepts the students should be learning. Future versions of Mechanix will automatically provide instructions with a description of the errors their students are making and the concepts they may be having difficulty with. This will be provide in an easy to use interface where professors can quickly obtain a real-time update on their students' performance and then adjust their teaching approach and examples as needed. The concept inventories are an effective tool for determining which concepts are most difficult for the students and should be targeted for feedback within the Mechanix software.

The concepts inventories provide quick identification of concepts students do not understand. Results from the concept inventories indicate that for the Statics Concept Inventory, almost all pre-scores are at the level of random guessing. This means that professors using the Statics Concept Inventory for students who have not had statics, it may not be necessary to do a pre-test. Our results do indicate that students may be familiar with the direction of forces at pin and slot joints. The concept inventories are indicating that Mechanix needs to better support students in learning how to separate bodies for free body diagram and the directions of forces at pin-in-slots.


## Introduction

Most faculty have limited time and resources to effectively evaluate their interventions. Developing targeted exam and quiz questions which are valid and reliable requires significant time and resources. Other more qualitative tools such as focus groups and surveys require skills that many engineering faculty do not have and significant time for collection and analysis.

Concept Inventories have great potential to quickly identify concepts and topics students do not understand. Unfortunately, there are a limited number of concept inventories available and a single inventory may not be targeted for a particular intervention. This paper demonstrates the use of two concept inventories in combination to quickly identify concepts that Mechanix, a software tool for free body diagrams and truss analysis developed by the authors, needs to provide better tutoring for. Figure 1 shows a screen shot of a student using Mechanix.

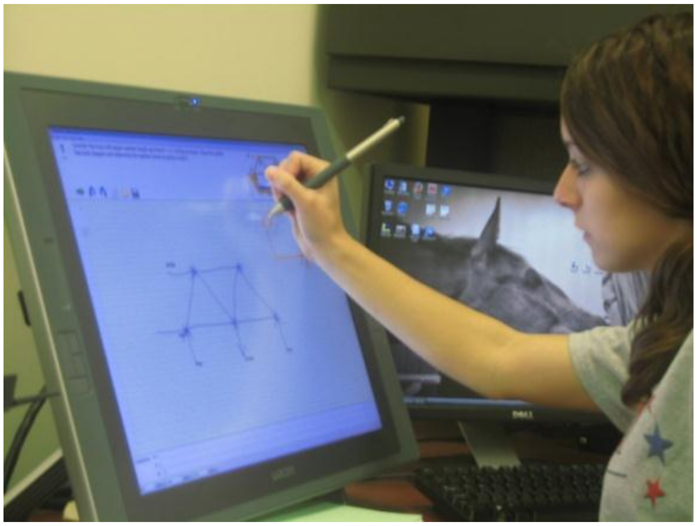

Figure 1: Screen shot of Mechanix and picture of a student using Mechanix with a tablet.

## Background

### *Mechanix*

While many professors are aware of the importance of open-ended and creative problems for their ability to deepen learning and enhance innovation skills, instructors tend to limit their use due to the excessive time commitments required for grading and other difficulties. Previous studies by Brose and Kautz[1] have shown that is important to discover the difficulties that students have in learning mechanics and statics concepts in order for them to understand real-world mechanical models. Steif[2] also discusses on how instructional approaches need to be implanted that improve learning in mechanics.

Mechanix addresses and can overcome many of these issues. Mechanix is a sketch recognition tutoring system for trusses which enhances engineering learning by providing intelligent and immediate feedback. It allows users to draw diagrams as they would naturally and thus there is almost no learning curve for this tool, unlike most tool palettes or other CAD-based programs. Mechanix can be used with tablet screens or standard mice. Mechanix facilitates the incorporation of open-ended design problems into large traditional classes by providing instant feedback and grading of the problem. See Atilola et al [3] for a more detailed description of Mechanix.

Figure 2 has a screen of the current system and shows a single answer problem. Open-ended, creative design problems such as designing a truss that spans ten inches, supports at least 25 lbs. and whose members can each support 3 lbs., are currently in development.

One of the major advantages of Mechanix is that it provides immediate and intelligent feedback to students whenever they submit answers. Mechanix tells the students if their answers are right or wrong, and provides helpful hints to reach the solution if the submitted answer is wrong. Feedback helps students to identify misconceptions, and guides them to a more accurate understanding of the topic being learned. Instructors can also benefit from this, as they can tell what aspects of the topic or problem their students are having trouble with when they are grading submitted assignments. These submissions can also be used to refine the feedback that Mechanix automatically provides to the students.

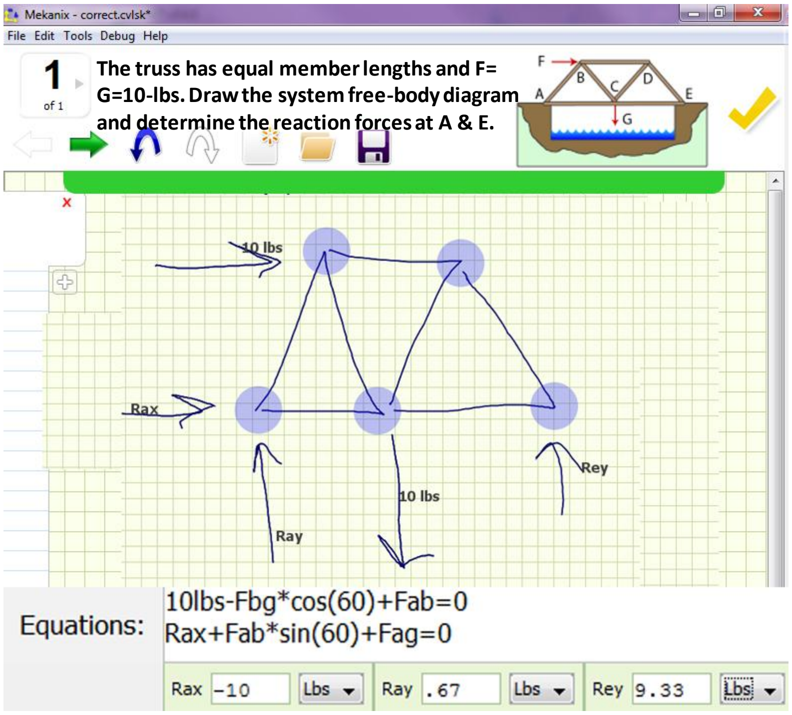


Figure 2: Screen shot of Mechanix and picture of a student using Mechanix with a tablet.

***Concept Inventories***

Concept Inventories are a quick and valuable tool for assessing student learning. Currently there is a large database of Concept Inventories for engineering and related topics (http://cihub.org/). Two concept inventories, the Force Concept Inventory and the Statics Concept Inventory, can measure topics covered in Mechanix. 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).
The Force Concept Inventory can be used to identify students' misconceptions [4].

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 [5]. 27 questions were presented to the students and they tested nine different concepts in statics:

1. Separating bodies/free-body diagrams (FBD)
2. Newton's 3rd Law (3rd Law)
3. Static equivalence of combinations of forces and couples (Static Eq.)
4. Direction of forces at rollers (Roller)
5. Direction of forces at pin-in-slot joint (Slot)
6. Possible directions of forces between frictionless and contacting bodies (Neg. Fric.)
7. Representing a range of forces using variables and vectors (Repres.)
8. Limit on the friction force and it's trade-off with equilibrium conditions (Friction), and
9. Equilibrium conditions (Equil.)

## Method

Evaluation of the Mechanix occurred by testing the program within an authentic classroom setting, the freshman engineering class ENGR 111. This freshman class was used because this is the first time that students are exposed to truss analysis at Texas A&M University. Using this class also served as a good predictor to how sophomore students would perceive truss analysis topics. Current class sizes are 70-100 per section with 5-7 sections per semester. Thirty-six students from the honors section (which is a smaller class) and 86 students from the regular section were recruited. 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. 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.

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. See Atilola, et al.[3] for a more detailed description of evaluation method and results which focused on the learning effectiveness of Mechanix.

Two standardized measures, Force Concept Inventory [6] and the Statics Concept Inventory [5], 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. These two measures can highlight areas where Mechanix needs to provide improved feedback to the students.

Since Mechanix captures a student's solution each time they submit an answer, an analysis of the concepts that students do not understand could also be identified with this approach. Figure 3 shows multiple submissions to the Mechanix Server by a student. This approach will require a detailed coding scheme to be developing. A significant number of hours of analysis will be required. Future work will compare the results from the concept inventories to the more detailed coding.

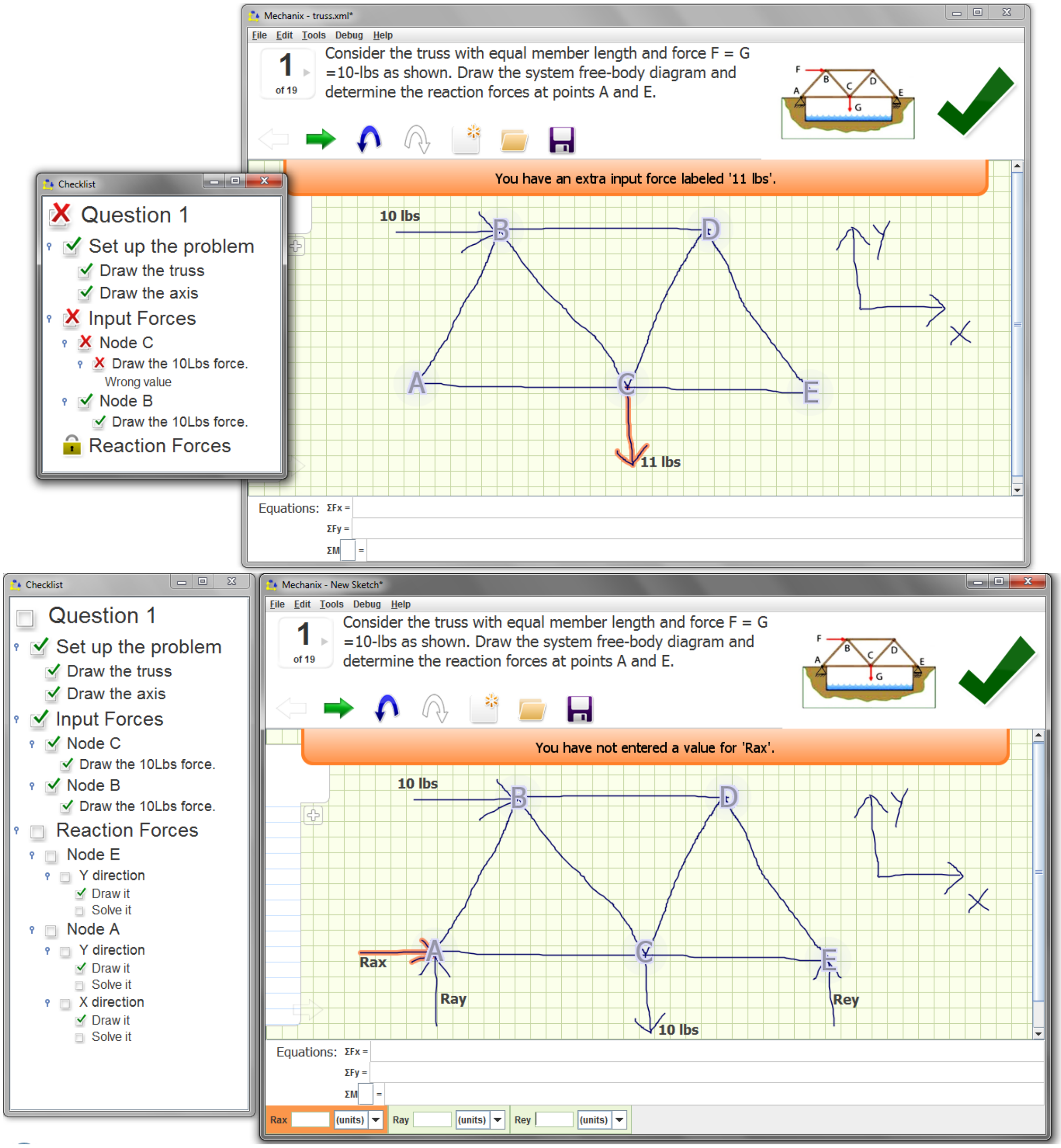


Figure 3: Conceptual errors can also be identified through coding a student's multiple submissions.

## Results & Discussion

### *Force Concepts Inventory Results*

From Figure 4 and Figure 5, we can that though there is a significant improvement in the students' scores from the pre to post-test when we compare each group with itself. The changes do not differ across the two conditions. The key concept that Mechanix attempts to teach that is measure by the Force Concept Inventory is determining the forces that act on an object. Figure 6 shows the results for this concept. Students are making only modest improvements over the semester even though most students are taking physics along with their freshman engineering course. Identifying forces which act on an object in different situations is clearly very difficult for students.

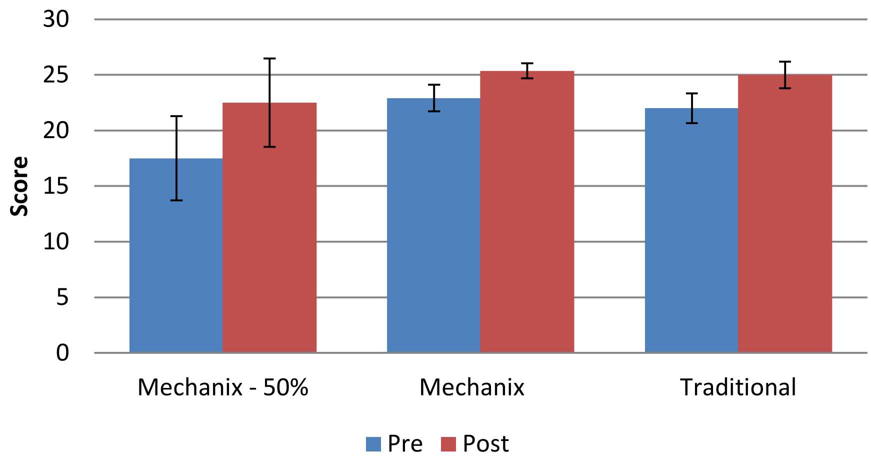


Figure 4: Pre- and post-Force Concepts Inventory Results for the Honors Section

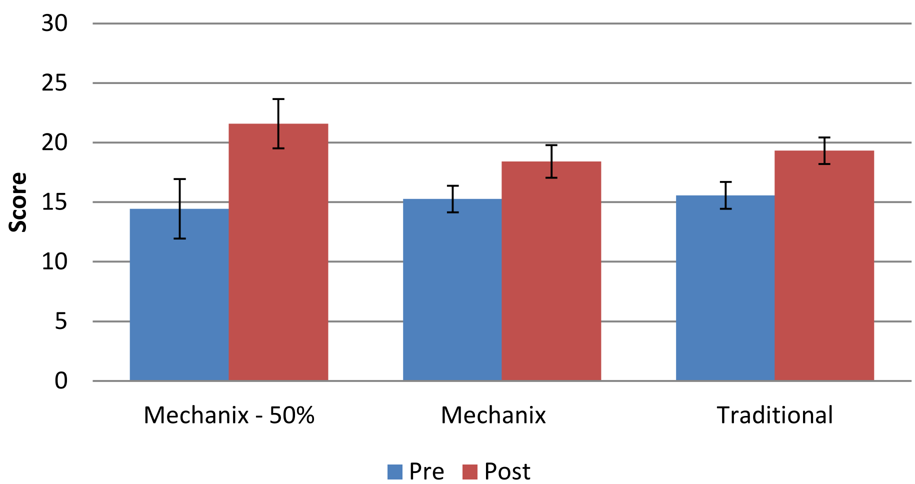


Figure 5: Pre- and post-Force Concepts Inventory Results for the Regular Section

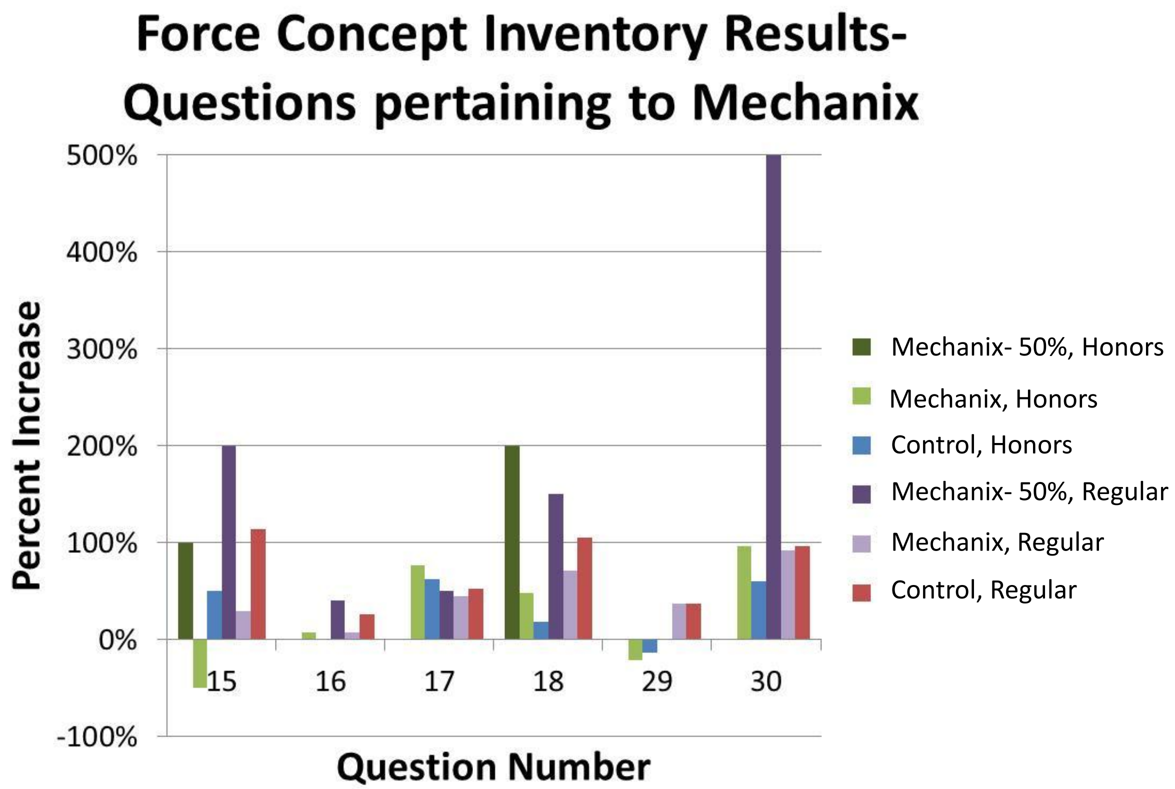


Figure 6: More detailed analysis of the Force Concept Inventory for questions that deal with the forces which act on objects.

***Statics Concepts Inventory Results***

The students were tested on the same questions at the beginning and at the end of the semester (pre- and post-). Figure 7 and Figure 8 shows the pre and post statics results for the students in the Mechanix and Traditional conditions in the honors section (the circled items: FBD, Roller and Slots, are the concepts that Mechanix can directly measure). Figure 9 and Figure 10 show the pre and post results for the students in Mechanix and Traditional conditions in the regular section.

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 7 shows us that for the Mechanix students in the honors section, there was a significant improvement in their performance and understanding of these concepts, this is also true for the students in the traditional condition in the honors section; they also performed significantly better in the post-statics results for these concepts. For the students in the regular section, we can see from Figure 9 that for the Mechanix students there was only an improvement in their performance for the roller concepts; the traditional students for the regular section showed an improvement in their performance for the roller and slot concepts (Figure 10). The two conditions for the regular class did not show any improvement on the FBD concepts.

For most topics covered in the Force Concept Inventory, there is substantial improvement but students' knowledge is lacking.  Figure 11 and Figure 12 show that students are not making significant increases in their ability to separate bodies in a free body diagram. They are also not correctly identifying the direction of forces at pin-in-slot joints.

Pre-test of the slot is the only one that is substainally above random guessing for all students and the roller for the regular class. This indicates that it may not be nescesary to use a pre-test of the Statics Concept Inventory since the students are ramdonly guessing anyway.

| Table 1: Topics on the Force Concept Inventory |
|---|
| 1. Separating bodies/free-body diagrams (FBD) |
| 2. Newton's 3rd Law (3rd Law)* |
| 3. Static equivalence of combinations of forces and couples (Static Eq.)* |
| 4. Direction of forces at rollers (Roller) |
| 5. Direction of forces at pin-in-slot joint (Slot) |
| 6. Possible directions of forces between frictionless and contacting bodies (Neg. Fric.)* |
| 7. Representing a range of forces using variables and vectors (Repres.)* |
| 8. Limit on the friction force and it's trade-off with equilibrium conditions (Friction), and* |
| 9. Equilibrium conditions (Equil.)* |
| 10. *Topics not covered by Mechanix at present |

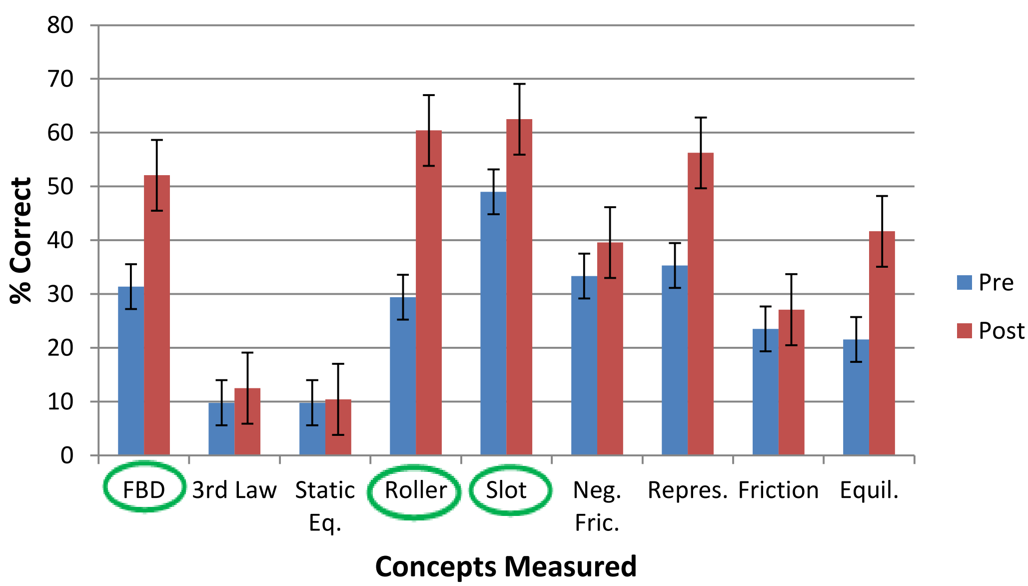


Figure 7: Pre- and post-statics Inventory Results for the Mechanix Students in the Honors Section

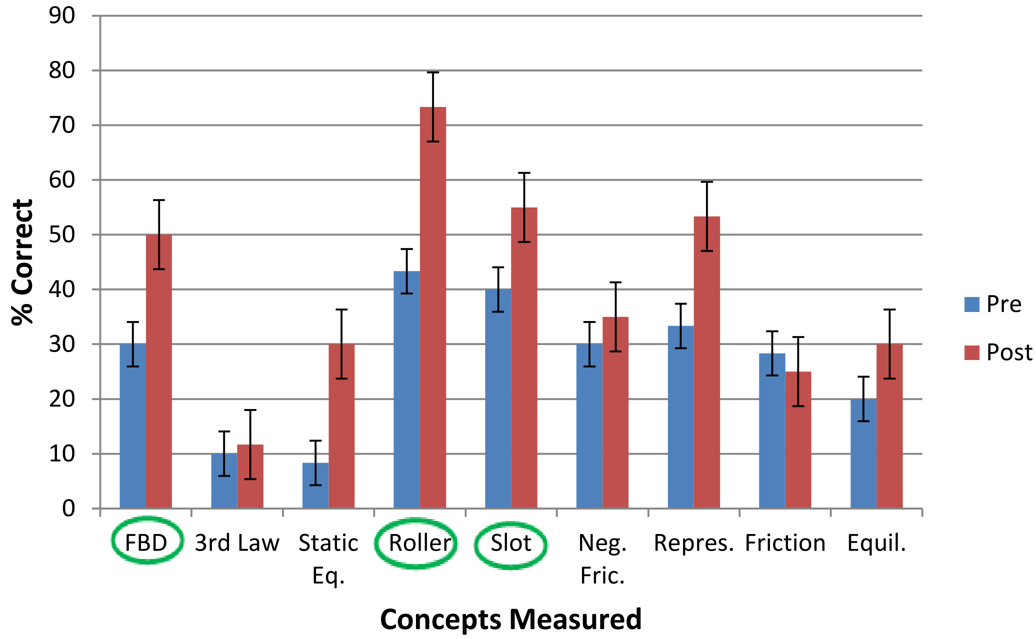


Figure 8: Pre- and post-statics Inventory Results for the Traditional Students in Honors Section

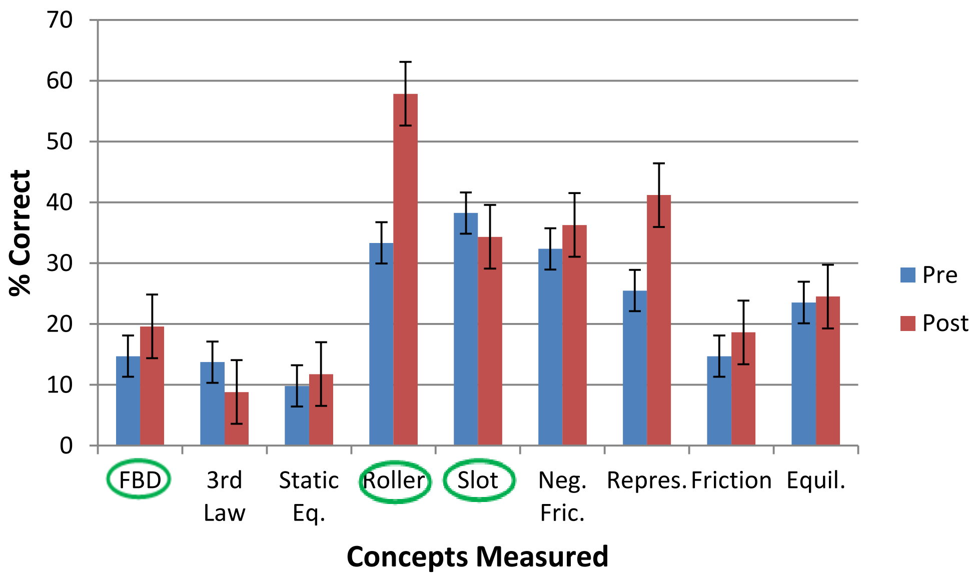


Figure 9: Pre- and post-statics Inventory Results for the Mechanix Students in the Regular Section

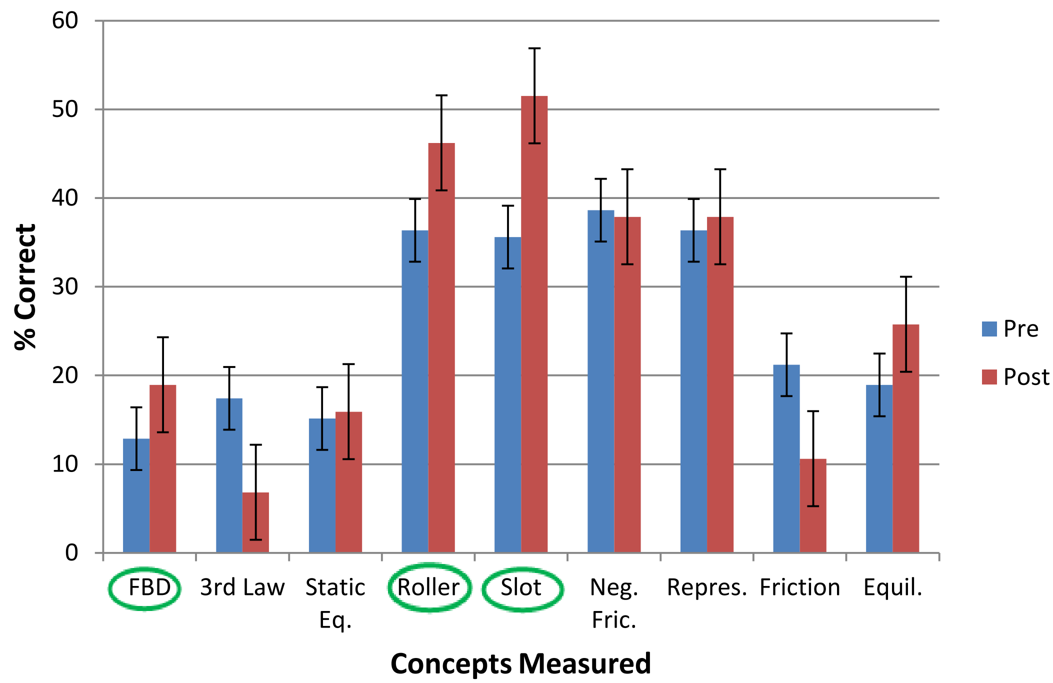


Figure 10: Pre- and post-statics Inventory Results for the Traditional Students in the Regular Section

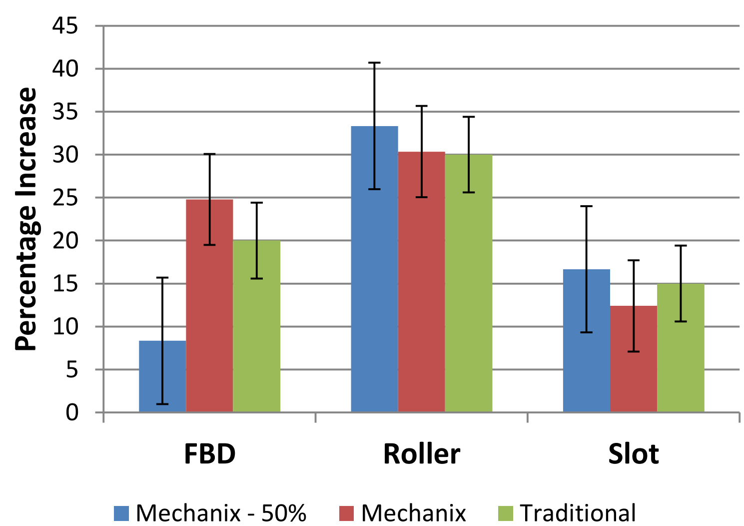


Figure 11: Percentage Increase in Performance of Students in the Honors Section for the FBD, Roller and Slot Concepts

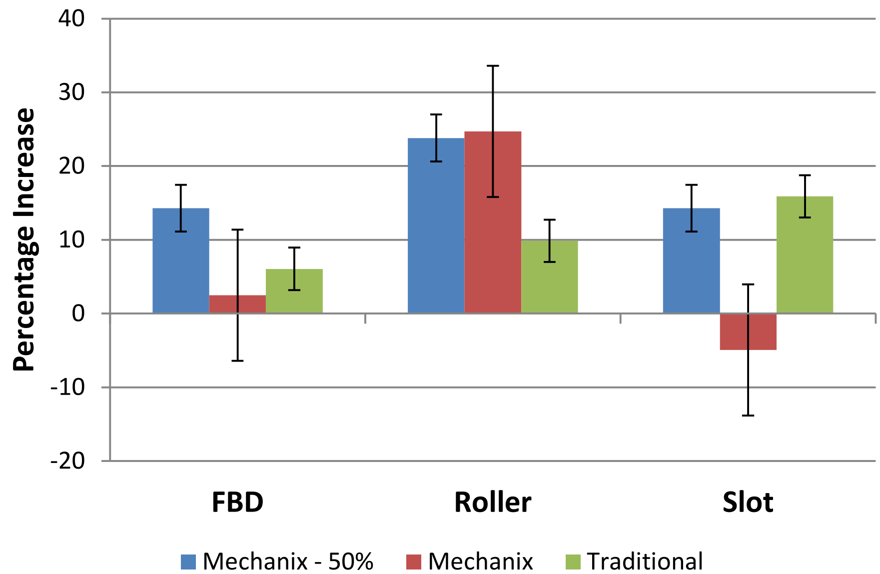


Figure 12: Percentage Increase in Performance of Students in the Regular Section for the FBD, Roller and Slot Concepts

**Conclusions and Future Work**

Concepts inventories are an effective tool to quickly identify which concepts students are improving on and for use in measuring the effectiveness of a learning intervention. For the case study in this paper, there are a number of topics for which the software Mechanix needs to provide more effective feedback and tutoring. Students need more practice and guidance on learning to identify the forces on an object. They also have significant difficulty with identify the direction of forces on a pin in a slot. Results also indicate that completing a pre-test with the Statics concept inventory is probably not necessary given that results indicate students are almost entirely randomly guessing. Future work will focus on comparing the results from the concept inventories to detailed coding of the mistakes students make during truss analysis and when drawing free body diagrams.

**References**

1. Brose, A. and C. Kautz. *Identifying and Addressing Student Difficulties in Engineering Statics*. 2011.
2. Steif, P.S. *An articulation of the concepts and skills which underlie engineering statics*. 2004. IEEE.
3. Atilola, O., C. Osterman, F. Vides, E. McTigue, T. Hammond, and J. Linsey, *Mechanix: The development of a sketch recognition truss tutoring system*, in *ASEE Annual Conference & Exposition*2012: San Antonio, TX.

4. Hestenes, D., M. Wells, and G. Swackhammer, *Force Concept Inventory*. The Physics Teacher, 1992. **30**: p. 141-158.
5. Steif, P.S. and J.A. Dantzler, *A Statics Concept Inventory: Development And Psychometric Analysis*. Journal of Engineering Education, 2005. **33**: p. 363-371.
6. Hestenes, D., M. Wells, and G. Swackhamer, *Force Concept Inventory*. The Physics Teacher, 1992. **30**: p. 141-158.