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Using Natural Sketch Recognition Software to Provide Instant Feedback on Statics Homework (Truss Free Body Diagrams): Assessment of a Classroom Pilot

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Using Natural Sketch Recognition Software to Provide Instant Feedback on Statics Homework (Truss Free Body Diagrams): Assessment of a Classroom Pilot

Abstract

Engineering students in large classes receive far too little feedback on hand-sketched Free Body Diagrams (FBDs.) Despite the importance of these diagrams for engineering education and practice, large class sizes often make providing detailed paper-based feedback impractical. Such issues are even further strained in MOOC classes. Relatively recently, computing technology has become powerful enough to enable instantaneous, detailed feedback on hand-sketched engineering diagrams. Researchers have recently developed the free "Mechanix[1]" sketch recognition tutoring system for free body diagrams (FBDs) and trusses. The Mechanix online software provides instantaneous and detailed feedback using a natural sketch recognition engine[2,3,4,5,6,7,8,9,10,11,12].

This paper describes the process and results of piloting the Mechanix software at a primarily undergraduate university. The experimental group included 39 students in a Statics class, contrasted with a similar class of 34 as a control group. Students in the experimental group completed the Mechanix tutorial and then worked 4 truss problems with instantaneous and unlimited online feedback regarding the accuracy of their free-body diagram drawing and numerical answers. The control group used commonly available online software giving feedback only on numerical answers. Results included here include student **attitudes towards technology, online homework scores, class test scores, and self-reported perceptions of the software efficacy**. Both quantitative learning outcomes and qualitative comments from users suggest the software system is effective and has great potential if further developed. Students in the experimental group performed as well as the control group, more than 90% of students chose to use the new software (rather than opt-out), and most students self-reported a positive learning experience.

1 Introduction and Background

1.1 Mechanix[1] Sketch Recognition Online Tutoring System

Both engineering education and engineering practice depend upon simple hand-sketched diagrams to frame and solve many engineering problems. Free Body Diagrams are one such hand-sketched diagram used in many engineering courses and areas of professional practice. For example, the vast majority of engineering students learn to draw a special class of free body diagrams called "trusses" in a second-year statics class. A truss diagram could be used to find the forces of tension and compression in members of a bridge framework, for example.

Despite the importance of such hand-sketched diagrams for engineering education and practice, large class sizes common in US engineering education often prevent provision of careful evaluation and feedback on such diagrams, and the situation with MOOC's is even more difficult due to size. Only recently has computing technology become powerful enough to enable rapid and detailed feedback on engineering hand-sketched diagrams. The Mechanix project is developing and evaluating software that enhances student skills for creating and applying truss free body diagrams common in engineering Statics classes. By algorithmically understanding truss problem-solving strategies, and by assessing the current state of a problem using recognition algorithms for natural (by-hand) sketches, Mechanix software is able to provide iterative, step-by-step guidance upon request. Mechanix is also able to provide automatic grading for both sketch and numerical answer components.

Exhibit 1 is a Mechanix screenshot in which a student has correctly sketched the truss, labeled forces, and entered the numerical answers to unknown forces. A student may request feedback as often as they wish, thus triggering alerts to deficiencies or errors such as "You forgot a reaction force," or "Check the units of force R_{ax}," or "The value entered for force R_{ax} is incorrect."

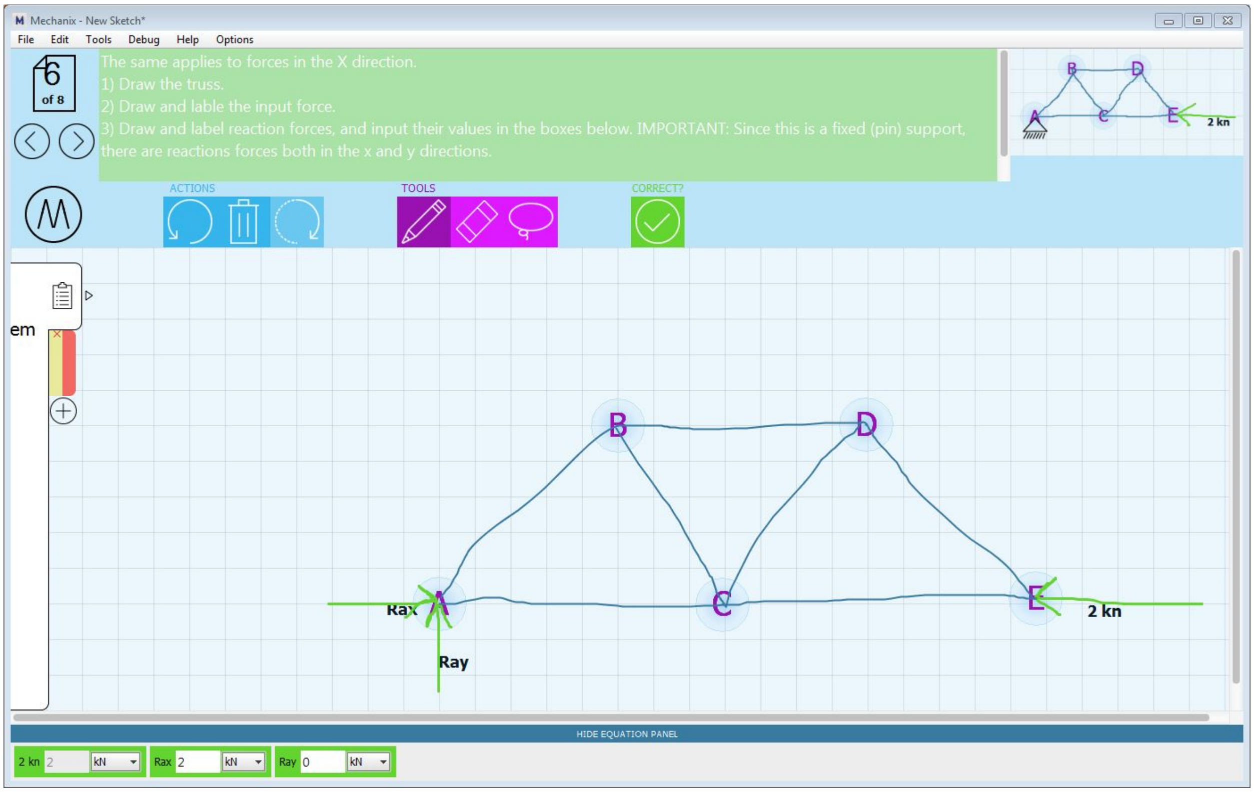

Exhibit 1: Mechanix Software Screenshot –
Student has Correctly Sketched the Truss, Labeled Forces, and Entered Numerical Answers

Students who benefit from the software are expected to experience increases in motivation, learning efficiency, and total learning outcomes. The software is currently focused on trusses (a specific type of free body diagram,) but other diagram types may be possible.

1.2 Context: Characteristics of the Class and University where We Tested the Software

In this collaborative project, LeTourneau University is the test university providing classroom assessment of the Mechanix teaching software under development. The test university is a private non-profit offering over 60 academic programs, including engineering and engineering technology, the aeronautical sciences, business, education, the liberal arts, and sciences. Nearly 500 of the 1400 undergraduate students on campus are in the School of Engineering and Engineering Technology. Students participating in this study were all enrolled in the Engineering degree in one of six concentrations: *biomedical, civil, computer, electrical,* *materials joining, and mechanical*. Students from two sections of Engineering Statics, with appropriate consent, were included in the study. The class employed standard online homework using the Mastering Engineering[13]® online homework system which provides feedback on numerical answers, but does not include free body diagram input or feedback. Class lectures utilized a dry-erase marker-board, and students completed tests on paper during class time.

1.3 Software Testing Timeline and Setup

Exhibit 2 outlines the Mechanix software testing timeline, highlighting in bold the data collection events. Exhibit 3 contrasts the control group with the experimental group. The two groups were two different class sections taught by the same instructor, other than a small number that chose not to participate. The 8 truss homework problems included four method-of-joints and four method-of-sections problems from a standard statics textbook[14].

Week#	Date	Due from Students	Class Activities
	9/26 F		Instructor emails students: Mechanix tutorial link & login credentials
6	9/30 T		Truss Analysis Lecture #1 (1.5hr)
	10/1 W	Install Mechanix Complete **Mechanix tutorial** (bonus if by 11:59PM)	Instructor emails Students: Tutorial link & bring laptop to class
	10/2 Th		**Survey: Technology Attitudes** PI: Demo Mechanix with example problem (15min) Truss Analysis Lecture #2 (1.25 hr)
7	10/7 T		
	10/9 Th	MasteringEngr. [13]® Online HW (11:59PM)	
	10/10 F	**Mechanix* HW due (3PM)**	
8	10/14 T		**Survey: Mechanix Effectiveness Perceptions**
	10/16 Th	**In-class Examination #2**	
12	11/12 W	**Focus Group #1**	
	11/14 F	**Focus Group #2**	

*If opting out of Mechanix, email instructor by 4PM Thr. 10/9 to get switched to MastEngr. Online HW.

Exhibit 2: Software Testing Timeline with ***Data Collection Events*** *in bold*

Factor	Control Group (n=34)	Experimental Group (n=39)
Instructor	Same	Same
In-Class Truss Lectures	2 hr Whiteboard	1.75 hr Whiteboard + 0.25 hr Mechanix software problem demo
Homework: Online answer + Paper Solution Required	3 MasteringEngr.®	3 Mechanix
Homework: Online answer required (no paper)	5 MasteringEngr.®	1 Mechanix + 4 MasteringEngr. ®

Exhibit 3: Control Group vs. Experimental Group Setup

2 Data and Results

2.1 Survey – Learning Confidence, Technology Confidence, and Learning Technologies Attitudes

Exhibit 4 presents the averages of each category in the attitudes survey, aggregating 10 questions per category. Appendix B presents detailed survey results. Students completed the survey before being introduced to the Mechanix software, and after 6 weeks of experience using the standard textbook-aligned online homework software MasteringEngineering® which provides no free body diagram input or feedback. Twenty-seven (69%) of students in the experimental group completed questions in categories A and B, and 21 completed questions in category C (apparently 6 students overlooked the back side of the survey.) As might be expected of engineering students, the surveys indicate reasonably high levels of confidence and acceptance towards engineering and technology, including technologies for learning engineering.

Question Category (10 questions each)	AVG.
A. Confidence with learning engineering	3.8
B. Confidence using computers and other technologies	3.8
C. Attitude toward computers etc. for learning engineering	3.7

Exhibit 4: Student Survey Category Averages -
Learning Confidence, Technology Confidence, and Learning Technologies Attitudes
[SCALE: 5=strongly agree, 3=neutral, 1=strongly disagree] (n=27 for A&B, 21 for C)

2.2 Software Testing Results Per-student: Tutorial completion, Homework Completion, Exam Scores

Three of the 39 students in the experimental section (8%) opted-out of the Mechanix software test and chose instead to use only the familiar textbook-aligned MasteringEngineering® online software, which does not include free body diagram input or feedback. Thirty-three (85%) of students completed the online tutorial for bonus points, and a slightly different set of 33 students completed the online homework with a grade of 75% or higher (out of the 36 who had not opted-out.) No significant difference was observed between students who did or did not complete the tutorial. Exhibit 5 shows the experimental group performed as well as the control group on the class exam – both on the truss-specific problem and on the exam overall. The four scores in Exhibit 5 have standard deviations ranging from 11% to 16%, and a student T-Test indicates no statistically significant difference between the control and experimental group.

	Control Group (n=34)	Experimental Group (n=39)	T-Test
Exam #2 Truss Problem	90%	87%	p=0.49
Exam #2 Total Score	87%	85%	p=0.36

Exhibit 5: Average Test Scores for Control Group vs. Experimental Group
(T-Test indicates no statistically significant difference between groups)

2.3 Survey – Software Efficacy (Appendix C)

Exhibit 6 presents survey results (n=37) comparing student perceptions of effectiveness of the: Mechanix software, Mastering Engineering® standard textbook software, and class lectures. Students had approximately six weeks of experience with the standard textbook software, and worked four truss problems in the Mechanix software after completing an online tutorial. Mechanix rated nearly as high as the standard software for learning fundamentals, and higher for learning free body diagrams (although p=.09 with a student t-test.)

	Mechanix	Mast. Engr. ®	Class Lecture
1. Helped me learn fundamental engineering concepts.	3.6	3.8	4.4
2. Helped me learn how to solve free body diagram problems.	3.6	3.2	4.5
3. Captured my attention and/or interest.	3.8	3.1	3.8
4. Evoked positive emotional responses ☺ (e.g., enjoyment).	2.5	2.8	3.5
5. Evoked a negative emotional response ☹ (e.g., frustration).	3.8	3.4	2.2

Exhibit 6: Student Survey (n=37) Averages –
Comparing Effectiveness of Mechanix, Standard Textbook Online Homework, and Class Lectures
[SCALE: 5=strongly agree, 3=neutral, 1=strongly disagree]

Two open-ended questions (shown at the end of the survey in Appendix C) yielded 60 critical comments and 42 positive comments. Exhibit 7 and Exhibit 8 give counts and examples of the three most frequent categories for critical and positive comments. (Comments are paraphrased here for brevity and clarity.) The qualitative survey comments indicate the software needs more development, and the Mechanix system has very important contributions to make to learning, some of which are already being realized.

Critical Comments	Freq.	Representative Response Text
Fix Bugs	17	• Several times a few glitches were frustrating. • Just fixing the little things would help a lot.
Need Better Feedback	9	• Give better feedback on why an answer might be wrong. • Work out bugs to give accurate feedback.
Improve Drawing Tools	8	• Include a "straight line" tool. Drawing with a mouse/trackpad is frustrating. • Current system is great for touch screen but not easy … using a mouse.

Exhibit 7: Critical Survey Comments – Frequency and Examples in the Top Three Categories

Positive Comments	Freq.	Representative Response Text
Early Feedback	11	• Receiving feedback on FBD's was very helpful. • Super helpful on the immediate feedback of FBD's. Helped me learn that very quickly. • Showed if my free body was correct; I didn't miss forces, concepts, etc. because of it.
Promotes Visualization	8	• It helped me visualize some of the concepts taught in lecture. • Allowed clear visualization of statics problems in a manner not experienced before. • I saw visually what steps of the problem I did right.
Good Problem Solving Process	6	• Forced me to think more completely by requiring complete FBD. • Forced the correct process ... This was a great idea. • Emphasized correct FBD analysis -- often de-emphasized by [other online software]

Exhibit 8: Positive Survey Comments – Frequency and Examples in the Top Three Categories

2.4 Focus Group Results

Two one-hour focus groups were conducted via web-conference by off-site researchers from another university. Five students in the experimental group volunteered to participate in the focus group, and received a small gift card in exchange. Student comments confirmed the survey results presented above: on one hand that the software needs more development, and on the other, the Mechanix system has very important contributions to make to learning, some of which are already being realized. Student comments confirmed that Mechanix reinforced the problem solving process, and offered incremental help throughout that process that students valued (although students did suggest help messages could be more clear.) The software's indication that a problem was correct up to a certain point helped students focus their learning; they did not have to backtrack to check that an earlier error was propagating to the final answer. Students expressed that this was especially helpful for complicated problems, but for simple problems Mechanix was no better than paper and pencil. Students also reflected that while they found sketching in Mechanix helpful, they all used paper and pencil sketching to supplement the Mechanix representations because Mechanix "could not get all of the information in one place."

3 Discussion

In student survey comments (Exhibit 8) the three most-mentioned learning benefits provided by the experimental software are: early feedback, promoting visualization, and teaching a good problem solving process. The most frequent positive comment received was that the early feedback on free body diagrams enhanced learning. The frequent comment that the software "promotes visualization" is an encouraging indication that the process of sketching free body diagrams (through software in this case) is serving the intended purpose of guiding visualization of the problem and solution.

The six comments stating the software promotes a "good problem solving process" may shed light on how ineffective current grading practices of paper or online homework are at promoting a correct and complete problem solving process. The reality of current paper-based and online homework is that many students skip steps, and sometimes omit a free body diagram entirely - often with disastrous results. This is perhaps the most useful feature of the software - handling free body diagrams - and this is a step which the benchmark online homework software from the textbook publisher leaves up to students to complete on paper. Free body diagrams are therefore not graded in the current benchmark online homework, and therefore may be skipped entirely by some students. Failure to learn to create correct free body diagrams can have disastrous results in future engineering courses and beyond.

The use of Mechanix by the experimental group in this study appears to result in at least equivalent performance to that of students using the modern, online text book manufacturer's software. Additionally, the Mechanix software appears to be engaging and motivating, both of which are helpful for engineering learning. Virtually all students chose to use the experimental software, and seemed to be able to get the software installed and running on their own computers. Most students chose to persist with the software and completed the homework, and they somewhat agreed (3.8 out of 5.0) the software "captured my attention and/or interest." Although emotional response was more strongly negative than positive, this was almost equally true for the comparison software with which students were already much more familiar. The reported negative emotional responses appear linked to bugs, vague feedback, and occasional failure of sketch recognition. "Vague feedback" can be directly improved in some areas (e.g. differentiating +/- sign errors from value errors); on the other hand, overly-specific feedback could defeat the learning process by eventually providing a nearly complete answer to a student who has not solved the problem.

The relatively small scope the software was used for (four closed-truss free body diagrams) meant that student training and set-up time was a large percentage of their experience with the software. Some time is required for installing and learning the new software, and yet only four problems were worked with the new software, and therefore it is impressive in light of this inefficiency that student response was still fairly optimistic. Expanding the software capability to a wider variety of statics topics would significantly increase the ratio of time spent learning statics to time spent learning the software.

4 Conclusions and Future Work

The qualitative survey comments indicate the software needs more development, and the Mechanix system has very important contributions to make to learning, some of which are already being realized. Students commented the software: provides early feedback, promotes visualization, and teaches a good problem solving process.

The need for fast and accurate feedback on hand-sketched diagrams is a severe and nearly ubiquitous issue in engineering education. Students who would benefit from the Mechanix software are expected to experience increases in motivation and total learning outcomes. The software is currently limited to a specific type of free body diagrams (closed trusses.) Future work including bug fixes, recognition of other free body diagram types, and proper scaling up, could plausibly result in software with wide-sweeping impacts on statics classes in virtually all of engineering education.

Acknowledgements

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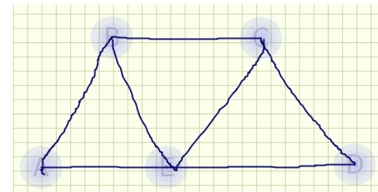
Appendix A: Mechanix Software Student Instruction Sheet Used for this Study

Statics Truss Software Instructions

1. **Start Mechanix** (MCX) and login. (Insure Java is up-to-date first.)
   http://srl-old.cse.tamu.edu/mechanixClient.jnlp

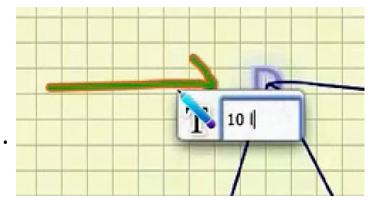
2. **Setup:** (a) Hide the checklist to the left (since it is not always reliable.)
   (b) Click on the image to the right to zoom in.
   (c) Scroll instructions as needed.

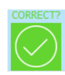


3. **Draw truss** until lettered nodes appear, indicating MCX recognizes it.

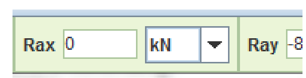
4. **Check your work** often by clicking the checkmark. 

5. **Draw input force arrows** on nodes; arrows **turn green** when recognized.
   Click **green arrows** to label them using these naming conventions:
   Lettered forces: label as "**P**" and enter value "**8 kN**" at the bottom.
   Given forces: enter **100 lbs**, 10 kN, etc. (Draw to make value positive.)
   Reaction Forces: **Ray** = **R**eaction force at node **A** in positive **y** direction.
   Use the **same units** as the problem for the entire truss (e.g. N or kN, but not both).
   At pin joints draw Rax and Ray, even if Rax=0.

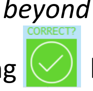


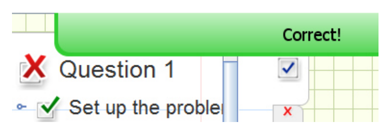
6. **Check your work** by clicking the checkmark. 

7. **Solve balance equations for entire truss** (*on paper – to be turned in*.)
   $\Sigma F_x=0$, $\Sigma F_y=0$, $\Sigma M_{point}=0$
   Enter reaction values at bottom. (Clicking the checkmark checks work.)



8. **Find member forces using "Method of Joints" or "Method of Sections."**
   (*on paper – to be turned in*.) Enter member forces at bottom.
   Note: Fab = Fba. Indicate Compression with a negative force value.
   Enter answers with two digits beyond the decimal point e.g. 102.42 lbs.

9. **Check your answers** by clicking  before continuing.
   The last time you click "check" is the electronic version "turned in."
   Green "Correct!" means you're finished (even if the checklist complains.)



10. **Save your work** by clicking **File Button** >> **Save Progress** and save to your desktop. Use **File >> Load Progress** to retrieve. Note: completing and submitting assignments in one session avoids needing to save work.

Software Issues?
Email: [name_removed]@letu.edu include "HELP MCX at LETU" in the subject line

Appendix B: Survey Data – Attitudes towards Technology

SCALE: 5=strongly agree, 3=neutral, 1=strongly disagree	**AVG.***
A. Confidence with learning engineering	**3.8**
1. I have less trouble learning mathematics and engineering concepts than other subjects.	3.6
2. When I have difficulties in learning mathematics and engineering, I know I can handle them.	4.0
3*. I have a mathematical mind.	4.2
4*. It takes me less time to understand applied mathematics than my peers.	3.5
5*. I sometimes feel myself able to easily learn new engineering and mathematics concepts.	3.9
6. I enjoy trying to solve new engineering and mathematics problems.	3.8
7*. I do not find learning engineering and mathematics stressful.	3.1
8. I find many engineering problems interesting and challenging.	4.0
9*. I have at times been very excited about engineering.	4.1
10*. I do not find engineering and mathematics classes confusing.	3.5
B. Confidence using computers and other technologies.	**3.8**
1. I have less trouble learning how to use new technologies than I do learning other things.	3.7
2. When I have difficulties using a computer, I know I can figure them out.	3.5
3*. I am what I would call a "computer person."	3.1
4*. It does not take me longer to understand how to use new technologies than the average person.	3.7
5. I enjoy trying new things on a computer or other technologies.	3.9
6*. I do not find having to use computers stressful.	4.1
7. I find many aspects of using computers interesting and challenging.	3.7
8*. I have at times been excited about using new technologies.	4.2
9*. I do not find using computers and new technologies confusing.	4.0
10*. I'm nervous that I'm not good enough with learning new technologies to be able to use them to learn engineering.	4.0
C. Attitude toward computers etc. for learning engineering.	**3.7**
1. Technology, particularly certain computer programs, makes it easier to explore engineering concepts.	3.9
2*. I know computers and technology are important, and I don't feel opposed to them to learn engineering.	4.0
3*. Computers programs are good tools for sketching and calculation, and for my learning of engineering.	3.7
4*. The symbols and language of engineering are confusing, but adding new technology won't hurt any.	4.0
5*. I think using new technology is not a waste of time in the learning of engineering.	4.0
6*. I don't necessarily prefer to do calculations myself, without using technology resources.	3.8
7*. I don't necessarily prefer to do sketching on paper, without using technology resources.	3.0
8. I want to get better at using computers and other technology resources to help me with engineering.	4.0
9. Having technology to do routine work makes me more likely to try different methods and approaches.	3.5
10. I am comfortable drawing on a tablet computer.	3.5

Questions with a "" are reversed here to allow meaningful averaging of results.

Appendix C: Survey Form – Mechanix Software Efficacy

What Helps You Learn? (Efficacy) **Name: ________________**

This survey is **voluntary** and your identity will only be known to the researchers. *Your response is appreciated!*

We need your honest feedback to improve student learning!

Indicate agreement or disagreement by √'ing or X'ing to the right.

		Strongly disagree.	Disagree.	Neutral.	Agree.	Strongly agree.
1. This item helped me learn fundamental engineering concepts.		-2	-1	0	+1	+2
1	Mastering Engineering (textbook) software					
2	Mechanix Truss software (new)					
3	Class Lectures					
2. This item helped me learn how to solve free body diagram problems.						
1	Mastering Engineering (textbook) software					
2	Mechanix Truss software					
3	Class Lectures					
3. This item captured my attention and/or interest.						
1	Mastering Engineering (textbook) software					
2	Mechanix Truss software					
3	Class Lectures					
4. This item evoked positive emotional responses ☺ (e.g., enjoyment).						
1	Mastering Engineering (textbook) software					
2	Mechanix Truss software					
3	Class Lectures					
5. This item evoked a negative emotional response ☹ (e.g., frustration).						
1	Mastering Engineering (textbook) software					
2	Mechanix Truss software					
3	Class Lectures					

Please explain, in what ways did *Mechanix Truss Software* facilitate your learning?

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How can the use of Mechanix be changed to improve learning? (more on other side →)