Score Improvement Distribution When Using Sketch Recognition Software (Mechanix) as a Tutor: Assessment of a High School Classroom Pilot

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Abstract

In an effort to improve the effectiveness of out-of-class practice regarding free body diagram, vector and truss analysis, the Texas A&M University Computer Science & Engineering Sketch Recognition Lab (TAMU SRL) has taken on the challenge of producing a globally available on-line tool, Mechanix, which provides immediate, constructive feedback to the learner while also providing student-level metrics to the instructor.

This study involves deploying Mechanix in a new environment. Mechanix was made available as a tutoring support tool for vector analysis in a STEM-infused (Science, Technology, Engineering, and Math) high school Project Lead the Way (PLTW) engineering classroom. The focus was to evaluate the progress realized by differing academic levels of students.

Analysis of the findings yielded a greater increase in the ‘A-level’ students while historical studies suggest significant progress may be realized versus current tutoring techniques at all levels as the students continue to utilize Mechanix.

Key words: Mechanix, Vectors, Flipped Classroom

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Engaging, rigorous, and interactive tutorials are the crux of quality online courses. Though improvement is realized from well-constructed digital lectures versus their in-class counterparts, studies centered around quality practice supports are reflecting opportunities for significant learning.

In a quest to address this important market, the Texas A&M Computer Science & Engineering Sketch Recognition Lab (TAMU SRL) has applied their human-computer expertise to the production of Mechanix. Mechanix is an online tutorial tool providing immediate constructive feedback to learners while also providing individual learner metrics to the instructor.

Previous studies have evaluated the deployment of Mechanix in first year college engineering courses with promising results. The purpose of this study is the evaluation of Mechanix deployment in a high school engineering preparation course with a focus on the improvement differences among student groups sorted by previous mathematics course grades.

Background

A challenge for all courses at all levels requiring out-of-classroom practice is providing the learners with timely and effective feedback on that practice. A recent instructional enhancement promulgating through math and science classrooms attempting to address this is described as a flipped classroom. Bergmann & Sams (2012) coined this term to describe a course delivery redesign whereby students learn from video lectures outside of class as ‘homework’ and then spend the time in class working through practice and extension activities with instructors present providing immediate feedback. Bishop & Verleger (2013, p. 3) studied this design after a few years of widespread deployment and found video lectures to be performing better than in-class lectures, and interactive videos were setting a new, higher standard. They found that these intelligent tutoring systems were consistently as effective as human instructors.

While flipped classrooms are proving effective, another movement is underway. In *Disrupting Class* (Christensen/Horn/Johnson, 2008), the authors project that by 2019, 50% of all high school courses will be delivered online. Building on that vision, my (Randy Brooks) 2015 presentation at the Texas Computer Educator Association (TCEA) Convention (Brooks, 2015) described a path for transitioning from flipped classrooms to online classrooms with recreating the rigorous and engaging classroom environment at the center.

VanLehn (VanLehn et al., 2005) provides supporting data regarding options using Intelligent Tutoring Systems (ITS) based on a 4-year study on the benefits to be gained by moving paper-based homework to a technology-based system. He found considerable growth (11% improvement versus control group) for a physics course which he attributed to the use of an Intelligent Tutoring System (ITS).

> A classroom has many instructional activities that can have significant impacts on learning gains, so upgrading just one activity does not guarantee large overall course learning gains. On the other hand, if much of the students' learning goes on during homework, then replacing paper-based homework with an ITS can have a large effect size. (VanLehn, 2011) (p. 213)

Though flipping the classroom does provide more learner interaction with peers and the instructor regarding conceptual questions and practice, the impending movement to online courses requires that we find a way to replicate this feedback loop in the digital space. As options are investigated, the digital world venue requires that we revisit instructional design for a method that is most effective in this new environment. Tripp & Bichelmeyer (1990) provide a basis for employing ITS as a key component of the Instructional Design Strategy (IDS) called Rapid Prototyping. Their analysis denotes the design method supporting the production of the TAMU SRL Mechanix software as that of an early adapter in the quality online tool movement.

> The advent of various powerful and modular software prototyping tools has allowed the prototyping methodology to be applied to a domain where previously it was impractical. Thus the use of rapid prototyping in software design is a function of the development media available. (p. 35)

Next they define the model operation for us. "Rapid prototyping continues with the parallel processes of design and research, or construction and utilization. It is assumed that full understanding of needs, content, and objectives is a result of the design process and not an input into it". (p. 37) Then Tripp & Bichelmeyer further drive home the correlation between software engineering and IDS.

> Given the similarities between software engineering and instructional design, especially instructional design for computer-based instruction, rapid prototyping may offer all the same advantages in instructional development that it offers in software development. The argument can be made that rapid prototyping is even more appropriate for instructional design because it allows the flexibility needed when dealing with the greater complexity of a human factors-intensive field such as the process of instruction. (p. 36)

Mechanix is proving to be the model of the tool that Tripp & Bichelmeyer describe both in construction and in learner use, while differentiating itself with a heavy design focus on the human element. Tracy Hammond (2007), Director of the TAMU SRL, laid the foundation for Mechanix in her MIT Doctorate paper regarding LADDER (Language for Describing Drawing, Display, and Editing in Recognition) with a “goal to build sketch recognition systems that allow sketchers to draw as they would naturally–that is, without having to learn a new set of stylized symbols.” (p. 45)

Sketching the free body and vector diagrams is a key layout element, but each student may develop a custom path to create the final design. The goal from the instructor perspective is that the student produce a sketch matching norms that supports student learning of the target concepts.

In concert with publication of a new offering regarding the growth and vision of the human-computer interface tool market due to the advancing pen and touch technologies (Hammond/Valentine/Adler/Peyton, 2015), Tracy Hammond makes a case for interactive and computer-driven ITS production by emphasizing the importance of the immediacy of feedback during a portion of a TAMU CSE promotional video (2015):

> Computer Science is Mathematics, but with instant gratification. You find out whether or not your algorithms work immediately. This is now true in every domain. It is now part of every single different field that there is and you get to really test and design and invent new things and immediately get the feedback about whether or not your ideas are correct.

Mechanix History

The deployment of Mechanix in a portion of the engineering classes at LeTourneau University provides some basis for study comparison (Green et al., 2015) and a source for prediction. From a scoring perspective, the 73 LeTourneau students involved in the study performed equally well whether in the control (textbook software) or experimental (Mechanix) group. (p. 5). Yet the key items from the LeTourneau study are found in the learner evaluation follow-up analysis:

> In student comments the three most-mentioned learning benefits provided by the experimental software are: early feedback, promoting visualization, and teaching a good 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. Failure to learn to create correct free body diagrams can have disastrous results in future engineering courses and beyond. (p. 7-8)

Detail of Mechanix construction is found as we explore TAMU SRL submittals in 2012 and 2013 with the Association for the Advancement of Artificial Intelligence (AAAI) regarding the TAMU SRL development of Mechanix. In the earlier submittal, the authors (Valentine et al., 2012) state:

> Our system checks the student's work against a hand drawn answer entered by the instructor, and then returns immediate and detailed feedback to the student. Students are allowed to correct any errors in their work and resubmit until the entire content is correct and thus all of the objectives are learned. Since Mechanix facilitates the grading and

> feedback processes, instructors are now able to assign free response questions, increasing teacher's knowledge of student comprehension. Furthermore, the iterative correction process allow students to learn during a test, rather than simply displaying memorized information. (p. 2253)
>
> One great advantage of a sketch-based system is that it allows users to continually modify or edit their drawings as they would on pen and paper. The current Mechanix system provides such functionality through our round menu, buttons, and free-hand erasure. (p. 2255)

Further, the TAMU SRL team provides some very encouraging results regarding their early deployment at TAMU which suggests that the student population may show limited improvement upon initial introduction to Mechanix, yet subsequent uses begin to reflect increased learning versus current methodologies.

> In the second semester of deployment, 20 of 64 student volunteers from a regular section of ENG 111 used Mechanix, and the remaining 44 used traditional pencil and paper for comparison. Mechanix was used for three homework assignments. The grades for the first assignment were similar between the experimental and control groups. On the second and third assignments, however, the experimental Mechanix group scored an average of 25% higher than the control group. (p. 2259)

A semester later, the same TAMU SRL team is back with furthered analysis presented in the AAAI magazine, *Artificial Intelligence.* (Valentine et al., 2013).

> The aim of our deployed system is to advance the artificial intelligence of automated mechanical and civil engineering instruction, such that the automated instruction emulates the expert performance achieved by human instructors. (p. 56)

The following description from that same analysis provides us with insight into just one of the many unique features deliberately constructed to improve on a simulated human action. In this case, rather than requiring use of an eraser selection, the user may simply ‘mark out’ an entry and Mechanix understands that this is user input for erase. This level of human action replication detail appears to be a function of Dr. Hammond’s Anthropology and Artificial Intelligence background.

> We allow erasure by means of scribbling strokes, which can be faster and more natural for interaction than explicitly using buttons or menus. Keeping this purpose in mind, we integrated scribble gesture into the Mechanix system. We can use the scribble gesture to remove either a complete shape or part of a shape. We recognize scribble shapes as combinations of strokes in which time intervals are within 400 milliseconds. If a scribble stroke intersects most of a shape, the scribble erases the entire shape. On the other hand, if the stroke intersects only one line of the shape, then the scribble deletes that single line. In the case of amorphous closed shapes, if the scribble is localized on the stroke, it deletes only that part. (p. 58)

My final offering regarding background is a joint paper submitted by the TAMU SRL and Georgia Tech peers (Nelligan et al., 2015) to an Intelligent User Interface (IUI) conference in the Spring of 2015. Part of their offering was a review of other tools addressing the same market need as Mechanix.

> Though similar in parts to Mechanix, none of these systems include the combination of sketch recognition with trusses and free body diagrams in order to provide a complete solution for working students through an entire problem.The usage of sketch recognition gives Mechanix several advantages that benefit both students and instructors.

With these citings as a backdrop, the TAMU SRL chose to take Mechanix to the next frontier, the high school classroom.

Class Specifics

Lovejoy High School in Lucas, Texas is an all Pre-AP College Preparatory Public High School regularly ranking highly on national evaluations of student performance such as those comparisons performed and published by U. S. News & World Report.

The classroom venue for the deployment of Mechanix is a Project Lead the Way (PLTW) Principles of Engineering (PoE) course and I (Randy Brooks) am the instructor of the PoE course. (PLTW is a STEM-focused non-profit currently providing curriculum and support to instructors in over 8,000 American schools.) PoE is an elective for students investigating their interest in studying engineering in college. In fact, many colleges are now offering first year credits for completion of PoE. We cover a wide array of activities with a focus on ingraining the Engineering Design Process in the student skillset, constructing and programming automated compound machines, and applying physics to concepts for addressing real world issues. The physical classroom provides significant construction space as well as a desktop computer for each student for accessing a myriad of digital tools to include Mechanix. It is a normal practice at Lovejoy High School for instructors of any subject to bring digital supports, whether time-tested or in beta-test, into their classroom as support for students.

Students are a mix of high school levels with previous Math and Science knowledge ranging from concurrent Geometry and Biology to previous completion of AP Calculus and AP Physics courses. The class target is sophomores, yet is open to advanced freshmen and interested juniors and seniors. Consequently, there is significant differentiation applied to all lessons. The grade-level distribution is: Freshman – 2, Sophomores – 19, Juniors – 6, Seniors – 9. Of the 36 students in the class, 31 students chose to participate. Participating student data was subsequently grouped according to their performance level in their previous semester mathematics course. 19 students earned an A, 8 students earned a B, and 4 students earned a C. Proficiency in mathematics is one of the determinants for suggesting that students consider this engineering course.

The platform for vector analysis practice was student choice. Traditional paper-based practice forms were provided as well as Mechanix logins for tool access. The same practice problems existed in each option. Mechanix was positioned as simply another digital tool that the instructors of Lovejoy High School have discovered and were offering for student support. There was no grade taken in regard to Mechanix use.

The Mechanix tutorial was constructed with progressively reduced scaffolding across 8 practice problems. The first practice action was designed to familiarize the students with Mechanix by providing solutions along with direction about how to sketch and document the solutions.

In an effort to get the student knowledge levels more in-line before having the students work in Mechanix, the Mechanix deployment began with a day of lecture and practice regarding free body diagrams and vector analysis.

As expected, the combination of a summer break and limited or no learner prior exposure to vector analysis of the majority of the students generated low scores on the pre-assessments (quizzes) used for this study. Armed with this data, the instructor then develops interventions targeting the identified weaknesses of the specific student population involved. New practice problems in Mechanix would be one of the interventions implemented.

The Mechanix tool proved a stable platform throughout the study. Students encountered issues related to the Java version on the high school computers driving some unplanned program closure, yet we quickly identified a work around that proved quite effective.

Appendix A is a screenshot of the instructor’s template for Practice Problem #4. This is provided as sample of the visual element of Mechanix. Note that students must sketch the free body diagram depicted and then determine the x and y components of each vector in order to determine a force level required to keep the design static.

Deployment

Appendix B depicts the timeline for vector analysis instruction to include the Mechanix tool as an available support in my (Randy Brooks) LHS PLTW PoE classes. The Mechanix impact evaluation involves comparing assessment (quiz) scores before using Mechanix for a week of practice to the scores immediately following that week of the use of Mechanix.

Data Collection

Appendix C reflects the quiz score comparisons grouped by the previous year’s overall math grade (A=1/B=2/C=3). The quizzes consisted of 4 similar challenges on each quiz scored out of 12 points with 4 points related to accurately completing the free body diagrams, 6 points allocated to accuracy of set-up and process, and 2 points allocated to calculation accuracy.

Analysis

There was measureable improvement (13.7%) overall from the pre-Mechanix quiz to the post-Mechanix quiz. The greater progress was realized by the A-level students (17.3%). As the engineering class attracts the math-focused students, this A-level group, many of which had little previous exposure to the vector language, spent the week in Mechanix making the connections that they are accustomed to making in their math courses. Consequently, many significantly increased their understanding of vector analysis. Though training and scaffolding was built into the Mechanix practice problems, more direction and instruction is required to better support the B-level and C-level student populations.

The vector practice in Mechanix was followed by participation in a Georgia Tech MOOC on Statics and an online bridge building contest with a focus on truss design. At that point we will again engage Mechanix for truss analysis practice where, similar to the previously identified TAMU SRL (Valentine et al, 2013) findings, I expect significant progress upon subsequent uses of Mechanix when compared with the impact at initial deployment.

I also observed a similar byproduct as noted in Green’s previously referenced reporting of student observations (Green et al., 2015) that Mechanix, by deliberate design, emphasizes the benefits of learning to follow a problem-solving process. Mechanix is expected to flourish in an environment where pen and touch technology is widespread yet my study population, with the exception of two outliers, was content to work exclusively with their standard computer mouse.

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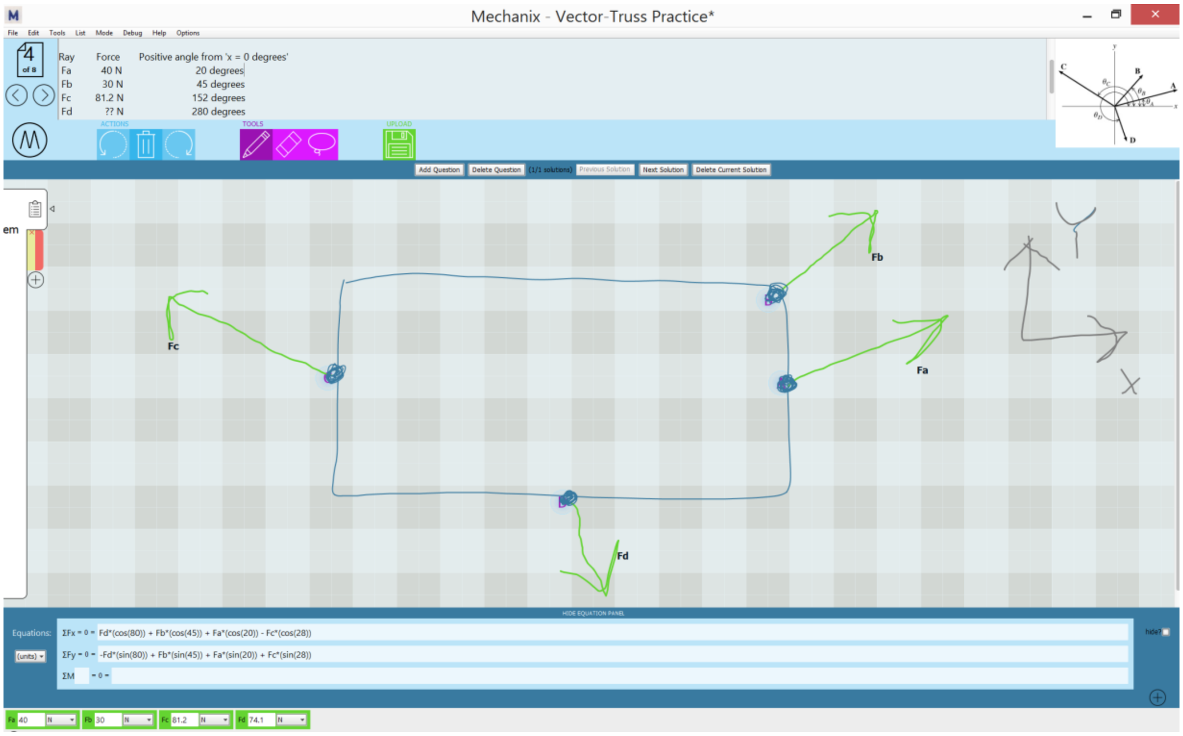
Appendix A

Screenshot of an instructor solution in Mechanix



Ray	Force	Positive angle from 'x = 0 degrees'
Fa	40 N	20 degrees
Fb	30 N	45 degrees
Fc	81.2 N	152 degrees
Fd	?? N	280 degrees

ΣFx = 0 = Fd*(cos(80)) + Fb*(cos(45)) + Fa*(cos(20)) - Fc*(cos(28))

ΣFy = 0 = -Fd*(sin(80)) + Fb*(sin(45)) + Fa*(sin(20)) + Fc*(sin(28))

ΣM = 0 =

Fa 40 N

Fb 30 N

Fc 81.2 N

Fd 74.1 N

Appendix B

Timeline of the Mechanix Deployment Plan

Mechanix Deployment Plan

Date	Activity
Monday, August 24, 2015	School Begins
Wednesday, September 02, 2015	45 minute lecture regarding construction of free body diagrams and analyzing vectors. 4 paper-based practice problems were assigned to be completed before the pre-Mechanix quiz on the following Wednesday. PowerPoint presentations and the key to the 4 practice problems were posted digitally for student reference.
Wednesday, September 09, 2015	Students complete 4 question paper-based pre-Mechanix vector analysis quiz during class.
Thursday, September 10, 2015	Short Mechanix demonstration for the class. Students were assigned 8 vector analysis practice problems with student choice to use paper-based, Mechanix (an ID/PW was provided to each student), or a combination of the two. No score was given regarding practice completion. Students are given some class time during the following week to work on the practice problems.
Friday, September 18, 2015	Students complete 4 question paper-based post-Mechanix vector analysis quiz during class.

Appendix C

Summary of student score improvement data

Analysis Category	Pre-Mechanix Quiz Score	Post-Mechanix Quiz Score	Quiz Score Improvement	Percent Improvement on 12 Total Point Quiz
Full Study Average	5.47	7.11	1.65	13.7%
'A' Student Average	4.93	7.01	2.08	17.3%
'B' Student Average	7.84	8.84	1.00	8.3%
'C' Student Average	3.25	4.13	0.88	7.3%