Deploying Intelligent Tutoring Systems (ITS) in the Engineering Classroom

Randy Hugh Brooks, Texas A&M University

Howdy,

After 23 years in Telecom building the internet and email, I observed that the front line personnel that I was hiring didn't have what I considered to be skills that they should be bringing to the table. I began investigating why, and that led me to high school. Alas, I began my journey in Education in 2010 inhabiting the classrooms of Lovejoy High School, where my two daughters attended.

I redubbed my PreCalculus course as Problem-Solving with Brooks and was also afforded the opportunity to lead a Project Lead the Way (PLTW) Principles of Engineering (PoE) course which is a project-based learning survey of the engineering discipline.

Since the Summer of 2015 I have been privileged to work with the Texas A and M Sketch Recognition Lab (TAMU SRL) to evaluate two online tutorial tools (Intelligent Tutoring Systems (ITS)) currently under development, Mechanix and Sketchtivity, that provide immediate constructive feedback to the students and student-level metrics to the instructors. I presented on this work at the state and national PLTW Conventions and at CPTTE in 2016.

I also spent 5 semesters beginning the Fall of 2015 in online courses learning how to construct and deliver online courses. This resulted in a MSEd from Purdue University in Learning Design and Technology (LDT).

This widely varied background prepared me well for my next big adventure. Beginning in August 2018, I accepted a role as the Texas A and M Professor of Practice for the Texas A and M Engineering Academy at Blinn College in Brenham. TAMU Engineering Academies are an innovative approach to providing the planet with more Aggie Engineers.

I am a technology learner and have been a regular presenter at the state TCEA (Texas Computer Educator Association) convention and PLTW state convention each year.

My career began with a B.S. in Telecom Engineering from Texas A and M. Upon graduation, my learning continued at MCI, Vartec, and Charter.

Deploying Intelligent Tutoring Systems (ITS) in the Engineering Classroom

Abstract

The volume and complexity of student analysis practice required to effectively navigate engineering courses drives the need for Intelligent Tutoring Systems (ITS) deployment to best manage the time of both students and instructors. This study will explore student feedback and instructor observation of a recent classroom deployment of the Physics Education Technology (PhET) online simulation tool [1] and two specialized web-based ITS tools, Mechanix and Sketchtivity. These three tools provide personalized and immediate feedback to each student while encouraging students to explore new pathways regarding the concepts that the tools address.

PhET, Mechanix, and Sketchtivity are digital products with instructor-tailoring capabilities and availability anytime and anywhere for students to continue their practice while receiving instructor-influenced visual and textual constructive feedback regarding their actions. The student feedback was generally positive regarding tool operation. Additionally, all three tools appear to have overcome some previous technology challenges, even since the initial student feedback was gathered in Fall 2019.

Introduction

Human-Computer Interaction (HCI) has given rise to the ability to construct digitally-based tools providing constructive feedback in response to human actions, to include hand-sketched products. [2]

PhET is a comprehensive online math and science (it has grown well beyond just physics concepts) simulation tool, with development driven by education research, that provides real-time visual responses resultant of student input. Launched in 2002 by the University of Colorado at Boulder, PhET has become a standard tool for instructors in grades 6-12, as well as a support for students in early college courses. Students may experiment with activities ranging from building electrical circuits to magnetism to molecular interaction. PhET is an engaging online environment with a game-like foundation.

Mechanix provides significant support for one of the more time-intensive homework/grading courses in engineering, Statics. Instructors build custom practices (truss and free-body analysis), or use existing standard configurations, and students may attempt the problems anytime and anywhere. The students receive immediate constructive feedback from Mechanix, and instructors may gather metrics regarding student/class performance. The student metrics may then be used by the instructor to tailor future lesson elements based on the results of the practice work observed in Mechanix. Mechanix has been shown, in numerous studies across multiple

universities, to facilitate progress in student understanding of truss analysis.[3] When Mechanix was used as a practice tool in a high school engineering classroom, "we used pre- and post-testing to assess progress, which showed an average increase of 1.65 points on a 12 point scale ($p < 0.005$). A greater increase was found in the 'A-level' high school students while historical, college-level studies suggest significant progress may be realized at all levels versus current tutoring techniques as the students continue to utilize Mechanix." [5]

Sketchtivity is enhancing drawing skills by analyzing performance on digital sketches of common shapes and progressing through to 3D constructs. Enhancing the offering is an award-winning gaming aspect that emphasizes the key measurable elements of a well-sketched line: speed, accuracy, and precision. Sketchtivity also collects student data as metrics for the instructor to evaluate and use to adjust future activities. Sketchtivity has a long history of enhancing student sketching capabilities through both the direct training and game-based design aspects. [4]

The foundation for Mechanix and Sketchtivity is based in Language to Describe Drawing, Display, and Editing in Sketch Recognition (LADDER) [2], a generic sketching programming language, with a goal to build a sketch recognition system that allows sketchers to draw naturally without having to learn a new set of stylized symbols.

This study explores the engagement levels (qualitative approach) for deployment of these products in an engineering freshman-level applied mechanics lab course. The Mechanix deployment is contrasted with a previous use in a Project Lead the Way (PLTW) high school classroom. [5] The Sketchtivity application will focus on self-efficacy of engineering students in their sketching capabilities in support of enhancing their ability to share their thoughts and ideas in an unstructured sketching environment. The PhET deployment is targeted to evaluate the impact of providing visual interpretations of physics concepts. The results will be in the form of student self-evaluations and instructor observations in regard to the impact of these tools on student learning.

Background

Two existing challenges of the engineering educational process targeted by ITS products are:

- Students do not receive timely feedback on voluminous and complex practice work.
- Student understanding of concepts is improved through timely viewing of a visual model, whether physical or virtual.

The need is to remove constant direct and in-person instructor interaction as the dependency for student learning. Students benefit from immediate feedback, hence the focus on formative assessment, yet the complexity of many engineering exercises inserts delay between when the student produces the work and when the instructor provides feedback.

I initially encountered the need for timely feedback support in my high school PLTW engineering classroom to enhance student understanding of electrical circuit design and operation, and to progress student skills regarding truss analysis. PhET provided a very impactful product depicting electrical circuits, and Mechanix held promise for truss analysis support.

Previous Deployment

Prior to my ITS use in the 2019-2020 school year, I deployed PhET and Mechanix [5] in my high school PLTW engineering classroom as an online resource where my students were able to virtually explore concepts discussed in class. PhET was particularly impactful as the design is game-like, so the students were drawn to it. At that time Mechanix was script-based, often a technical challenge just to get the program running, and not available on all computer products.

Though both PhET and Mechanix provided constructive feedback to students, neither provided performance metrics which the instructor could use to adjust future lessons. The construct had begun in Mechanix, but was not yet at a level that an instructor could pull data in order to analyze individual/group performances and adjust future lessons. As such, any Mechanix-driven course adjustments were based upon direct student-instructor feedback or real-time instructor observations.

Even though the technical challenges limited student use of Mechanix, I was able to gather enough performance data on 31 students to support assertions regarding the impact of the tool. Using pre- and post-tests covering free body diagrams and truss analysis, the student scores increased an average of 13% when comparing their scores on the pre- and post-tests. The A-level math students realized a 17+% gain. An unexpected benefit was students learning the structured problem-solving process involved in truss analysis as they followed the guidance detailed in Mechanix. [5]

Study Application

The classroom associated with this study is an engineering lab supporting both a physics mechanics lecture and a general engineering mechanics lecture. This is the second semester course of the first-year student program. The first semester course focused on computer program design using Python, so this is the students' first collegiate exposure to mechanics concepts and activities.

PhET was quickly engaged by students due to the game-like design as well as many students having a familiarity with PhET from use in high school classrooms. The intuitive flow allowed them to confirm concepts and then move on to virtually pushing boundaries of mechanical systems.

Mechanix now exists as an HTML5 tool. Students were able to use any media device to access and engage with the toolt. Some even used Mechanix on their phone. Because there are no tutorials in place, there is still significant base information that needs to be pre-taught before assigning student work. Once a student understands truss basics, Mechanix provides guidance through the process via constructs and textual hints. A green bar drops down with 'Success!' written in the center when a student has taken the correct action. Students find this immediate feedback unusually satisfying.

Sketchtivity is designed to help students enhance sketching skills that are rarely addressed throughout their educational and professional careers, yet can prove impactful when they encounter an impromptu, unexpected opportunity to ‘sell’ their idea. Students start from the basics, such as drawing a line, and are well-supported with lesson videos and visual guidance for each lesson. Practice may be pursued through a structured plan, or by selecting their own path through the lessons. The most popular item is an award-winning gamified line sketching activity whereby points are awarded for achievement levels of three basic sketching metrics.

Instructor Observations

All three tools provide digital formative assessments with immediate feedback to the students from the tools. PhET and Sketchtivity respond with visual stimuli to be interpreted by the student, while Mechanix is designed to provide textual hints and guidance.

PhET is an online simulation tool widely utilized at all levels of education and is currently accelerating the move of all of the simulations to HTML5 to ensure they appear seamless across all platforms.

Student engagement with PhET suggests that they enjoyed working through the simulations, although they may not always effectively tie their observations to the underlying and guiding concepts. There is less structure for guiding the students, so learning is most effective when the students are given specific tasks by the instructor, such as building a parallel circuit and showing the calculations that validate the values represented in their simulation. PhET simulations act as a vehicle of learning with tangible, visual feedback.

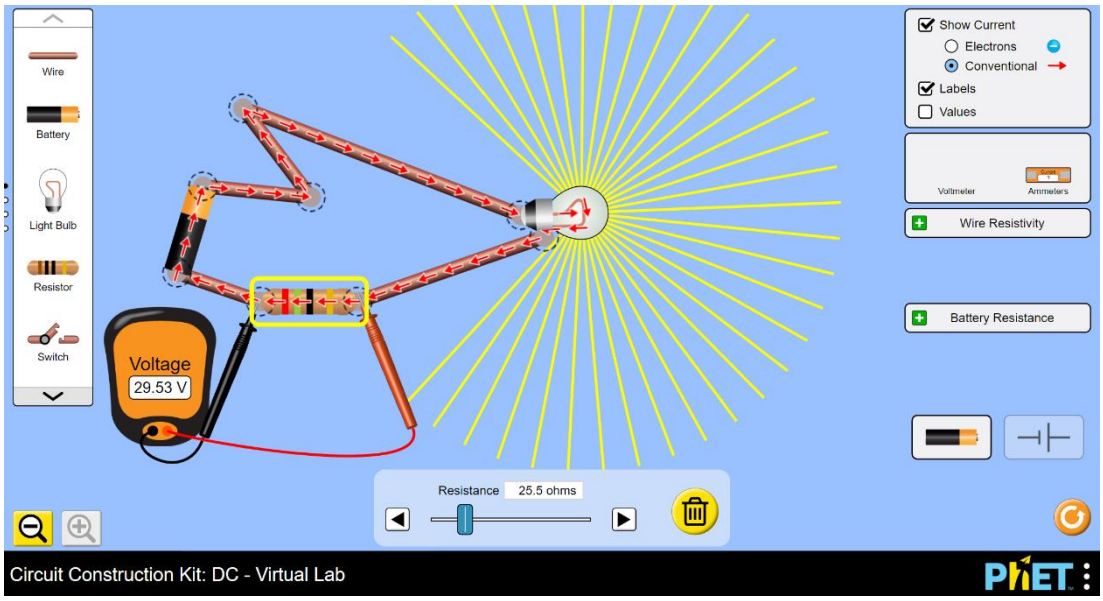

Figure 1- PhET

A PhET simulation of an electrical circuit with light and multimeter.

The Sketchtivity and Mechanix tools continue to be adjusted by the Texas A&M University Computer Science Sketch Recognition Lab (TAMU SRL) with the fine-tuning driven by both programmatic efficiencies and instructor feedback. Students adapt well to the guidance provided in Sketchtivity and are drawn to the game. Mechanix is a greater challenge such that, when deploying all three tools concurrently, students tend to abandon their work in Mechanix as too difficult. Pre-teaching the truss analysis process, couched in curriculum, is critical to create foundational understanding to best interpret the guidance and hints provided by the tool.

At the end of the course I have students submit a reflection regarding their learning in the course. Many students highlighted the benefit of PhET in helping them do the lab work as well as better understand the concepts in their concurrent Physics course. A few lamented about not being made aware of PhET earlier in the semester, and several others considered PhET a key tool for helping them get through their sudden online courses resultant of the COVID-19 physical school closures.

Student comments and my observations are from classes with second- and third-semester engineering students in Fall 2019 and Spring 2020. The Fall 2019 cohort consisted of 19 students that used all three tools. Spring 2020 consisted of 80 students which used PhET, with 23 of those 80 also using Sketchtivity and Mechanix. Sketchtivity and Mechanix are best experienced on a touchscreen device, and not all of the students had access to such a device once we moved the Spring 2020 courses online. A few completed the activity on devices in the lab before departure.

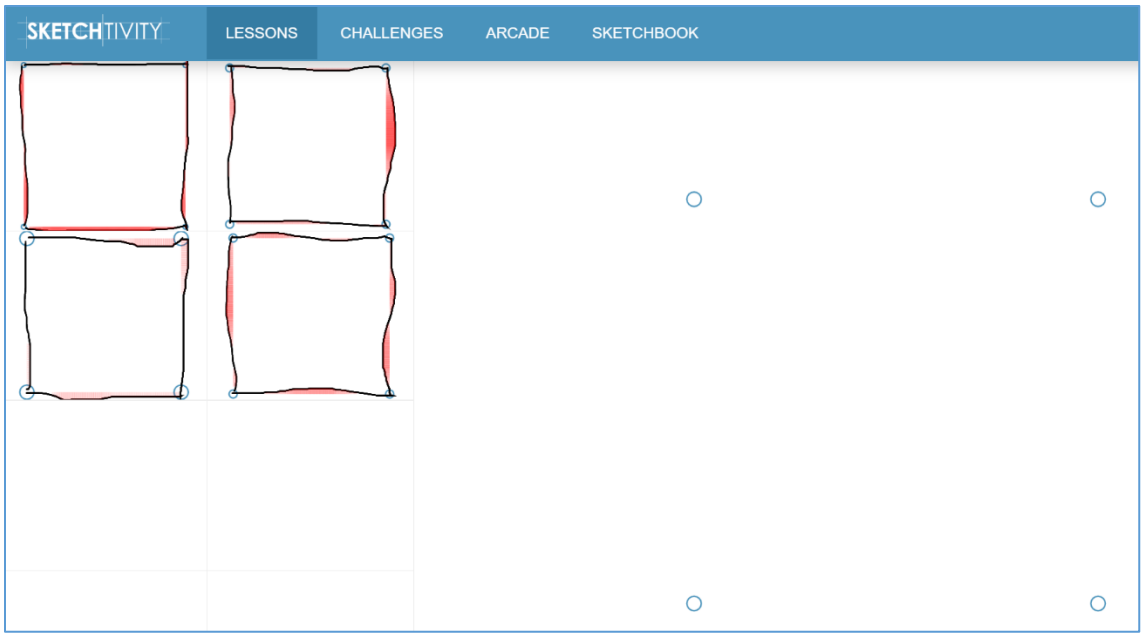

Figure 2 – Sketchtivity

Drawing squares lesson with first four attempts and red highlighting misalignment

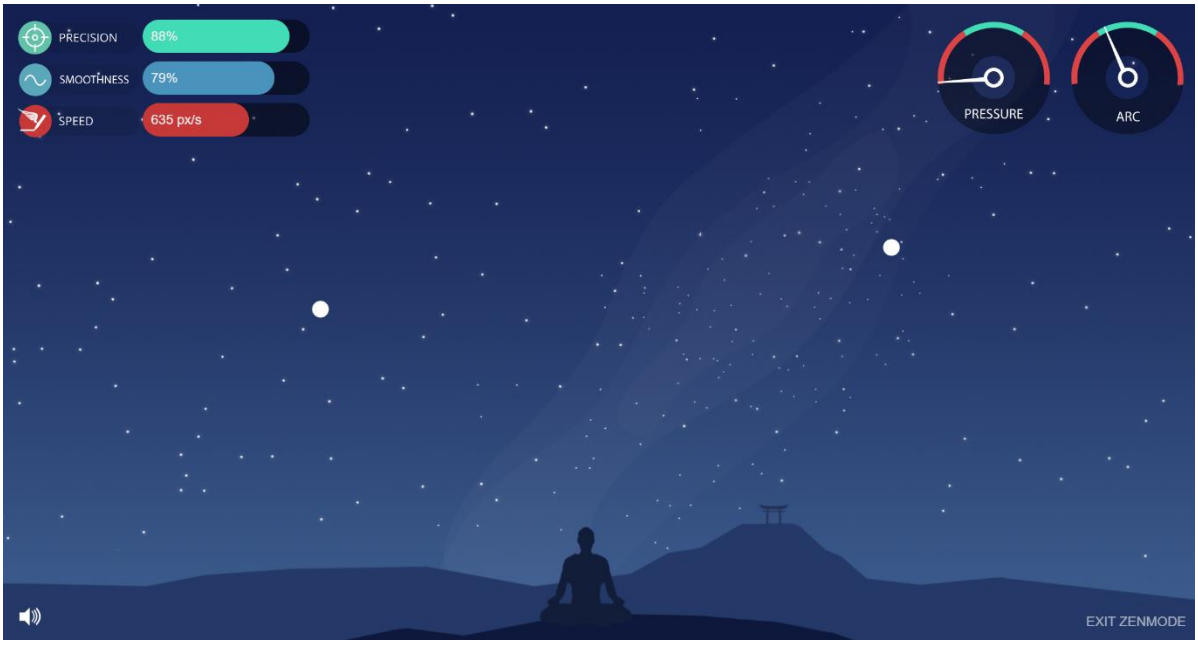

Figure 3 – Sketchtivity

Line drawing game with scores for the last line in top left corner.

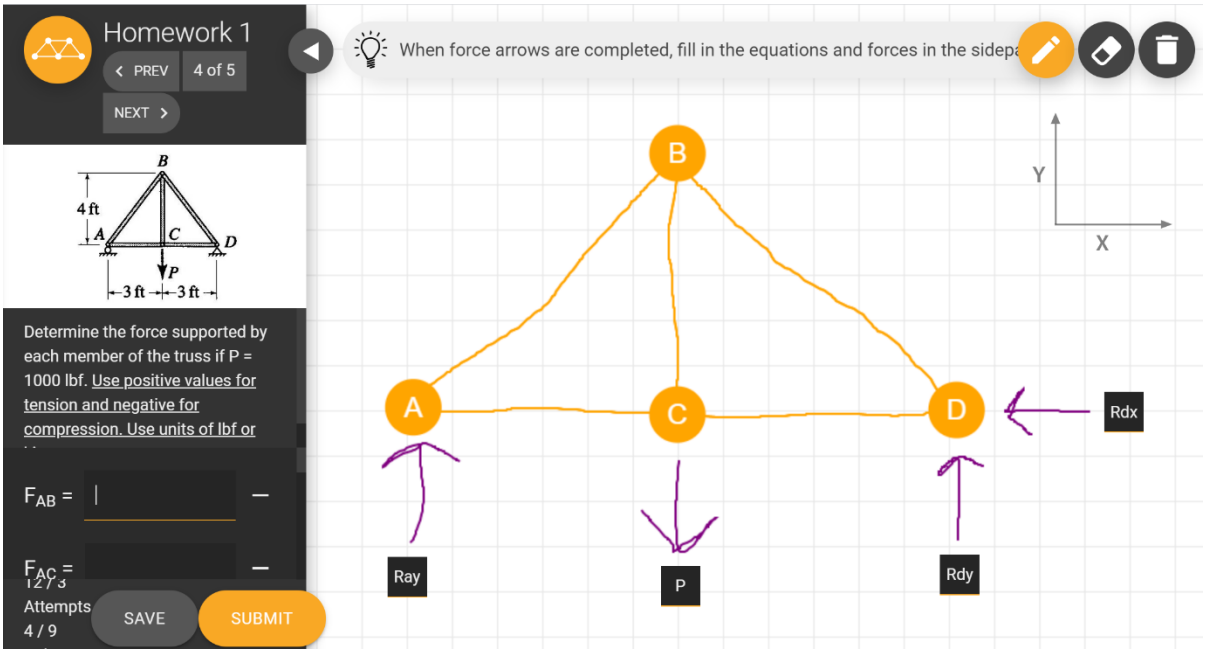

Figure 4 – Mechanix

Successfully drawn truss with external forces drawn and labeled.

Student Comments

I collected comments regarding all three products from 19 third-semester engineering students in Fall 2019. Also included are comments from 80 students in Spring 2020. Many of these were unable to experience Sketchtivity or Mechanix fully without a touchscreen device. Below are representative comments from the students regarding the three tools targeted in this study.

PhET

- "I felt that the functionality of the tools, reminding me of old games, made the experience more engaging, and the options to include other aspects such as center of mass and the speeds of objects in the collision and forces/motions labs were very interesting and visually engaging, making understanding the way forces acted on one another much easier to observe."
- "Even though the simulations are fairly simple, it would still be helpful to have a tutorial function to help guide the user in using the simulations."
- "Once you enter the lab there are no further instructions as to what can be done so the user must figure this out for themselves. Though this is not hard, some of the features that make the program so good such as the vectors for velocity and acceleration are hidden and could be hard to find on your own."
- "When it came to the forces and motions lab it was neat in the way that it had many customization options to run a wide range of conditions."
- "Overall these simulations are great, for understanding and visualizing concepts they are perfect. However, since they are so basic eventually they lose their effectiveness when concepts become more complicated than these simulations."
- "There is not any noticeable instructions or lessons linked with the simulations, which somewhat leaves the participant in the dark of what they should be directing their attention on."
- "The 'Mass and Spring Basics' simulation is an exact representation of the relationship between a mass and a spring. I think this simulation provides the right amount of visual feedback to help a user understand both the conceptual and application side when learning this topic in physics."
- "As I started running through each of the few simulations I began to realize that this application was a great tool for visualization of physics topics."
- "The page with all of the simulations is long and annoying to navigate. A better and more compact design would be helpful."
- "While running through some of the other simulations though, I found that most of them did not have any instructions. I believe this was intentional, because the website wanted students to learn through trial and error. Coming across some of the simulations, I was confused on what I was supposed to do, so I began with just pressing random buttons. I think this made it a much better learning environment; in that I was able to learn how to perform the 'experiment' myself."
- "The ability to pause and step through a lab in .01 sec intervals is also an amazing feature."
- "I think software like this is very helpful for students who are trying to get a better understanding in physics."

- "Overall I like that the simulations PhET provides were well engineered for anyone who wants a visual understanding about any physics concepts."
- "'The brain processes visual information 60,000 times faster than text.' -Unknown. The PHET Interactive Simulations is a great resource for those who like to see things and get a different perspective in order to understand the content learned. Not only is it a great representation of theoretical scenarios given in class, but it's also interactive, helping you change different measurements or forces to help you understand the results."
- "This clearly has been a passion project from teachers and it shows, creating resources for both younger and older demographics. It exudes design integrity and availability."
- "If I were confused on a certain subject matter regarding any of these certain physics concepts and needed a good visual to help understand how to do something, I would refer to the PhET simulations because they are truly beneficial."
- "Two main problems that I had with the simulations were these: they did not explain the math and sometimes I had no idea how to work the simulations because there were no instructions."
- "The concept of having a massive databank of simulations that allow the user to witness STEM principles in action is incredible."
- "My high school physics teacher was also once a physicist for NASA and found these simulations to be very impactful."
- "The picture icons for each simulation allowed me to have an idea of what each simulation was going to consist of, as well as draw me toward some simulations that were not recommended to me."

<u>Sketchtivity</u>

- "I like the variance in different sizes to be drawn which allowed for different approaches to draw."
- "Using the software, I learned that my skill in drawing circles is lacking and could see improvement compared to my other skills. The difference in drawing with a pen or stylus was also helpful as it allowed for more control than the use of the trackpad resulting in a better performance."
- "The feedback the program gives you feedback on how you did with each drawing and what to work on was also beneficial towards learning these skills, as it gave you a direction to go moving forward rather than just trying to guess what you need to improve on."
- "From drawing simple vertical and horizontal lines all the way to drawing 3D objects, it was interactive and enjoyable. I found the red shade between the 'perfect' drawing and the user's is extremely beneficial and illustrates the amount of error very well."
- "In calculus three you must graph in three dimensions and this is a very good way to practice."
- "I believe if there were less drawing and more of a focus on improving previous drawing the app would be more beneficial."
- "Drawing circles proved to be difficult but the more practice I got, the more accurate my circles were."
- "Found that the grading was a bit too harsh, especially if a student user were to attempt the lessons."

- "I believe I would definitely use this application to further improve my sketching skills outside of a classroom."
- "The response was immediate, and the drawing part felt extremely fluid. I found myself playing and doing this lab longer than I needed to, which was amazing. I was amazed how it shows the error of your drawing, especially for circular drawings, and it makes me wonder about the math for that."
- "The Sketchtivity application was extremely helpful while, at the same time, remaining entertaining. I enjoyed the sleek design of the tool, and each section was divided up nicely into each individual part. The star-based rating system added to the fun and pushed me to draw better. I was surprised at the lack of skill I possessed in drawing straight lines, but I soon found myself improving. Seeing that improvement in the span of a few minutes was encouraging and kept me engaged."
- "I encountered a new way to draw a circle. Before this lab I would mostly freehand circles in sketches, but the guidance of that SketchTivity provided for circles made the shape more accurate when I drew it."
- "The sketchtivity app seems to be an effective method of teaching students to be more fluent and organized in drawing sketches. Having an interest in drawing and sketching designs myself, I'm familiar with this method of teaching by repeating lines or drawings which has definitely helped me with my problem of having uneven lines in my sketches and overall confidence in my ability as an artist."
- "The most beneficial features of the app were easily-to-navigate modules, and the bridge game. I could see younger students playing the in-app game and improving their drawing skills without even knowing it! The Sketchtivity app proved to be very fun and beneficial to an engineering curriculum."
- I thought the lessons would be boring because we were taught how to draw and stay inside a picture in elementary school, but the program used a red shade to criticize each drawing and gave you a score. This kind of criticizing made each lesson even more interesting and it produced a fun learning environment.

<u>Mechanix</u>

- "The program did a good job of recognizing what was drawn, even when poorly drawn."
- "When you get a wrong answer there is not any instruction on how to fix it or what you did wrong in the first place. "
- "It would have been nice if the program had a function that would give you hints or guide you through similar problems so you could get a better grasp on how to complete the task. Perhaps for someone that already understands the concepts it would be a good way to practice these skills, but it didn't seem particularly good for someone who is still learning, as they would require outside notes to complete the tasks."
- "This program was very frustrating to use because there was no clear instructions on how to complete the task."
- "This application is super useful to give students additional practice. Unfortunately, there is no tutorial or help with the practices."
- "I found it useful because it would give hints and guide you on how to solve the problem. Although it helped me understand how to find the forces, I would suggest that the app would give more hints as people who don't know much about truss forces might have difficulty in finding the forces."

- "Not exactly simple for a rookie audience."
- "I like how it prompts you, after each force arrow is drawn, to fill in the equation that arrow represents."
- "There could be a lot of changes for this website to make it useful such as adding tips or guidance to the problems so the students gain insight to what they are solving."
- "The interface was difficult to try and figure out what the tool was wanting the user to do. Once I figured out what was required of me the tool still had a hard time picking up my arrows as the correct force arrow."
- "I was unsure if the problem was asking for the actual force or the equation that found the force at each point. After I passed the number of attempts that was allowed I thought that it would walk me through where I messed up but it did not. It just kept letting me enter wrong answers."
- "The prompts were also a nice addition, however it would be nice if they were more detailed and gave more in depth instructions."

Future Enhancement Opportunities

The PhET management team is currently pursuing funding to move all of their resources from scripts to HTML5. A portion of these are already complete. This is key to keeping the activities operating on future operating systems. PhET needs to investigate opportunities for adding instructor support such as building a class for students to enter where the instructor can evaluate their work both individually and as a group. Additional guidance for the students is also needed on several simulations. The movement of learning online in Spring 2020 has also driven the PhET team to begin work on better instructor and classroom-level supports.

Sketchtivity is ready for mass deployment, and the department is currently pursuing funding options. The tool is addressing a skill overlooked in most school curriculums. Sketchtivity has proven stable, though the students on iPads still periodically encounter a lock-up and may need to restart their lesson. The highlighting of the errors in their sketching in red is very impactful and guides students to pay attention to all aspects of their technique. The game is designed to emphasize and score each of the three sketching aspects for each line that they draw.

Mechanix requires further study and enhancements before the tool is ready for mass deployment. There are still challenges regarding easy access of student metrics by the instructor. In contrast to Sketchtivity, students need to understand the free-body drawing and truss analysis process before attempting work. The hints and guidance are effective once in the flow, but many students find it difficult to get started if they are not well-grounded in the analysis steps.

Summary

PhET is widely deployed in an array of learning situations and the move to HTML5 is timely. Though no tools yet exist for instructor management, student assessment may still occur through collection of screenshots or screen-capture tools.

Employing Mechanix requires significant pre-teaching regarding topics such as free-body diagrams and truss analysis, as well as some tool-specific interpretation training.

Sketchtivity is a full student-centric package whereby a directive to complete particular lessons allows a student to learn, with significant scaffolding in place in the form of instructional videos and intuitive feedback and scoring. The addition needed is instructor support such as student/group metrics and lesson customization.

All three tools have overcome previous technical access challenges that have stymied them in the past. Now both student and instructor can focus on best using the tools to master the concepts.

References

[1] PhET Interactive Simulations. (n.d.). Retrieved April 30, 2020, from https://phet.colorado.edu/

[2] T. Hammond, "LADDER : a perceptually-based language to simplify sketch recognition user interface development," Ph. D. dissertation, Dept. Elect. Eng. & Comp. Sci., MIT, Cambridge, MA, 2007.

[3] S. Bante, and E. Hilton, and K. Talley, and K. Shryock, and J. Linsey, and T. Hammond, "Board 65: Changing Homework Achievement with Mechanix Pedagogy*," in 2019 ASEE Annual Conference & Exposition, Tampa, Florida, June 2019.* https://peer.asee.org/32398

[4] B. Williford, and M. Runyon, and J. Cherian, and W. Li, and J. Linsey, and T. Hammond, "A Framework for Motivating Sketching Practice with Sketch-based Gameplay," in *Chi Play '19, Barcelona, Spain, October 22-25, 2019.* doi: 10.1145/3311350.3347175.

[5] R. Brooks, and J. Koh, and S. Polsley, and T. Hammond, "Score Improvement Distribution When Using Sketch Recognition Software (Mechanix) as a Tutor: Assessment of a High School Classroom Pilot," in *Frontiers in Pen and Touch Human–Computer Interaction Series*, T. Hammond, A. Adler, M. Prasad, Ed. New York: Springer, 2017, pp. 125–135. doi: 10.1007/978-3-319-64239-0_9