4.1 Overcoming the Critical Shortage of STEM – Prepared Secondary Students Through Modeling and Simulation

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Abstract:

In developing understanding of technological systems – modeling and simulation tools aid significantly in the learning and visualization processes. In design courses we sketch, extrude, shape, refine and animate with virtual tools in 3D. Final designs are built using a 3D printer. Aspiring architects create spaces with realistic materials and lighting schemes rendered on model surfaces to create breath-taking walk-throughs of virtual spaces. Digital Electronics students design systems that address real-world needs. Designs are simulated in virtual circuits to provide proof of concept before physical construction. This vastly increases students' ability to design and build complex systems. We find students using modeling and simulation in the learning process, assimilate information at a much faster pace and engage more deeply in learning.

As Pre-Engineering educators within the Career and Technical Education program at our school division's Technology Academy our task is to help learners in their quest to develop deep understanding of complex technological systems in a variety of engineering disciplines. Today's young learners have vast opportunities to learn with tools that many of us only dreamed about a decade or so ago when we were engaged in engineering and other technical studies. Today's learner paints with a virtual brush - scenes that can aid significantly in the learning and visualization processes. Modeling and simulation systems have become the new standard tool set in the technical classroom [1-5].

Modeling and simulation systems are now applied as feedback loops in the learning environment. Much of the study of behavior change through the use of feedback loops can be attributed to Stanford Psychologist Alfred Bandura. "Drawing on several education experiments involving children, Bandura observed that giving individuals a clear goal and a means to evaluate their progress toward that goal greatly increased the likelihood that they would achieve it." [6].

As a young sailor racing small-scale sail boats I was told by an experienced competitor that I needed to develop "a really good sense of speed." This meant that I needed to be able to perceive the associated increase or decrease in the boat's speed as I made a change. I could then optimize these small changes to outperform other competitors. This little story illustrates what we are attempting to do with modeling and simulation systems employed in pre-engineering and Career and Technical Education. Having learners reach the "Evaluation" stage in Bloom's taxonomy – is the the holy grail for many educational initiatives. Students would then be able to gauge their progress and correct their course accordingly. However, we restrict this goal to the competencies which our learners are tasked with – which should be achievable goals on an individual basis. The larger task of educating fully-prepared professional engineers will be left to the university environment. [7-8]

Students are applying modeling and simulation systems as feedback loops that inform their learning process. They construct and test an element of their design and the modeling and simulation system allows them to explore its attributes and functionality in-process prior to moving forward. In this feedback loop – the student is not required to consult an outside source – such as the instructor or another student to test basic relationships and design ideas. The feedback offered is nearly immediate and very dynamic. The modeling and simulation system will allow for a rich exploration of the learner's creation which is used to improve design ideas in-process. This has the effect of deepening and enriching interactions between learners, their peers and instructors due to the fact that they are often interacting about larger more systematic issues that are central to the functionality of the design [9-10].

Carnegie Mellon University implemented an instructional initiative which deployed custom-developed software designed to give individual immediate feedback to support learners in it's Open Learning initiative which consists primarily of mathematics and science courses. The goal of this grant-funded project was to improve the learning experience for learners who did not have access to campus-based lectures or labs through software that would give learners individual feedback. When compared to a control group of campus-based learners who had the same course-work without access to lectures and labs – there was no significant difference found between the two groups performance on standardized tests. Rather than pursue the thought of eliminating teaching positions in favor of software – Carnegie Mellon is now exploring deployment of this software in live, on-campus courses to allow instruction to accelerate - better-utilizing the expert abilities of their instructors by allowing them to cover topics in more depth and help learners to see their real-world applications[11].

In mechanical design courses learners sketch their ideas in two dimensional virtual space using software such as Autodesk Inventor. They then extrude their ideas into three dimensional form – applying concepts from geometry and trigonometry continuing to mold and shape with virtual tools creating objects that exist only in digital form. These forms can be freely manipulated within the software – allowing learners to see any view of the object they desire to aid in the visualization of their creation. Learners can animate their creation which will behave based-on physical constraints applied in the model before it is built in real life. Finally learners can send the model file - previously only a construct in software - to a 3D printer – creating in three dimensions a part that now exists in the real world[12].

Mechanical Design – Catapult

- Task was to create a 3d model of a given catapult and modify it to improve its design.
- Students did this by changing the power source from a tension system to one that uses a counterweight.
- Beginning of video is a loop showing how the catapult would react upon firing in real life using the force of gravity on the 1 lb counterweight.
- Next view is rotated to show different angles of the device.
- Lastly video zooms in to the browser to show all of the individual parts that have been created by the students

Mechanical Design – Lab Support Stand (Scissor Jack Mechanism)

- Task - create a 3D model of the given lab support stand and properly constrain all parts to simulate its motion
- Beginning of video loops through multiple turns of the Acme thread screw to fully extend – then collapse the scissor jack mechanism of the lab support stand

Aspiring young architects and civil engineers create models in software that allow them to effectively simulate the professional tasks required of professional practitioners. Again the learners are using dome of the most practical applications you might imagine from all of their prior mathematics instruction – particularly geometry and trigonometry. Architects and civil engineers utilize modeling and simulation software as a project data management system and as a coordination tool for their interaction. Both disciplines also use the system to develop presentations of their work to clients, governing bodies and other interested parties.

Learners in Architecture courses create spaces with realistic materials, many flexible elevation views realistic and lighting schemes rendered upon the model surfaces to create breath-taking walk-throughs of virtual spaces that can be shown to potential clients or users of a building. The modeling and simulation package, Autodesk Revit includes tools to offer clients a variety of design options from which to choose – enhancing the possibility that a potential client can have the opportunity to choose a satisfactory design solution. The system also allows the user to perform site opportunities analysis – optimizing the siting of the structure to allow for day-lighting, wind protection and opportunities for pleasing views of the surrounding landscape. They can even model the natural light in the various seasons of the year for a particular location. The internal structures within wall systems are still 2D elements that require significant detailing due to the variable construction practices that are used in different geographical areas of the country. This produces a wide variety of choices that have to be made without automation – an opportunity to explain the challenges of professional practice[13-14].

Civil projects have an even greater variability as much of the information about a project, it's benchmark, elevation, topographical data and property boundaries must all be acquired and effectively integrated into the project files with a high degree of accuracy. Some of this work is generated from 2D drawings and other data references this 2D data as the project is transformed into a 3D project file. The opportunities for error are many - admonishing learners to develop excellent habits when they are working with project data. Again, Autodesk Revit offers the Civil Engineer a tool that is capable in the 3D realm while allowing traditional 2D format site data to be easily integrated[15].

Architectural / Civil Design -

- Task – design a single-family dwelling complete with interior and exterior detailing with a "walk-through" visualization for potential clients
- Problem is addressed by using Autodesk Revit for the site plan, floor plans and elevations - followed by application of realistic materials and lighting appropriate to the site in Autodesk 3D Studio Max
- Learners get experience simulating appropriate spatial relationships in three dimensions and receive rich feedback as they see design choices illuminated in the walk-through of their design.

Digital Electronics learners design systems that address real-world needs – providing the ability to sense the state of systems and respond accordingly. We teach that digital electronics are only of use if they can effectively interface with the real world – which is analog in nature. Learners use National Instruments' MultiSIM to simulate their designs in virtual circuits – providing a proof of concept before investing the time in building the circuits in real life. This vastly increases learners' ability to confidently design and build challenging systems with many input variables and many output states. Trial and error testing is easily accomplished in a safe and flexible test environment. Learners may actually learn more due to the ease with which they can play "what-if" with the simulation. In real-world circuitry – some of the what-if scenarios would produce component damage that would create the need for a potentially time-intensive and frustrating trouble-shooting process. This time can be better-utilized learning how to implement more complex designs or for adaptation to real-world situations.

Electronics Engineering / Design – 60 Second Timer

- Task - construct a 60 second timer utilizing D Flip-Flops and 7 Segment Display Drivers
- Problem is addressed by configuring the Flip-Flop stages as decade counters
- First stage (one's place) counts 0 to 9 then carries over to the second stage (ten's place)
- The second stage has AOI reset logic that resets the counter when the counter sees a 7 – however, the user only sees a 6 on the display in the tens position – as the reset logic acts within milliseconds.
- The user may manually reset/restart the counter by pressing a push button

normally open switch (PBNO)
- The 7 Segment Display drivers decode the binary count and Drive a one's place and a ten's place (SSD)

In summary, we would suggest that contemporary learners in technical coursework where modeling and simulation software is available can best be served by integrating these powerful tools into instructional practice. There is a powerful feedback loop that forms between the learner's experimentation with design ideas and the near-immediate feedback from the modeling and simulation system that informs the the design process. Ideas for design of new forms that have beneficial characteristics can be honed prior to prototype creation and eventual data-acquisition from a physical model. This reduction in the number of physical models that must be constructed and tested while learning the basics of the applied discipline allows the learner to acquire new knowledge at a faster pace. Interaction between the learner, peers and the instructor may be improved by focusing the interaction required on larger, more systematic concepts – deepening the learning process for all parties[16.]

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