Taking Control of Control Systems: A Student Developed, Multimedia and Simulation Tool for Control Systems Education

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Abstract

Among engineering students, control systems are a notoriously challenging subject for its abstractness—making difficult to connect each of its subtopics for a comprehensive understanding. The undergraduate capstone project discussed in this paper focused on developing a free, online education tool for control systems that integrates the traditional curriculum with interactive components to create a more comprehensive learning experience. The technical products used to develop the learning tool project were often free and opensource-- indication of the increased accessibility of developing virtual education tools. The project was evaluated with user feedback surveys and common user metric research methods with a sample of students that have recently taken the control systems course at The University of Texas at Dallas. The results ultimately underlined the appeal of immersive, gamified learning experiences to students and highlights the opportunity the education field has in developing more multimedia, engaging learning materials.

Introduction

This undergraduate capstone project was developed out of the need to create a virtual project under the circumstances of the pandemic. The capstone team quickly identified that control systems as the most difficult topic in their undergraduate education; and ultimately developed the idea to create an online learning tool to support future students learning about control systems. As engineering students from a generation that is accustomed to turning to supplemental online resources, there was a clear need in the control systems area compared to other engineering topics. The students not only wanted to create just another online resource for control systems, but to deliberately add interactive components and overarching themes to fill in gaps of difficulties from first learning the material.

The capstone team believed that an overarching example or theme to the learning tool could support continuity among difference subtopics in control systems; thus, the main structure of the learning tool is developed around a single real-world example that can be referred back to throughout the curriculum. The capstone team wanted the project to be free, transparent, and flexible to increase accessibility of the education tool. Finally, the students wanted to present the curriculum in a compelling and immersive way with real world topics by introducing gamification and interactive components.

Gamification in Education

Simulation and visualization are proven tools in education, consequently the capstone team wanted to incorporate these components into the learning tool as they were missing from their course curriculum [1,2]. Gamification in education spans much further than just better visualizations. A few papers highlight some aspects on points, levels, and achievements as motivators for students [3]. Though, this was not a priority for this project as it was targeted for college students to use this as a reference as flexibly as possible.

Gamification also adds elements of repeatability and feedback in a more streamlined fashion than can be achieved with in person learning. Repeatability and real time feedback can be adjusted to help students get more practice and improve with guidance; as a case study performed by the Rotman School of Management found that more than 70% of students found that these elements were helpful in their learning [4].

This project hoped to enhance the control systems learning experience by introducing elements of gamification by using multimedia to create relevant animations and by harnessing the capabilities of technology to provide feedback and repeatability for students at their own pace.

Current Control Systems Education Tools

While there exist supplemental resources for control systems education, many were inadequate or had other barriers from sufficiently supporting the undergraduate control systems curriculum. Videos explaining PID control are available to students and practicing engineers on platforms such as YouTube [5]. Similarly, simulations are available for platforms such as MATLAB or LabView [6,7]. These are undoubtedly useful learning aids for engineering students but still have several limitations.

Videos available on YouTube do not adequately align to undergraduate control systems curriculum, from the experience of students at The University of Texas at Dallas. Videos also lacked sufficient connection to real world examples to ultimately combat the abstractness of the topic at hand.

Simulink by MATLAB and LabView by National Instruments have its place in control systems education by providing experience with tools used in the field and block diagrams. Though until the students take the lab course, they do not get the opportunity to connect the control systems to physical visualizations. Learning MATLAB while simultaneously learning the content also provides yet another challenge for students new to control systems material. Notably MATLAB has a quadcopter simulation available, but the interface presents itself less than intuitive for an undergraduate engineering student being presented control systems content for the first time.

Quanser, a company known for educational lab equipment, also developed an app that presents some control systems topics in an educational format. The app also has interactive components to engage the users. It ultimately lacked the direct correlation to undergraduate control systems curriculum and felt more tailored to topics directly covered in laboratory sections [8].

Other research groups and universities have embarked on similar projects to create education tools for control systems education; but are mostly outdated. A publication in ASME from 1998, similarly discussed a multimedia learning tool tailored for the Georgia Tech curriculum [9]. It used

representations of real-world applications with simple videos and diagrams to support the learning material. Another publication in IEEE from 2003 developed a simulation tool; though the interface is similar to what is now readily available on Simulink 2020—deeming the tool itself outdated.

Ultimately new technologies have been introduced and further accessible since these projects deeming them outdated. These projects still serve as valuable examples of incorporating interactive and multimedia components for a comprehensive learning experience.

Methods

The following section will discuss the curriculum layout, the technical products integrated, and finally the methodology for evaluating the tool with recent control systems students.

Curriculum Layout
The architecture of the learning tool was designed with a recognition to the trouble areas that the capstone team and their peers had faced when taking the control systems course; namely abstractness and continuity. As mentioned before, the architecture of the education tool features an overarching real-world example of a system the student user is hoping to control. The real-world examples ultimately used in the tool are reflective of the engineering concentrations of the capstone team. The biomedical track used an example of controlling the glucose level within a human body; and the mechanical track used an example of controlling car speed.
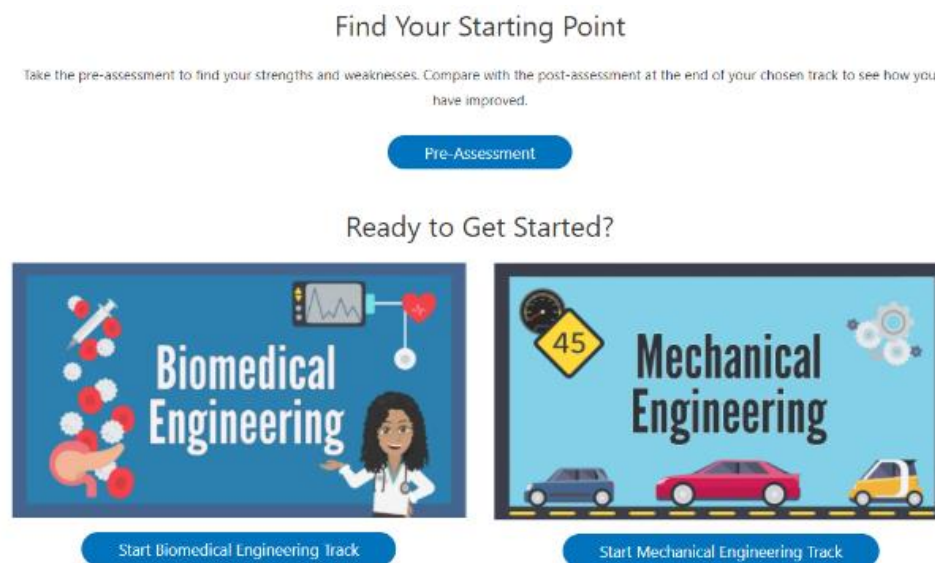

Figure 1. Screen capture of the track selection page

The material covered is identical between the two tracks, and students can also easily flip between tracks for maximum flexibility and to understand the same topics with different examples.

There were many other areas of flexibility that the capstone team wanted to ensure. The curriculum itself was divided into 6 main modules based on the most prominent topics taught part of the control systems course at The University of Texas at Dallas. Figure 2 shows an example of the layout of a module, submodules (topics covered), and integrated learning checks.

Figure 2. Screen capture of a module outline with content and assessments

These modules fit into a larger flow for the education tool that ultimately allow for students to jump around and use the tool to their needs. The student can complete the modules sequentially or even just take the pre assessment and focus on target submodules. Figure 3 shows the "suggested" flow, but the tool was made to optimize flexibility to meet student user's needs. It combines traditional aspects of educations, like assessments, with paired interactive components. The middle section process in the diagram is iterated for each module in the suggested flow, but as described before the student can really jump around to any point in the flow chart.
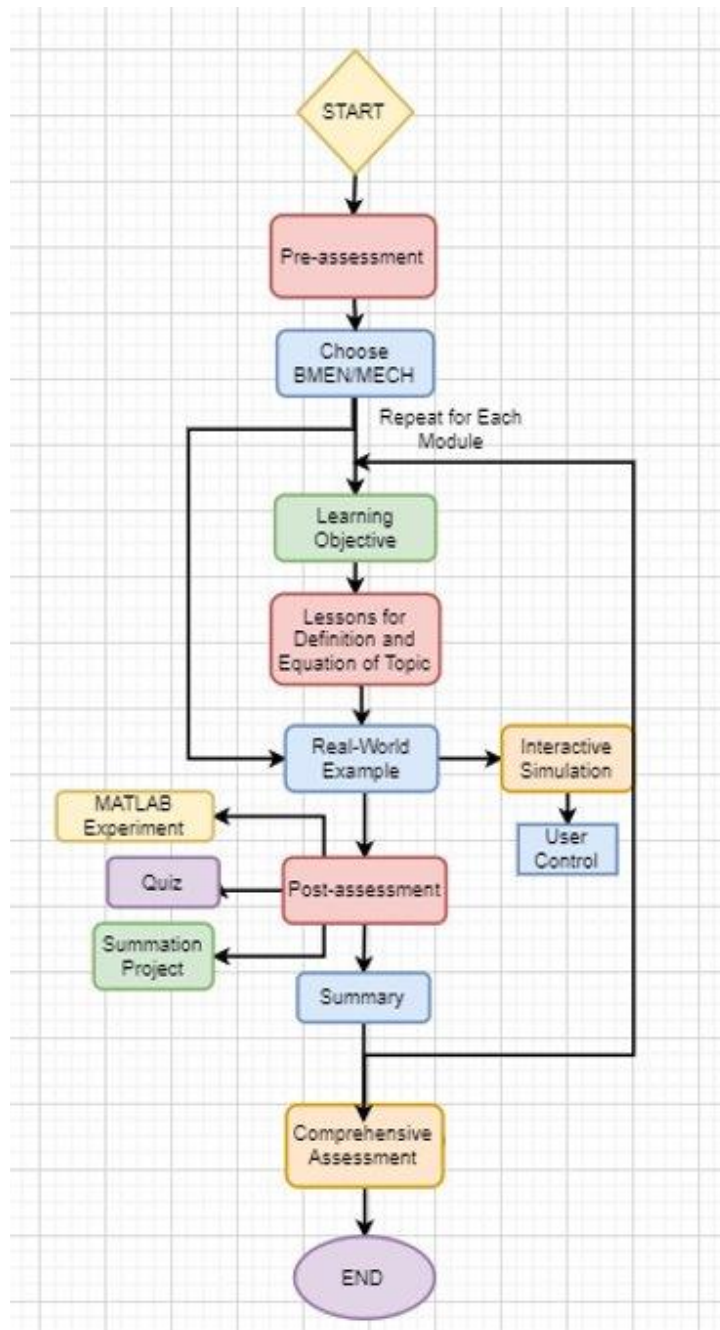

Figure 3. Suggested flow of the education tool

In order to fully support the curriculum, the capstone team also felt that it was important and necessary to include some other components. There is a reference wiki section on the website highlighting the main formulas and charts needed for each module or topic. There is also transparent documentation of the entire project—from where to find the resources supporting the curriculum aspect to how the technical products were integrated. An accompanying blog also highlights the student experience building this tool.

Integrated Technical Products

Many different technical products were integrated in order to create an immersive learning experience. Figure 4 provides a high-level view of the technical products used and their integrations.
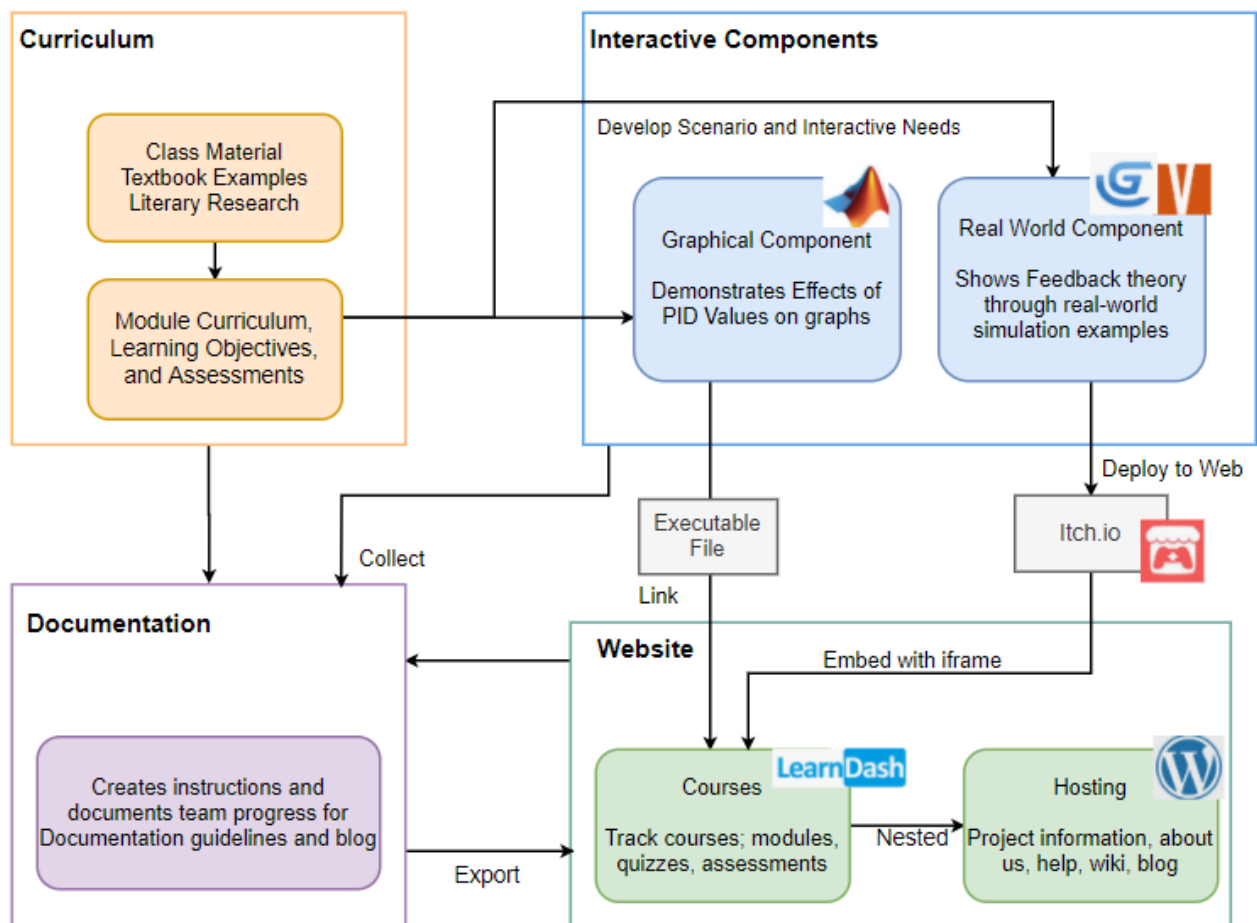

Figure 4. Technical overview

WordPress served as the website platform, which provided both website hosting from WordPress and the software available to Wordpress.org. The course elements were created using the LearnDash WordPress LMS plugin, which is a learning management systems product.

The original architecture of the learning tool included integrating aspects of Unreal Engine, a free game engine, with MATLAB Web App Server on a single webpage. This was the planned framework in providing a visualization with MATLAB graphs, that are familiar and integral to engineering education. Due to some incompatibilities with the MATLAB server hosting, this was not possible with the constraints of the capstone project.

Instead, the capstone team resorted to developing downloadable MATLAB executables. The standalone MATLAB apps were created using MATLAB App Designer, packaged for distribution using MATLAB App Compiler. These can be run on users' computers using the free MATLAB Runtime product and downloaded as an executable file. These MATLAB apps provided users with the robustness of interacting with concepts using MATLAB without requiring prior knowledge and experience with MATLAB.

Unreal Engine also quickly proved too time consuming for the capstone team to learn and complete a project within the constraints. Instead GDevelop, another open-source game engine, Vyond, a visualization creation tool, and animated MATLAB graphs were combined to create user responsive animations for each module. The GDevelop simulations were hosted on itch.io, then embedded into the relevant submodules using HTML iframes and were mobile friendly

User Feedback
Key performance indicators (KPIs) were outlined as a part of the capstone project's acceptance test plan; the KPIs guided the creation of user feedback surveys. The surveys were based on John Brooke's System Usability Scale (SUS). The original SUS uses ten different statements and a five-point Likert scale. The Likert scale is commonly used in user feedback, ranging from strongly disagree, disagree, neutral, agree, and strongly agree.

The website was originally to be evaluated by at least 20 students who have recently taken the control systems course at UT Dallas. However due to the circumstances of the pandemic, only seven students were surveyed and subsequently an open feedback section was added for depth in evaluation. A feedback survey was distributed to the seven participants to respond to after using the education tool and completing at least one module from beginning to end.

Results and Discussions

The feedback survey was sent out and more adjustments to the education tool were made in reflection of their responses. There was some concern about the difficulty level being "too" much easier than what was taught in the curriculum at UT Dallas, so the capstone team has since added more thorough material to the modules. Though, the student feedback were generally positive and showed that the material was ultimately presented in a more comprehensible way to the students.
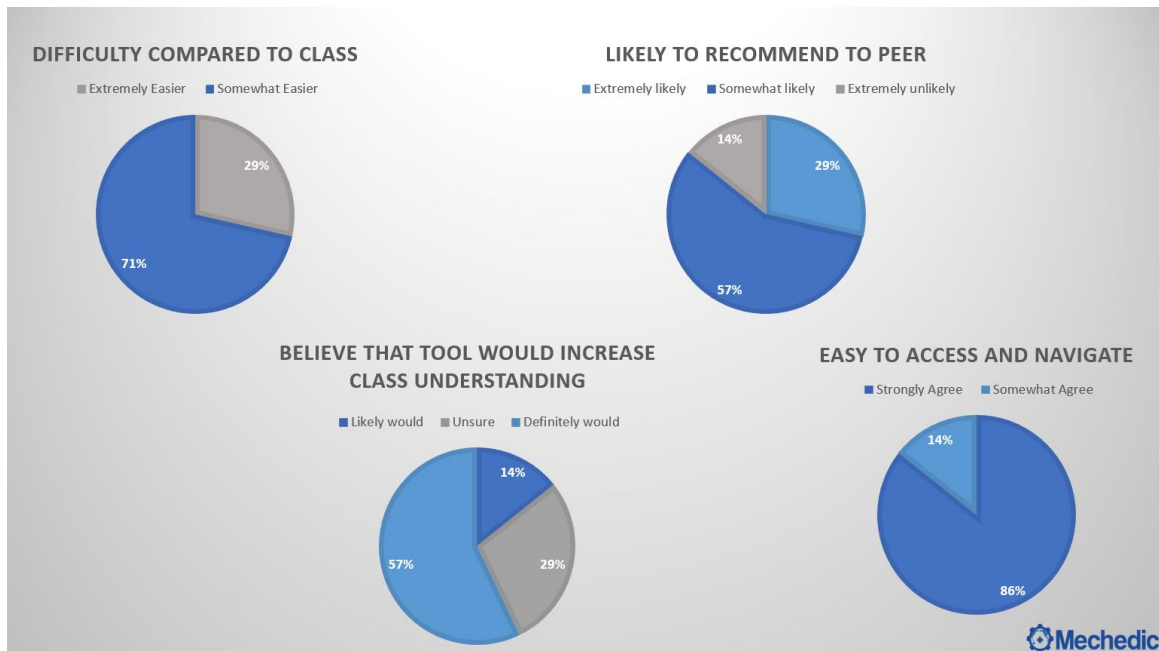
Figure 5. Highlights from the student feedback survey

The open-ended responses helped fine tune some of the technical aspects of the education tool. Some of the highlights from the open-ended responses included some more ways to visualize and enhance the interactivity of the website with more multimedia components. Some of the suggestions, like increased graph interactivity on the webpage, were limited by the capstone's team inability to use MATLAB Web App Server. Ultimately the student feedback was very positive for interactivity and the inclusion of multimedia.

Future Work

The capstone project has ended for the team and this direct project, though the department of control systems will house the project moving forward. There has been interest within the department in adding more real-world examples to be reflective of more engineering concentrations. The educational tool is still just out of prototyping phase and still has much fine tuning and additions that can be made. The transparent documentation enables the educational tool to be added to, edited, or replicated to by future capstone groups or engineering students.

Many of the respondents to the survey suggested more enhanced ways to incorporate multimedia aspects to the educational tool; and there can be more user research done to reflect the needs of students currently learning control systems.

Conclusion

This project ultimately culminated many open source and increasingly accessible technical products to develop a multimedia learning experience for control systems education. The duration of the capstone project lasted approximately six months and had many limitations from being a student project. Though, the project can be noted as a signifier of the tools available to the education community in creating multimedia and engaging education tools.

Outside of control systems education, there has been a huge boom in virtual learning experiences. Educators are modifying Minecraft, a very popular video game, to teach concepts from chemistry or virtually tour the ruins of ancient Rome. While the Minecraft movement may seem far off from exactly what undergraduate engineering education may need to embrace, there are many tools that college level engineering educators can harness to create engaging virtual learning experiences.

Previous education research has underlined the benefits of gamification, not only for its increased engagement but also for its nature to more readily appeal to a broader range of learning styles. As the pandemic has forced educators to rethink their courses in a virtual context, there has also been a more sudden push to online materials supporting education. This ultimately presents itself as an opportunity for education to make use of the technical products that are more accessible than ever in developing new educational experiences.

Acknowledgements

References

1. B. Balamuralithara and P. Woods, "Virtual laboratories in engineering education: The simulation lab and remote lab," in Computer Applications in Engineering Education, Wiley Online Library, 2008, pp. 108-118.
2. D. Cook, S. Hamstra, B. Zendejas, J. Szostek, A. Wang, P. Erwin and R. Hatala, "Comparative effectiveness of instructional design features in simulation-based education: Systematic review and meta-analysis.," in Medical Teacher, pp. 867-898.
3. Kiryakova, Gabriela & Angelova, Nadezhda & Yordanova, Lina. "GAMIFICATION IN EDUCATION." (2014).
4. Huang, Wendy Hsin-Yuan, and Dilip Soman. "Gamification of education." Report Series: Behavioural Economics in Action 29 (2013).
5. Kaufmann, Daniel A. "Reflection: Benefits of Gamification in Online Higher Education." Journal of Instructional Research 7 (2018): 125-132.

6. MATLAB, "Understanding PID Control," Youtube, 2018. [Online]. Available: https://www.youtube.com/playlist?list=PLn8PRpmsu08pQBgjxYFXSsODEF3Jqmm-y. [Accessed 29 June 2020].
7. MATLAB, "PID Control with MATLAB and Simulink," [Online]. Available: https://www.mathworks.com/discovery/pid-control.html. [Accessed 29 June 2020].
8. National Instruments, "Construct PID in Control Design and Simulation Module," National Instruments, 2009. [Online]. Available: https://forums.ni.com/t5/Example-Code/Construct-PID-in-Control-Design-and-Simulation-Module/ta-p/3531054?profile.language=en&nisrc=RSS-514a5a3. [Accessed 29 June 2020].
9. Experience Controls. (2020). Quanser (Version 2.5.1) [Mobile App] Retrieved from http://itunes.apple.com
10. A. Gero, "Use of Real World Examples in Engineering Education: The Case of the Course Electric Circuit Theory," in World Transactions on Engineering and Technology Educcation, vol.15, no. 2, 2017, pp. 120-125.
11. V. Kroumov, K. Shibayama and A. Inoue, "Interactive Learning Tools for Enhancing the Education in Control Systems," IEEE, Vols. T4E-23, 2003
12. Lee, Kok-Meng, Wayne Daley, and Tom McKlin. "An interactive learning tool for dynamic systems and control." Proc. of International Mechanical Engineering Congress & Exposition. 1998, pp 71-76.

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