

Bridging Gaps in Electronic Circuit Design Education: An Action Research Study

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Abstract

This paper presents an action research project aimed at improving the performance of second-year students in electronic circuit design, as part of their practice in the undergraduate module MEC104 at Xi'an Jiaotong-Liverpool University. Several issues have been identified through observations by module leaders and feedback from students, including gaps between lectures and lab sessions, safety concerns, and lengthy debugging periods. To address these challenges, this study proposed integrating the TinkerCAD simulation tool into the module, outlining a three-step action research plan. The results and analysis indicate a positive impact of the simulation-based approach on student learning and performance in electronic circuit design.

Keywords: STEM Education, Technology-enhanced learning and teaching, Curriculum Design.

Introduction

A. Teaching Electronics Design in MEC104

The action research reports enhancing the performance of electronic circuit design for second-year students taking the MEC104 as practice. The MEC104 module, "Experimental, Computer Skills and Sustainability," offers a comprehensive learning experience in electronic engineering at the School of Advanced Technology, Xi'an Jiaotong-Liverpool University, which also covers fundamental experimental techniques, computer literacy, and engineering sustainability. This module targets on second-year engineering students and carries 5 credits. In addition to lectures on sustainability topics, the module primarily focuses on experimental electronics design, which consists of three projects: a Digital Clock project, a Smart Car project, and an Open Project. These projects account for 70% of the total marks for the module's assessment, highlighting the importance of electronic circuit design for students participating in this module.

B. Features of Teaching Electronic Design in MEC104

1) Very hands-on topics

Module MEC104 is designed to provide students with a highly interactive and experimental learning

experience. With a strong focus on hands-on learning, this module is particularly valuable for second-year students who may not have extensive background knowledge or practical experience in electrical engineering. By emphasizing experiential learning, students can actively participate in the learning process, enabling them to develop a deeper understanding of the subject matter.

2) Continuous lab projects on a weekly basis

One of the key features of MEC104 is the incorporation of continuous lab projects throughout the semester. By assigning weekly lab projects, students are encouraged to consistently practice and apply their theoretical knowledge in a practical setting. This approach promotes continuous learning and helps students develop the necessary skills to succeed in the field of electrical engineering. Moreover, the regular lab projects enable students to build upon their previous work, reinforcing their understanding of the concepts and fostering a systematic approach to problem-solving.

3) Systematic design skills

A primary goal of MEC104 is to equip students with systematic design skills that can be applied in real-world scenarios. Recognizing the importance of industry expectations, this module aims to bridge the gap between academic learning and practical applications. By honing their design skills, students are better prepared for future careers in electrical

engineering and can meet the demands and standards of the industry. This emphasis on systematic design not only enhances their technical abilities but also cultivates a professional mindset necessary for success in their chosen field.

C. Conventional Teaching Pattern of MEC104

The pedagogical approach adopted in the instruction of MEC104 can be delineated into two primary components: lectures and laboratory sessions. During the lectures, instructors impart theoretical concepts and concisely overview electronic components. Subsequently, students actively engage in the practical application of their acquired knowledge during laboratory sessions. Here, they are tasked with the design of electronic circuits and are required to troubleshoot and rectify any issues encountered until the circuits operate as intended.

D. Challenges of Teaching MEC104

After observation in the classroom, several challenges that need to be addressed:

1) Large class size

The large class size limits individual attention and interaction, creating a heavy workload for module leaders and teaching assistants. Hands-on learning strategies should be incorporated to overcome this challenge, promoting group activities and collaborative projects. This fosters peer-to-peer learning and engagement within the classroom.

2) Safety issues

In subjects like electrical engineering, safety is crucial due to the inherent risks of working with circuits and equipment. The trial-and-error approach can lead to safety hazards, especially for inexperienced students. Neglecting safety concerns compromises student well-being and creates an unsafe learning environment.

3) Gap between lecture and lab

The gap between theoretical concepts taught in lectures and their practical application in labs can be challenging for students. Lack of integration between lecture material and lab projects hinders knowledge transfer and the development of practical skills. Bridging this gap is essential for a comprehensive understanding of the subject.

4) Long debugging time

Debugging is integral to engineering projects, including electrical engineering. However, lengthy debugging periods frustrate students and impede progress. Extended debugging time demotivates students, impacts their confidence, and limits exploration of alternative solutions or further coursework aspects.

Based on the past feedback from students, we also identified that the students have the following problems with MEC104.

- Limited design practices
- Difficult in applying theory to practice
- Confusion in debugging
- Frequent damage to hardware parts

All these points are due to the character of MEC104 that hands-on experience is required to get a high performance, but the hands-on experience is limited from lab sessions. Such giant gap between theory and practice leads to unsatisfactory performance from students.

Literature Review

A. Methodology on Simulation Based Education

Engineering students frequently engage with complex real-world systems, such as electronic circuits, robots, and deep neural networks (Kutz et al., 2016). These systems often possess high dimensionality, with thousands of parameters that can significantly impact their behavior (Kutz et al., 2016). Additionally, real-world complex systems are subject to external perturbations and internal uncertainties, which pose challenges in engineering education. University practices often fall short of meeting the requirements outlined by teaching standards, resulting in students having limited understanding of these complex systems. Consequently, graduates often require additional training before effectively applying their engineering skills in practical settings (Gruler et al., 2019).

Previous studies have highlighted the potential of virtual simulation platforms to improve students' comprehension of abstract concepts and enhance their learning experiences through repeated exploration (Juan et al., 2017). Simulation-based education (SE) emerged as a valuable tool for enhancing learning experiences as early as the 1960s (Schild, 1968), and it has since evolved across various fields in higher education, including engineering, nursing, and business management (Campos et al., 2020).

The growing popularity of SE can be attributed to advancements in personal computing devices, which now possess the capability to provide precise simulations of real-world environments (Faria et al., 2009). Such accurate simulations enable students to practice in realistic environments, accumulate valuable experience, and deepen their theoretical understanding. Another factor contributing to the popularity of SE is the integration of gaming elements, which increases student engagement and fosters a more enjoyable learning experience (Cai et al., 2016). SE can be designed in a pedagogically engaging manner, incorporating competitive elements where students must solve specific issues and surpass their peers to achieve notable accomplishments. This approach holds particular appeal for current students (Pasin & Giroux, 2011; Stanley & Latimer, 2011; Deshpande & Huang, 2011). Comprehensive reviews

on related topics can be found in previous works (Campos et al., 2020; da Silva et al., 2019).

Given that the module under consideration falls within the sciences, technology, engineering, and mathematics (STEM) realm, it is essential to explore the role of SE in STEM education. Previous research has indicated that SE can bridge the gap between theory and practice, enhancing understanding and performance in business training (Riley, 2012). It has also been suggested that SE offers valuable experience with extensive training capacity, addressing the challenges of traditional physically constructed and costly laboratories (Alnoukari et al., 2013). Recent studies have successfully employed SE to simulate factory operations, providing students with a comprehensive understanding and potentially serving as a training tool for future workers (Frantzén & Ng, 2015). Furthermore, the use of an electronic circuit simulator has been shown to significantly improve students' performance (Mavinkurve & Patil, 2016). Similar simulation platforms have been employed to replicate real-world environments in military training, further highlighting the effectiveness of SE (Bruzzone & Massei, 2017). In summary, SE has emerged as a valuable tool for bridging the gap between theory and practice in STEM education.

The key benefits of SE include increased student motivation (Klug & Hausberger, 2009), valuable experience within a safe practice environment (Ören et al., 2017), enhanced problem-solving and decision-making skills (Tzimerman et al., 2014), and the cultivation of critical thinking in learning activities (Pirker & Gütl, 2015). However, SE also presents certain drawbacks, including potential distractions, the need for specialized training, and challenges in assessment (Ören et al., 2017). Nonetheless, it has been suggested that these drawbacks can be mitigated through careful project design (Campos et al., 2020).

B. Simulation Tools Selection

For the electronics design, evaluation, and simulation, or simply for understanding electrical circuits, various platforms, such as EasyEDA, PartSim, EveryCircuit, Falstad, DoCircuits, LTspice, OrCAD PSpice, fritzing, GEDA, NI Multisim or Proteus, can be found. However, these programs require installation, which can be a potential user barrier. Additionally, they are not very user-friendly and can be quite challenging for beginners. Another limitation is that these tools do not allow teachers to monitor their students' progress remotely, even if they are in the same room.

Nonetheless, it is possible to do so with the TinkerCAD platform. The efficacy of this platform compared to other simulation software available for engaging engineering students in learning key hands-on laboratory skills was also demonstrated recently (Abburi et al., 2021). The results from some other works show that this platform can provide similar

experiences as conventional laboratory activities (Shalannanda, 2020) or can be used to indicate that students have positive intentions to learn programming and computing-electronic skills (Vidal-Silva et al., 2019). Hence, TinkerCAD platform is a potentially suitable candidate for conducting the project

Action Research Methodology

A. Research Question

Based on the review and analysis above, the research question is identified:

To what extent does the TinkerCAD simulation tool bridge the gap between theory and practice in electronic product design (including enhancing familiarity with electronic circuits, improving assembling and debugging experience, and improving student performance)?

B. Action Research Plan

Based on the research question and contents of the MEC104, we have devised an action research plan comprising three projects from easy to difficult using TinkerCAD. Step-by-step guidance has been provided to students.

1) Starting simulation project – Digital Clock

To familiarize students with the simulation platform, we have designed a preliminary project wherein students are tasked with designing a digital clock. Detailed operational instructions are provided to guide students, and the lab sessions are utilized to ensure that all students complete the project. This exercise enables students to become acquainted with the process of designing, assembling, and debugging electronic circuits.

2) Design project with a pre-selected topic – Smart Car

In this phase, students are required to undertake a design project centered around a pre-selected topic: a smart car system. Following a procedure similar to the starting project, students go through the design, assembly, and debugging processes. Once the simulated project is completed, students are encouraged to assemble the electronic circuits physically. Drawing on their experience from the simulation platform, they can employ the simulation results as a guide for hands-on debugging. If students encounter any unclear issues, they can attempt to replicate the bugs within the simulation and then seek solutions. Furthermore, since all students are working on the same topic, they are encouraged to engage in discussions and collaborate to identify solutions.

3) Open project with a free topic

Upon completion of the smart car project, students are granted the freedom to embark on a new project based on their individual interests. The design procedure mirrors that of the smart car project, with

the distinction that students must now independently complete the project as the topics vary. Throughout this phase, instructors and teaching assistants provide only general guidance, fostering an environment where students are motivated to find solutions through their own efforts.

A common thread across all projects is that students must first complete the simulations before proceeding to the physical experimentation stage. Debugging within the simulation platform proves highly efficient, allowing for multiple trial runs within a short timeframe and enabling students to accumulate experience through simulated debugging processes. Moreover, the safety issues in the practical hands-on lab sessions can be significantly reduced since students gain much experience during the practice in the simulation.

Therefore, as shown in Figure 1, the traditional teaching pattern has been transferred to a new simulation-based teaching pattern with a middle stage. The proposed simulation-based teaching approach allows students to acquire valuable experience during the simulation stage before the hardware practice in the lab, which distinguishes it from traditional teaching methods.

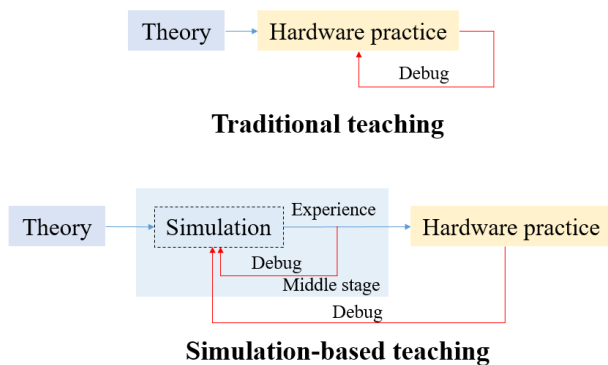


Figure 1. Proposed teaching pattern with simulation middle stage

Results and analysis

A. Student Feedback

To evaluate the outcomes of integrating simulation-based teaching into MEC104, we employed anonymous questionnaires to gather feedback from the students. The questions included in the questionnaires are:

- Is TinkerCAD helpful when designing electronic circuits?
- Please evaluate the most helpful point by using the simulation platform TinkerCAD.

92 responses were collected. The following section evaluates the collected results in Figure 2.

Approximately 89% of the participating students found TinkerCAD to be beneficial in the design of electronic circuits. This indicates that simulation-

based teaching is valuable in delivering the content of MEC104.

Figure 3 clearly illustrates that the aspect of TinkerCAD that students found most helpful is its assistance in practicing circuit assembly. This is likely because assembly is a new skill for students and is the foundation for constructing electronic circuits. Furthermore, approximately 36% of the students identified debugging as the most helpful aspect of TinkerCAD. This aligns with the objectives outlined in the action plan, as the simulations provide students with valuable debugging experience, which can then guide them when debugging physical circuits.

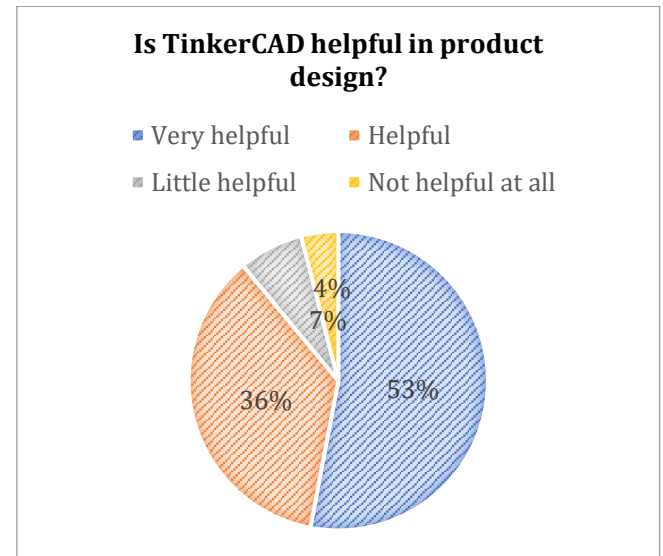


Figure 2. Students' feedback on survey question 1

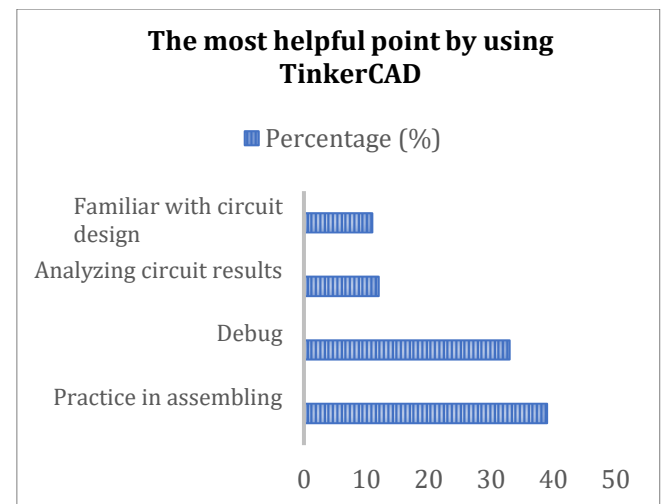


Figure 3. Student feedback on survey question 2

B. Student Assessment Performance

During the pandemic, temporary changes were made to the assessment methods. However, in the academic year 2022-2023, the assessments were reverted to the original format. Therefore, we compare the data from the 2022-2023 academic year with that

of the 2018-2019 academic year to analyze the impact of the action research in Figure 4.

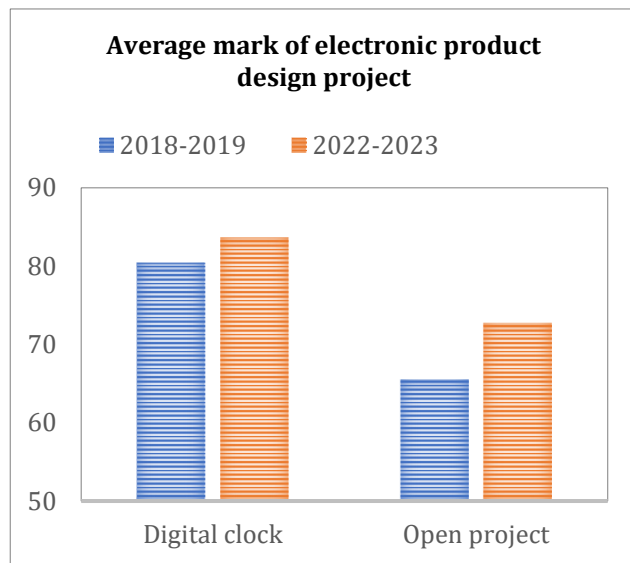


Figure 4. Average mark of electronic product design project

To ensure fairness in grading, we have employed the same marking guidelines for all assessments. Upon analyzing the marks depicted in Figure 4, we have observed an improvement in both the smart car and open project assessments. This demonstrates the benefits of integrating simulation-based teaching into MEC104. Specifically, students achieved higher scores in the smart car project due to a higher completion rate, indicating that more students successfully completed the project. Moreover, students received higher marks in the open project because they could implement more complex functionalities in their designs. With the assistance of TinkerCAD, students have gained more experience in electronic circuit design and have become more confident in incorporating intricate features into their own projects.

Based on the feedback obtained through the questionnaires and the assessment results, the integration of simulation tool into the teaching of MEC104 has proven to enhance students' comprehension of the module's content and improve their performance in electronic circuit design.

Discussion and Future Work

After analyzing the above results, the following aspects have been reflected upon and discussed, along with future directions for improvement.

1) Introducing a virtual simulation platform has shown to be effective in improving students' performance in MEC104. In the future, it is recommended to integrate simulation demonstrations into the teaching process further. This can help students gain more hands-on experience and enhance their understanding of the concepts.

2) The aspect of practicing circuit assembly was identified as the most helpful by students. To capitalize on this, it is suggested that a specific simulation project be introduced during lectures that focuses on familiarizing students with circuit assembly techniques. This can help students develop the necessary skills and confidence in this area.

3) The use of simulations has proven to be beneficial in guiding students through the debugging process. As a future direction, it is recommended that specific debugging techniques using simulations be introduced and demonstrated. This can provide students with valuable experience and enhance their troubleshooting abilities.

4) Students have found that simulations help get acquainted with electronic components. To leverage this advantage, it is proposed to integrate simulations when introducing each electronic component in order to make the theoretical concepts more intuitive and tangible for students.

By implementing these future steps, it is expected that the integration of simulation-based education in MEC104 can be further optimized to enhance student learning outcomes and improve their overall performance in electronic circuit design.

Conclusion

This paper presents an action research plan to examine the impact of integrating simulation-based teaching into the teaching of electronic circuit design. The plan consists of three sequential steps designed to progressively familiarize students with the simulation platform and facilitate their experiential learning. The findings and assessment results indicate that students perceive the simulation-based education approach as beneficial for acquiring knowledge and skills in electronic circuit design. Furthermore, the results demonstrate an improvement in students' experience on electronic design and overall performance because of utilizing the simulation platform. Therefore, it is evident that integrating the TinkerCAD simulation tool can effectively bridge the gap that exists between lectures and lab sessions, which could enhance the teaching of electronics design.

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Conflict of Interest

The authors declare that there is no conflict of interest associated with the publication of this manuscript.

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