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Hands-on Using EDA Tool-Assisted Learning for Digital Electronics Among Freshmen

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ABSTRACT

BACKGROUND & CONTEXT

One of the courses offered to freshmen in the Electrical Engineering program is Digital Electronic. Understanding how basic logic elements i.e gates and flip-flops to perform operation of logic modules such as multiplexers, adders, comparators, counters, and registers is an important aspect for this course. It is expected of students to perform well while analysing and designing digital logic since the course becomes a prerequisite for other coming courses in the program.

PURPOSE OR GOAL

This paper presents findings from engagement of these freshmen through active learning activities in and outside the classroom while using industry-standard tools as the tool-assisted learning to rapidly enhance their integrated circuit design skills.

APPROACH OR METHODOLOGY

Active learning is implemented during and outside of class, where students need to work together, exchanging thoughts and viewpoints for given tasks. Using lecturer's comments and insights, students can further proceed to practical simulations using EDA tool-assisted learning. Feedback from students to evaluate these activities and their opinion about the effectiveness of the tool to assist them better comprehend digital logic design are collected.

OUTCOMES

Students are happy with the improved understanding of integrated circuit design taught in the Digital Electronic design course. Most agree that EDA tool-assisted learning is suitable for freshmen, even though it uses an industry-standard tool. They feel this approach has greatly increased their confidence and ability to apply what they've learned to take on more advanced projects.

CONCLUSIONS

The findings indicate that active learning activities in and outside the class with EDA tool-assisted learning effectively supports students' understanding of the logic design course. Students' enthusiastic feedback after completing the tasks highlights that the active learning approach, including hands-on simulations, enhances comprehension.

KEYWORDS

Hands-on, Digital Electronic, EDA Tool-Assisted Learning, Freshmen.

Introduction

Traditional lecture based is no longer feasible as the majority of the teaching delivery is only one way. Feedback from the lecturer that teaches the course commented that students tend to memorize without having to understand the working principle and operation. Otherwise, students believe that there aren't enough tutorials or exercises for each topic they've learned. Most students anticipate more practical exercises to help them better understand the topics. (I. Ismail et al, 2023). Therefore, the implementation of active learning activities as part of the New Academia Learning Innovation (NALI) in higher education is necessary to direct the teaching and learning (T&L) practices to be a more student centered approach particularly for engineering students since they are freshmen. This is in line with 21st century skills to produce graduates that are creative, able to communicate effectively, think critically and collaborate with others. The engagement of students especially the freshmen through discussions, problem solving and other methods in class activities becomes necessary where two ways of communication between students and the lecturer can happen (Anderson, 2011).

One of the courses offered for freshmen of Electrical Engineering is Digital Electronics. An essential component of this course is comprehending how basic logic components such as gates and flip-flops operate logic modules including multiplexers, adders, comparators, counters, and registers. It is expected of these newcomers who have just entered the world of higher education to do well for this subject i.e analysing and creating the digital circuits. As technology in the field of digital circuits design has developed, EDA tools i.e Quartus are necessary for current design in order to effectively utilise their capabilities. The choice of this tool over other EDA tools like NI Multisim is due to its capability not only to simulate designs but also to perform synthesis, allowing for direct translation of the design into hardware implementation. For freshmen, engaging with such tool from the beginning fosters deeper understanding of digital systems, as they can see their designs come to life on real hardware.

This paper presents the implementation of active learning activities such as hands-on digital circuit design and simulation after learning the theories in class and mini project development outside class using EDA tool-assisted learning. The use of that design and analysis tool in this study is appropriate for educational purposes, since it helps students rapidly enhance their design skills while keeping in mind the ultimate necessity to use industry-standard tools. Students are given a structured assignment supervised by the lecturer, and then require the students to design and verify the circuit's functionality while still in class (H. Y. Shen et. al, 2018). The findings from this paper show the reflections of the freshmen about the effectiveness of the tool to assist them better comprehend digital logic circuit design.

Related Works

Historically, T&L for digital systems course was taught through traditional lectures and paper-based problem solving. Therefore, the shift of T&L techniques toward more student-centered learning methodologies has led to the integration of simulation tools and virtual labs. Work by (Blikstein and Wilensky, 2004) has advocated constructivist approaches for developing systems thinking through hypothesis testing and model revision. EDA tools align well with constructivist principles by enabling learners to interact with digital circuit components, test hypotheses, observe results, and revise their mental models accordingly (O. Bada et. Al, 2015). For instance, in a constructivist environment, students are not passive recipients of knowledge but rather active participants. Using platforms like Quartus tool, learners can design digital circuits and witness the consequences of design decisions in real-time. This hands-on construction of knowledge makes abstract concepts more tangible and fosters deeper learning.

(Williams and Davis, 2017) has shown that flipped classroom models using simulation tools resulted in deeper conceptual understanding and improved exam performance. Another approach is introducing DCLab, a web-based system for conducting digital logic experiments online. DCLab allows students to draw circuit diagrams or write VHDL code to design circuits, providing complete simulation functions and facilitating effective digital logic experiment

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teaching (Ding et. al, 2018). According to (Chen and Thompson, 2018), simulation tools significantly improve students' understanding by allowing them to visualize the behavior of logic gates, multiplexers, and sequential circuits in real time. This aligns with constructivist learning theory, where knowledge is built actively through interaction and experimentation (Piaget, 1973). They also had reported that combining virtual and physical labs provided a more holistic learning experience, balancing theoretical instruction with practical exposure. (Nguyen and Kumar, 2021) has implemented project-based learning supported by simulation tools, which enhanced students' problem-solving abilities and teamwork. (Zhu, 2023) has explored the role of EDA tools in fostering self-guided, creative learning, especially for novice learners. Hands-on simulation provides immediate feedback, which is critical for problem-solving and conceptual reinforcement. Students can test and debug their designs instantly, promoting self-correction and iterative improvement (Smith and Lee, 2023). This process also aligns with Kolb's experiential learning theory (Kolb, 2014), emphasizing active engagement, reflection, and application.

(H. Zhu, 2023) has proved the tools can be utilized to enhance students' learning experiences by providing immediate feedback on their digital design projects. It also helps students identify mistakes quickly, experiment with different solutions, and better understand the design process, fostering a more engaging and active learning environment. (I. Ismail et al, 2023) has implemented an active learning approach in class and a series of milestones that was done through a problem based learning approach supported by EDA tools. This work shows that these tools allow students to simulate, analyse, verify and implement digital designs to an affordable hardware, thereby promoting active learning and deeper conceptual understanding. Students have actively engaged in building, testing, and improving their circuits, reinforcing learning through hands-on experience. According to (Galan Benitez, 2024), students become more motivated and satisfied with the use of commercial CAD tools. Moreover, the use of EDA tools provides students with additional skills and in-depth knowledge of the different design and synthesis tools and methods used in both open-source and proprietary environments, so that they get a stronger background and practical expertise to address a number of challenges in diverse scenarios of the semiconductors industry. (Flegr et al. 2023) has emphasized the benefits of hybrid labs that combine virtual and physical experimentation, fostering richer learning experiences. (Negahban, 2024) has discussed the expansion of virtual and immersive laboratories that offer scalable, safe, and cost-effective experimentation environments. (Álvarez Ariza, 2024) has explored the efficacy of online and mobile active labs in overcoming logistical constraints and broadening access to engineering education.

While these studies highlight the benefits of EDA tools in digital electronics education, most focus on out-of-class simulations, flipped classrooms, or hybrid lab environments. The work in this paper uniquely investigates the impact of in-class, hands-on simulation using EDA tools, where the target students are freshmen, actively engaged with digital circuit design during lectures rather than in separate lab sessions. By integrating real-time simulation through structured assignment within the classroom, this approach ensures immediate application of theoretical concepts, fostering deeper understanding and retention among students. Additionally, this study explores how the activities and EDA tool usage in class help students to address more challenging problems through open-ended questions outside the class. By focusing on active learning activities, in-class industry-standard tool usage, this study offers a novel approach to digital electronics education, ensuring that freshmen develop a stronger foundational understanding while gaining practical skills early in their academic journey.

Methodology

Figure 1 shows the basic flow of activities for the freshmen that are taking this Digital Electronic course. The activities are divided into 2 parts which are during class and outside the class. Both activities require students to use EDA tool-assisted learning. Once the students have performed all the activities, students will give their reflection at the end of the semester.

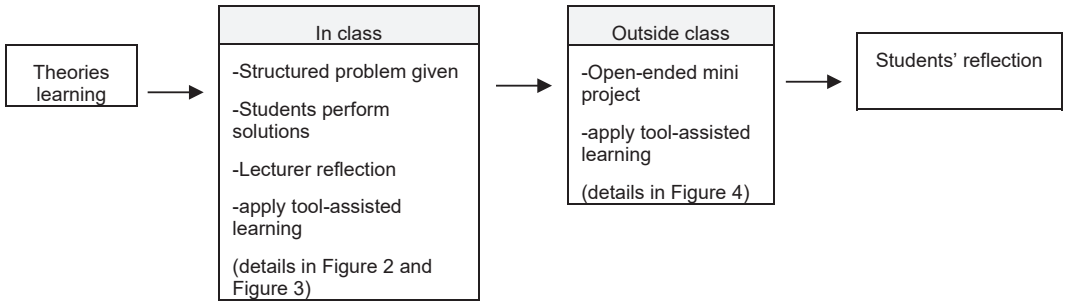


Figure 1: Flow of activities

Before implementing class activity, students have learned some topics in previous classes. During the activity in class, students are given a problem that is related with the topics, for example as shown in Figure 2. The students will be formed in groups with two or three members. Each group needs to discuss among them after obtaining the structured assignment. They need to analyze the problem specifications and figure out possible solutions, for example, design the combinational circuit based on the problem that is related to the environment. From this observation, it shows that each student will increase their understanding from the discussion (T. Mandic et. al, 2017).

The class activity is:

1. Do a task that is related to Topic 6: 'Logic Simplification with Karnaugh Maps' and Topic 7: 'Combinational Logic Design'.
2. Students are given the problem statement: In your group, design and simulate a combinational logic circuit that consists of three or four inputs and at most three outputs. You are required to come up with your own problem and solution, which can be anything related to the environment, relationships, people, vehicles, machines, etc.
3. Derive the solution by discussing with the group member.
4. Show the solution to the lecturer for the feedback before implementing it using Quartus tool.
5. Design, simulate and verify the solution using Quartus tool (hands-on in class)

Figure 2: Structured assignment for active learning activity in class

Students will share the ideas or opinions in order to get the correct answer among them. At this stage, students are able to develop skills such as problem-solving and working in groups. They also learned how to analyze and synthesize the problems. The finalized answer is shown to the lecturer during learning in the class. The lecturer will promptly give the reflections and comments based on the answer. Therefore, students are concluded with a solid solution i.e final circuit design from this activity after obtaining feedback from the lecturer. Once they get the solid solution, students do the hands-on practice by implementing and verifying the design using Quartus. Our approach draws on constructivist learning theory by engaging students in active, iterative problem-solving. Using EDA tools such as Quartus, learners design and test

Alu_op	Operation
1	4-bit adder, A + B
0	4-bit subtractor, A - B

You are required to perform a modular design of the arithmetic logic unit (ALU) with the given specifications above. The design should use schematic based entry using logic gates for all components, except the register. **The goal is to obtain a design that uses the least number of logic gates.**

Figure 3: Mini project specification for outside class task

digital circuits, observe real-time results, and refine their designs based on feedback. This hands-on process develops skills to real-world engineering contexts. Thus, by applying the conceptual they have learnt and their tool-using skills during in-class activities, students can

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go to the next challenge. Figure 3 shows mini project specification, where it is an open-ended question which leads the students to a wide range of solutions in terms of circuit designs. Students are prompted to provide detailed explanations and insights. For developing the project, students work in groups (can be the same as in the class activity) and they need to finish the project in a few weeks before the end of semester.

Since students are required to use the EDA tool for both hands-on and project development, they will apply a creative process called digital design to determine the collection of digital logic components to perform a specific function. Figure 4 summarizes the framework of the digital design process. It starts with the specification stage where students need to understand the design requirements i.e students need to translate the input-output relationship through a truth table and obtain the Boolean expressions. In the design entry stage, a description of the digital circuit is entered into the design software called schematic capture. It is a graphical method for entering logic circuits directly for small circuits or hierarchically for larger circuits. After the designs are entered, they are compiled to extract netlist, which describe the connection between individual logic components (gate). The netlists become inputs to functional simulation or timing simulation. During functional simulation, a circuit is tested to verify its logic operation without regard to timing analysis, whereas, timing simulation tells the designer how fast signals go through the gates and how fast the circuit can operate. Students have two options in this stage either they can achieve the design result through simulation only (waveform) or implement the design on specialized physical hardware (working prototype). If they chose for the physical implementation, in the final stage which is logic synthesis, the netlist which passes the simulation stage is mapped to the actual chip where the function of the circuit can be seen on physical prototype i.e circuit connection on breadboard. Figure 5 shows the screenshots of the design and verification process using the tool for combinational logic design.

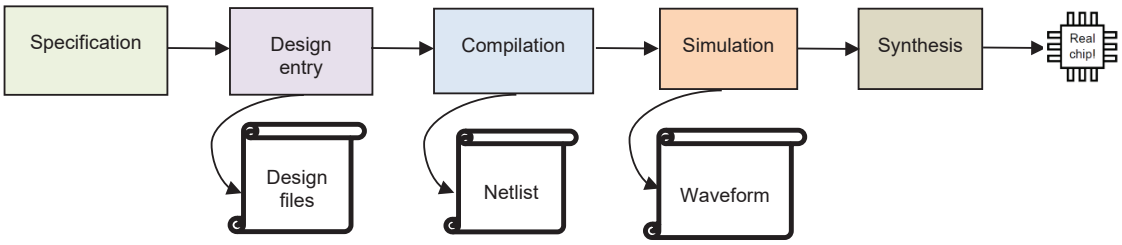
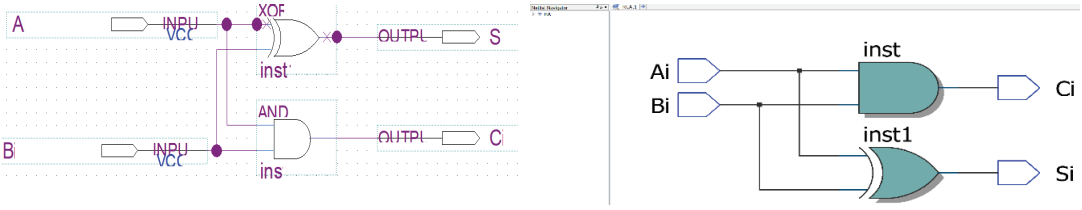
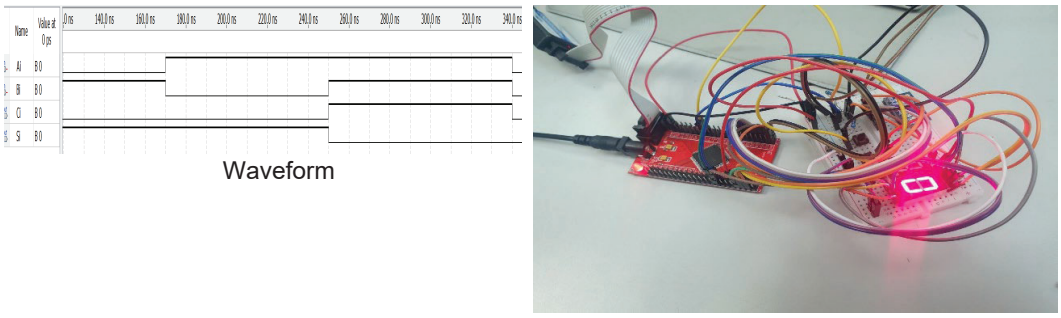


Figure 4: Digital design process framework



Design file (schematic circuit) Netlist



Waveform

Application on real chip

Figure 5: Design and verification using EDA tool

Finding

At the end of in class and outside activities, students perform feedback through reflections based on a series of questions using Google form given to them at the end of semester. There are two types of questions, first is a multi-choice question (students give the rate) and second is opinion questions where students will give their comments. Based on students' feedback on the active learning with hands-on simulation for class activity as shown in Table 1, most of them are satisfied with their improvement on the level of knowledge and understanding for related topics which is designing the combinational logic. They agree that the class activity was deemed highly useful, helping them grasp theoretical concepts through real practice and at the same time familiarizing them with the tool. The combination of hands-on practice, teamwork, and effective instruction made the class both enjoyable and educationally valuable.

Table 1: Students' feedbacks on class activity with the tool-assisted learning

Student	Comments for hands-on activity (during the class)
1	Using Quartus makes it very interesting to learn as we can simulate it without using the real deal.
2	Quartus Tool helps us to verify our inputs and outputs are the same as the circuit from Quartus Tool that being arrange same like our design.
3	I think it was a really practical lesson.
4	It is very exciting and understandable since it is a class activity where we can discuss together on how to solve the problem and use the Quartus tool.
5	Help immensely in teaching me how to use the archaic Quartus tool and it helps me understand how logic gates are applied in real life.
6	Good and efficient teaching lecturer as well as a fun learning atmosphere.
7	Fun and effective way to learn about combinational circuits and the Quartus tool.
8	Using Quartus was very fun. And Lecturer was very kind in helping us to give a good solution.
9	This class is useful.
10	It made me understand better the k-map and logic design.
11	This activity is good for students because it help students to use Quartus tool.

Table 2 presents student reflection toward their confidence in their design knowledge after completing the mini project. Based on their engagement for this project, they believe that using the tool-assisted learning approach has greatly increased their sense of accomplishment and self-confidence in their capacity to apply the knowledge they have learnt in the classroom and take on more challenging projects in the future. Although they first encountered some

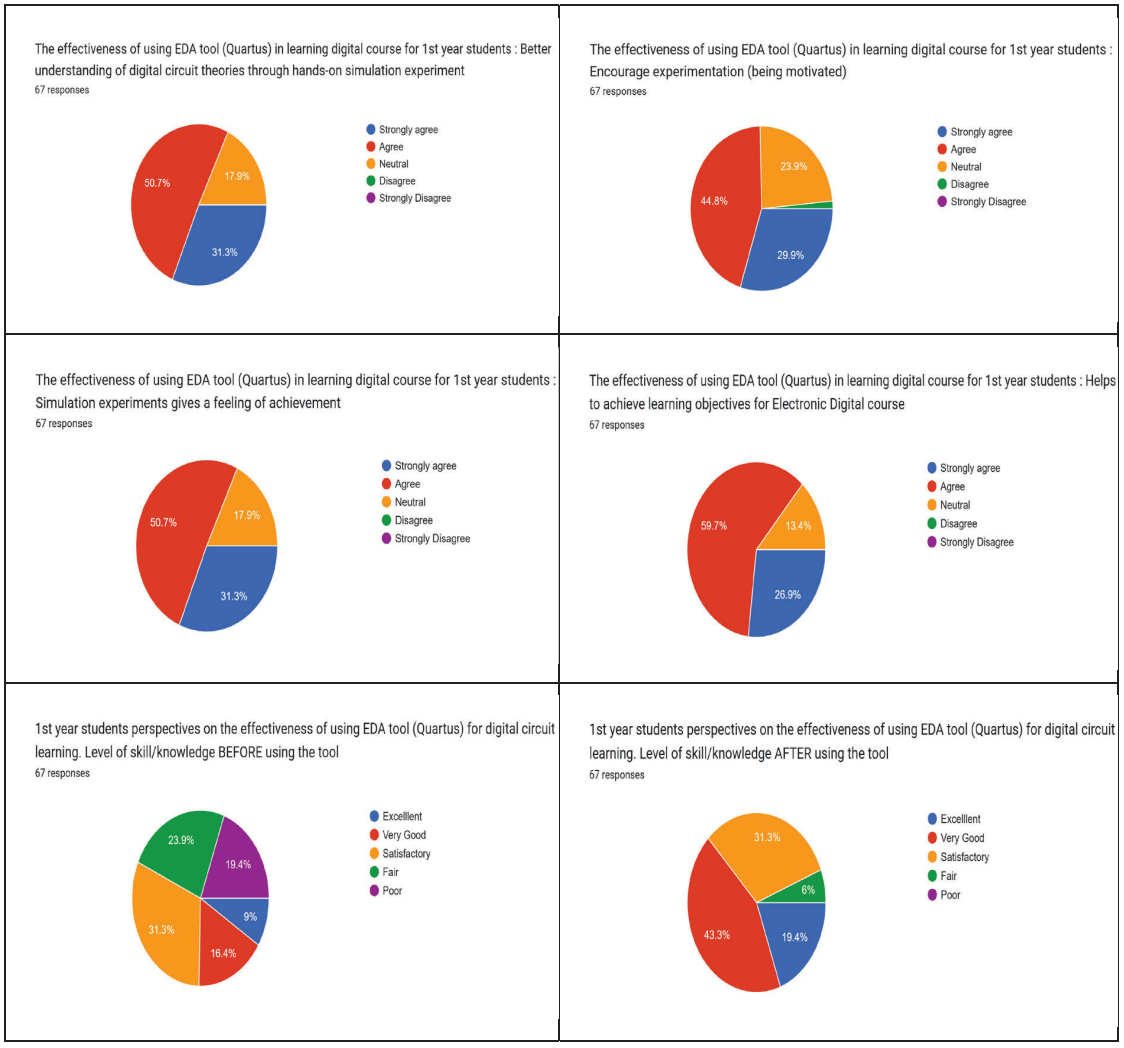
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challenges when utilizing the common industrial instrument, they were able to get over the problems and get the desired outcomes.

Table 2: Students' reflection on their self-confidence after completing a mini project with the tool-assisted learning

Student	Comments for mini project development (outside the class)
1	Completing this project has given us a great sense of achievement and boosted our self-confidence in our abilities. We were able to apply our knowledge of digital logic to create a functional circuit, which has given us the confidence to tackle more challenging projects in the future
2	The use of Quartus software and simulation, along with the use of truth tables and Karnaugh maps, make the design process organized and efficient.
3	Completing the project and seeing the results gave me a sense of accomplishment and improved my self-confidence.
4	I am happy when doing this project because I had learnt many things through this project. In this project I learnt that how to use Quartus to draw logic circuit and simulate it. Apart from that, I had learnt also to analysis the timing diagram.
5	This mini project has increased my self-confidence and self-responsibility in executing daily tasks and other group projects from different courses as well.
6	Working on a mini project with a team requires clear and effective communication, especially when discussing the design and implementation of the circuit. Good communication can help avoid misunderstandings and ensure that everyone is on the same page.
7	Self-confidence is crucial when working on a little project of a combinational circuit in an electrical digit subject since it enables the person to approach the task with a positive attitude, trust in their abilities and expertise, and feel capable of finishing the project. Without self-confidence, a person can feel overwhelmed, hesitant, or doubt their capacity to finish the project, which would sap their enthusiasm and make it challenging to get things done.
8	Overall, the little project was a good learning experience, and I am more confidence in my abilities as a software engineer as a result
9	The Quartus enables us to analyse and synthesis our circuit design and simulate its reaction to different stimuli.
10	Learning new knowledge about using Quartus is one of the best things. I hope that good things that are able to produce students who excel in learning and think of thoughtful ideas in applying the knowledge learned can continue in the future.
11	I was confident that our project become a successfull project. I was responsibility to prepared and make a video about how to use make a circuit and tested it on Quartus Prime. I explained it well done and posted it on YouTube to make the lecture easily to access.
12	Personally, I have experienced and enjoyed working with my group. I have learn how to brainstorm a problem and properly learn how to make a schematic diagram, Quartus and waveform.
13	One important thing that I realized during this assignment is i got to increase my self-confidence. This is because every person in this group needs to express their views and opinion to solve this problem.
14	So far, I think the Quartus is so helpful for students 1st like us and it makes me easier to gain knowledge about Digital Electronics.
15	The creation of a combinational circuit mini project can raise your confidence since it gives you the chance to use the information and abilities you have acquired in the classroom to solve a practical problem.
16	This assignment helped me to understand more about this course that we learned this year.

Figure 6 shows feedback from students regarding how well the tool supported their learning, how well they understood the course material both before and after using it, and whether the technology was appropriate for their first-year learning. From the findings, the students expressed mixed opinions about the effectiveness and their perspective of the EDA tool in supporting their learning, where they were more comfortable to choose 'Agree' instead of 'Strongly agree' and 'Very good' instead of 'Excellent', respectively. A further investigation is conducted to find the reasons behind their choice. The observation found that many students feel the tool is overly complex, requiring significant time to learn before practical use, which they felt was inefficient. Some struggled with understanding its functionalities, noting that the tool was not particularly user-friendly for beginners. Despite its complexity, a few acknowledged a sense of achievement after successfully navigating it. Additionally, students highlighted the lack of sufficient instructional materials, making the learning process even more challenging. While some believed its effectiveness varied depending on the project. However, the majority of students agree that EDA tool-assisted learning is suitable for freshmen like them even though the tool has standard instruments for the industry, suggesting room for improvement in accessibility and educational support.



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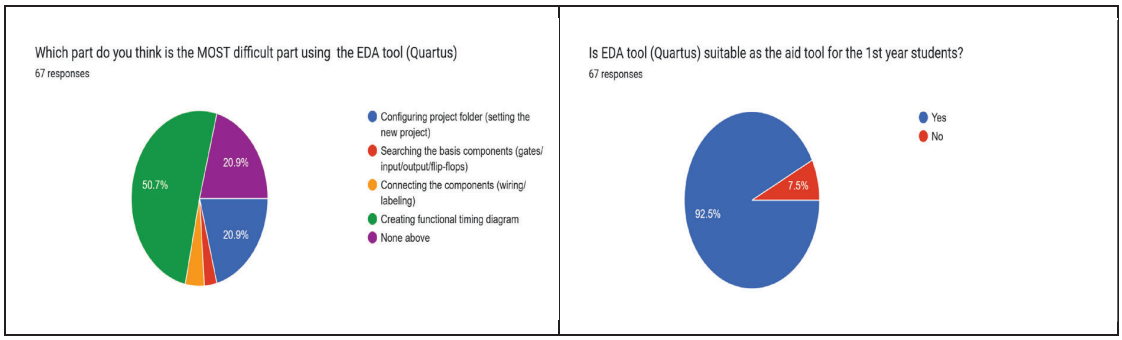


Figure 6: Students' feedbacks in terms of the effectiveness of the tool in assisting their learning, their perspectives to the level of knowledge to the course materials before and after utilizing the tool and their thoughts to the suitable of the tool in the learning as a freshman

Conclusion

Based on the findings, it can be concluded that using Quartus tool in combination with a structured assignment helped students understand more about the topics covered in the Digital Electronic design course. Students' enthusiastic comments after completing the assigned tasks show that the active learning activity, which includes the hands-on simulation, aids in comprehending. Since classroom instruction is more engaging than traditional instruction, students also appreciate it. The results indicate that students were able to get a deeper understanding of integrated circuit design, a topic taught in the Digital Electronic Design course, by utilising EDA tool-assisted learning. Understanding the course is aided by the positive feedback from students who have used the design framework, which incorporates some practical exercises. Students also value the tool-assisting learning style since they find it to be more engaging than standard lectures. In the future, a more comprehensive and well-structured data analysis will be carried out, drawing from the students' reflections. Furthermore, more detail on the course outcomes i.e student's achievement based on the course learning outcomes (CLO) is expected to be analysed.

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