

## Simulation-Based Approach to Teach Electronic Circuit Design

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### Abstract

Engineering students often consider complex real-world systems with complex structures and uncertainties. The engineering practices in traditional education systems could only offer limited opportunities for students to understand the concrete properties of the real-world systems, limiting the performance of students. In this action research, simulation-based education (SE) is considered to improve the performance of the students in engineering practices. We introduce virtual simulation platform to help students get familiar with the considered systems; because students could practice with the systems with unlimited trials, they could get sufficient practices in the considered systems and improve their performances when dealing with real-world systems. Feedbacks are collected from questionnaires after the module is completed and the results demonstrate that the introduction of virtual simulation platform helps students get more familiar with the real-world systems and improve their performance compared to previous records.

*Keywords:* simulation-based learning, experiential learning, engineering education, higher education, action research

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## Introduction

In higher education, students are facing the pressure of preparing for their future profession and their professional competences should involve a range of 21st-century skills (Chernikova et al., 2020). Students in engineering departments often deal with complex real-world systems like electronic circuits, robots, deep neural networks. These systems are often high-dimensional, being influenced by the thousands of parameters that could change the behavior of the complex systems (Kutz et al., 2016). Moreover, the complex systems in real-world are often subject to external perturbations or internal uncertainties, making the engineering education challenging to students as the practices offered by university are often limited compared to the requirements of the teaching criterions (Byers et al., 2013). This is the main drawback in traditional teaching systems where students often have limited understanding of the complex real-world systems and thus they need more training after graduation and before they could engage in the engineering works (Gruler et al., 2019).

According to Juan et al. (2017) that employing virtual simulation platforms could help students better understand the abstract concepts and enhance the learning experience through repetitive explorations in the simulation platforms.

## Simulation-Based Education

Simulation-based education (SE) is first identified as a useful tool to enhance learning experience in 60s last century (Boocock & Schild, 1968) and continues its development in higher education. Simulation-based learning provides students' learning with "the approximation of practice, allows limitations of learning in real-life situations to be overcome, and can be an effective approach to develop complex skills" (Chernikova et al., 2020, p. 502). Beaubien and Baker (2004) define simulation as a tool that replicates the real-life characteristics of situations and scenarios. A more specific definition suggested by Cook et al. (2013) stated that simulation is an "educational tool or device with which the learner physically interacts to mimic real life" (p. 876). The simulation training sessions often partner with the stages of the experiential cycle, combining the active experiential component of the simulation exercise and effective reflection on the learning experience (Chernikova et al., 2020).

Simulations are now increasingly used in higher education (Chernikova et al., 2020). In science, technology, engineering, and mathematics (STEM) education, they are used to facilitate a deeper understanding of concepts and relationships between different disciplines, advance inquiry,

problem solving, and decision making (Koh et al., 2010; Wu & Anderson, 2015). In recent STEM area, researchers use SE to help students understand the operation of a factory by building a virtual factory using software (Frantzén & Ng, 2015). SE could provide valuable experience with large training capacity which is difficult for employment of traditional labs which are constructed physically and expensive (Alnoukari et al., 2013). In engineering education, simulation-based learning could improve student academic performance. Mavinkurve and Patil (2016) reported how the electronic circuit simulator is successfully involved in learning and facilitate students' academic studies with sufficient training.

In summary, SE has been identified as a useful tool to bridge the gap between theory and practice in STEM education. The main benefits of SE could be identified as

- increasing motivation for students (Klug & Hausberger, 2009; Koh et al., 2010);
- valuable experience via safe practice environment (Ören et al., 2017);
- inspiring problem solving and decision making in academic area (Tzimerman et al., 2014);
- fostering critical thinking in learning activities (Pirker & Gütl, 2015).

Meanwhile, the main drawbacks of SE include distraction, special training, and difficult assessment (Ören et al., 2017). Student number is also a challenge for in-class simulation-based classes. But Campos and his colleagues (2020) indicated in that such drawbacks could be overcome if the project could be well-designed. Our action research will explore the design of simulation-based learning approach for a large class with more than 200 engineering students.

### **Experiential Learning**

Experiential learning is a process of learning from direct experience. Kolb (1984) suggested that ideas are not fixed but are formed through experience. Research on experiential and community engagement learning shows that the concept of experiential learning has been mostly applied in the arts and humanities, has been implemented some in natural sciences, and has received increasing attention in engineering (Hajshirmohammadi, 2017; Kolb, 2014; Kolb et al., 2001). Experiential learning has been applied to several engineering disciplines, such as electronics and electrical engineering (Hajshirmohammadi, 2017; Kim et al., 2008; Li et al., 2019). Ayob et al. (2011) reported the positive effects of experiential learning activities on developing and enhancing student creativity dimensions in engineering education. In a machine

design course researched by Wood and his colleagues (2005), increasing the hands-on activities followed by Kolb's learning cycle (1984) is beneficial to establish clearer relationships between machine design principles and the reality of machine components. Understanding engineering and educational concepts is also evidenced effectively with students' full involvement in experiential learning process (Verner & Korchnoy, 2004). This study will discuss how engineering-majored students learning from experience and maximize the theoretical knowledge from the experiential learning.

### **Electronic Circuit Design Course**

The course "Experimental, Computer Skills and Sustainability", denoted as MEC104, is designed to provide a comprehensive engineering learning environment on basic experimental methods, computer literacy and engineering sustainability. It is a course with five credits, taught by one teacher and designed for 260 Year Two students in engineering. There are 19 classes in the course with 8 lectures and 11 labs. Students need to have some basic knowledge such as digital electronics to choose this course. The main part of this course is three projects:

Group Project 1 – Matlab: to be familiar with scientific computing software Matlab;

Group Project 2 – Robot: to design

simple robotic systems like voice controlled LED lights and smart car with electronic devices;

Group Project 3 – Open Project: to design electronic circuits for specific functions where the topics are selected by the students themselves.

For the assessment of this module, Group Project 2 and Group Project 3 makes 60% of the total marks, making designing of electronic circuits important to students involved in this module. In this report we are going to focus on improving the performance of the electronic circuit design for Year 2 students.

### **Learning Challenges**

Based on the main contents of MEC104 and the previous course feedback from students, we identify three challenges in MEC104 learning:

- difficult in applying theory to practice;
- confusion in debugging;
- frequent damage of 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 the current 11 lab sessions. Such giant gap between theory and practice leads to unsatisfactory performance from students.



## Research Questions

1. How could simulation-based approach facilitate engineering students' learning in Electronic Circuit Design?
2. What are the potentials of using simulation-based learning in engineering education?

## Method

An anonymous student survey was administered using Likert scales and comment boxes for students' self-evaluations and perceptions. There were over 200 participants in this project with 124 valid answers. Questionnaire is divided into three parts:

1. the evaluation of simulation-based learning experience;

2. the perception of using TinkerCAD for electronic circuits designing activities;
3. the perception of using simulation tools for future electronic circuits design.

## Action Research Plan

We select a virtual simulation platform TinkerCAD to simulate electronic circuits. It includes several common electronic elements, which are important in engineering practice for students in MEC104. Moreover, it provides opportunities for students to assemble the circuits, which are also valuable for students to train their assembling skills. The platform TinkerCAD (see Figure 1) is free to all users and is web-based, i.e., it could be accessed through any web browser.

**Figure 1**

*TinkerCAD Design Interface*



Based on the functions of TinkerCAD, we have designed following action research plan, including three main steps:

1. A starting simulation project:

We provide a starting simulation project to help students get familiar with the simulation platform: students are asked to design a digital clock. Detailed operation steps are provided to students, and we use the lab session to ensure all students have finished the project. Through this practice, they will get familiar with the design, assemble, debug process in designing electronic circuits.

2. A design project with pre-selected topic:

Students are required to finish a design project with pre-selected topic, a smart car system. Following similar procedure as the starting project, students will go through the design, assemble and debug process. When the simulated project is finished, students are allowed to assemble the physical electronic circuits. Also, with the experience they obtained in simulation platform, the debug of the physical circuit could be guided by the simulation results: students could refer to the simulation as the instructions for hands-on debug. If they have some unclear problems, they could also try to reproduce the bugs in simulation and

then try to solve the issues in simulation. Moreover, because the topic is the same across all students, they are encouraged to discuss the project with each other and try to find out solutions.

3. An open project with free topic:

When the smart car project is finished, students could start a new project with their interested topics. The design procedure is similar to the smart car project, the only difference is that they have to finish the project on their own as the topics are different. Throughout this project, teachers and teaching assistants will not provide detailed instructions, only some general guidance will be provided to encourage the students try to find the solutions with their own efforts.

It is clear that with the three projects, students are guided to get familiar with the simulation platform and develop the ability to design electronic circuits. In these projects, students would first use the simulation platform to obtain experience about assembling and debugging, then apply their experience in implementing the physical electronic systems. We design such action research plan to ensure that students are carefully guided and could integrate simulation platform into the electronic circuit design process.

## Results

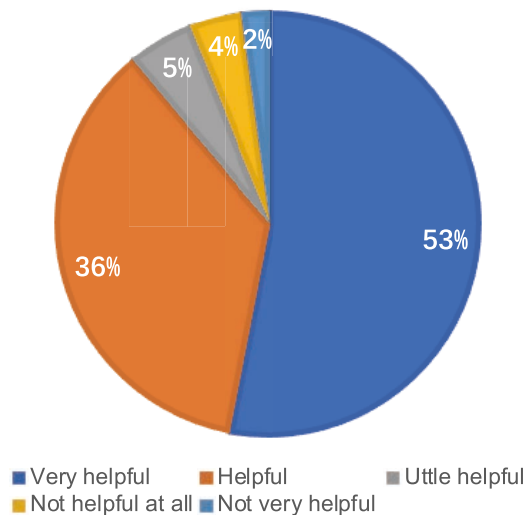
### Students' Self-Evaluations

#### *Part 1: Perception of Using TinkerCAD for Electronic Circuits Designing Activities*

It is easy to find from Figure 2 that nearly 89% of the surveyed students think that TinkerCAD is helpful when designing electronic circuits. This implies that SE is useful when delivering the contents of MEC104.

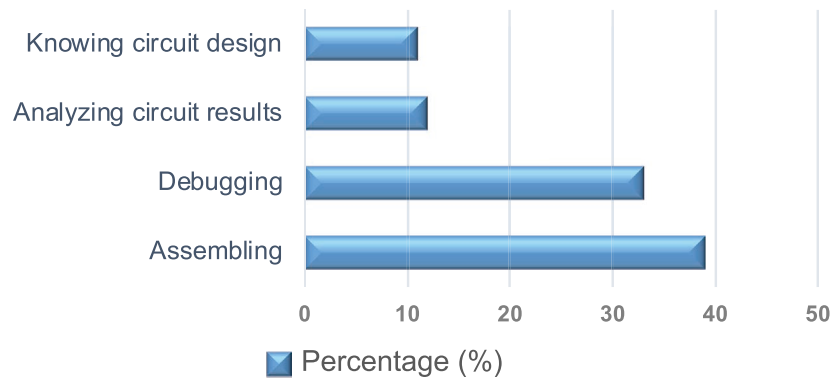
**Figure 2**

*Student Perception of Using TinkerCAD in Learning*

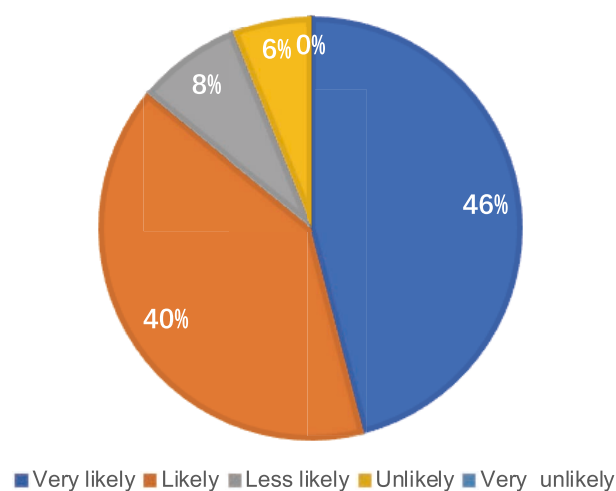


#### *Part 2: Evaluation of Simulation-Based Learning Experience*

It is clearly shown in Figure 3 that the most helpful point by introducing TinkerCAD is to help students practice assembling. We think that this is because assembling is new to students and this is the basis of constructing electronic circuits. Besides, nearly 36% of the students think that TinkerCAD is most helpful in debugging, this concurs with the aforementioned objectives when designing the action plan, that students could get debugging experience from simulations and this could instruct students when debugging physical circuits.

**Figure 3***Skills Improved by Using the Simulation Platform*

Students are very likely to use the simulation platform in their future design (Figure 4). This confirms that using simulation platform helps them get familiar and more confident with the design of electronic circuits. Moreover, it demonstrates the effect of introducing SE to MEC104 that students are trained to solve real-world issues for their future development.

**Figure 4***Student Intention of Using Simulation Tools in Future Electronic Circuits Design*

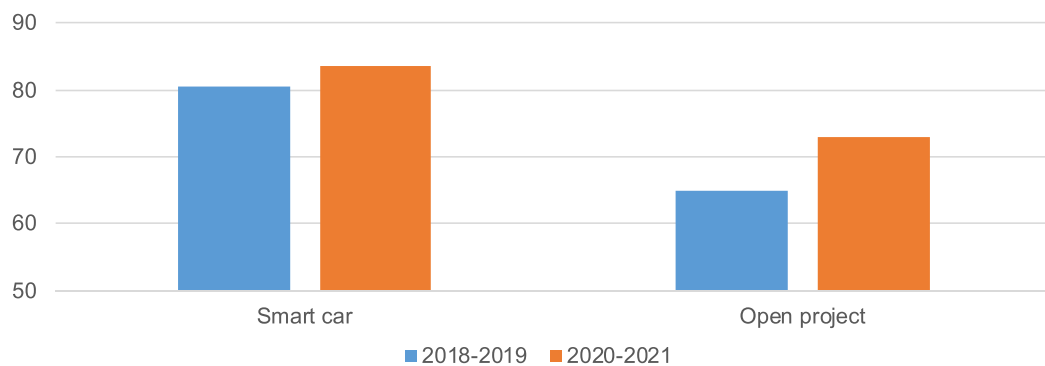
### Students' Academic Scores

We have investigated the course scores of the students who have studied this course in academic year 2018-2019 and 2020-2021 with a comparison of two project scores in Figure 5. To ensure the neutrality of the marks, we have ensured that the scores are given based on the same marking guideline (an example is attached in the Appendix). Also, two teaching assistants who had evaluated the works in academic year 2018-2019 are hired again to evaluate the submissions in academic year 2020-2021.

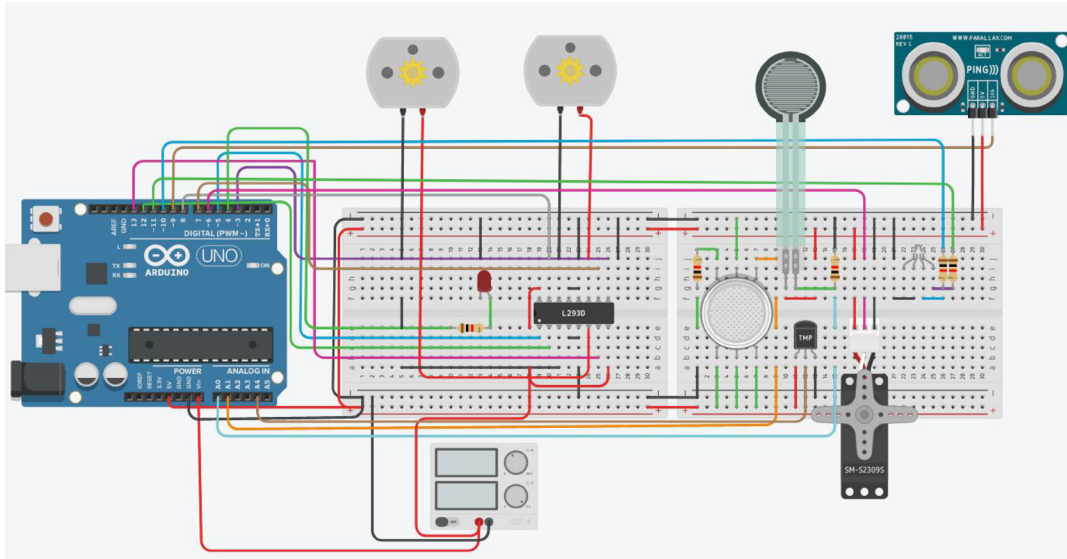
Based on the marks shown in Figure 5, we have observed an increase in both smart car and open project. This reveals the advantages of introducing SE to MEC104. Concretely, students get higher marks in smart car project mainly because the complete rate is higher, showing that more students have completed the project successfully; also, students get higher marks in open project mainly because more complex functions are implemented in the designed products (an example is shown in Figure 6). The design circuit includes 5 different types of sensors and 2 different types of actuators. We believe that with the help of TinkerCAD, students are more experienced with electronic circuit design and are more confident to include complex functions when designing their own works.

**Figure 5**

*Average Student Score of Electronic Product Design Project in MEC104*



In summary, based on the results collected using the questionnaires and the course scores, introducing SE into the teaching of MEC104 could help students understand the contents in this module and improve their performance in electronic circuit design (see a student work in Figure 6).

**Figure 6***A Design Example for Open Project*

## Discussion and Findings

### Improving Learning Motivation

Based on our observation and students report, students' learning motivation is highly improved compared to the previous year when the simulation-based teaching platform was not introduced before 2020. Students are more willing to explore the characters and functions of electronic components in the simulation platform; subsequently, they are more confident to practice with the explored components in the real-world experiments. Such achievement is first reported by the teaching assistants and then confirmed by the

course leader via informal conversations. Moreover, the improved learning motivation has a direct influence on students' academic scores and engineering education. Due to the new components and functions have been employed in their designed products, students' academic performances are improved in the open project which is usually regarded as the most challenging assessment in the course. Because the simulation platform is safe and iterative, students could try various components and their functions without worrying that casual trials would damage the components. The risk of exploring new things and error checking is low. The simulation

platform allows them to design the products with their conception, regardless of the complexity of assembling; after the verifying the validity of their design, students could simplify the design for the real-world physical product.

### Pre-Training in Simulation-Based Education

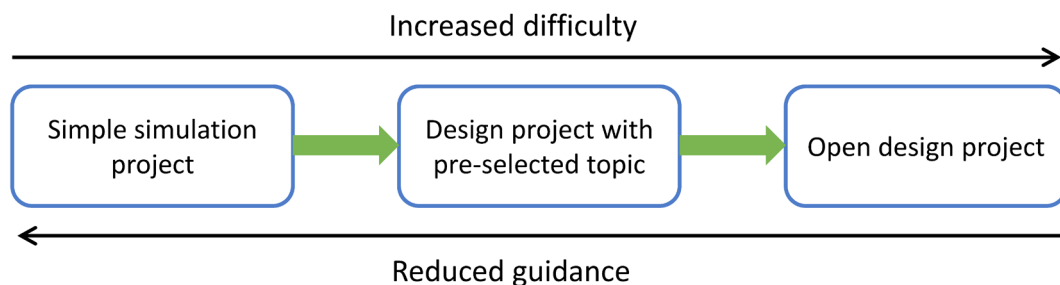
It has been pointed out in previous work like Mavinkurve and Patil (2016) that simulation-based education would require careful guidance when introducing the virtual platform. Similar ideas are given in some internal and external peers' comments to this module. When designing the action research plan, we have set a starting simulation project where great efforts, from teaching assistants and module leaders, have been made to ensure that every student could successfully imple-

ment a simple simulation project. After that, a project with pre-selected topic is arranged. When all students were working on the same topic, they could discuss together while the teaching assistants and the teacher were able to answer their questions to identify similar problems across all student groups. Finally, the project with free topic was worked out by themselves.

We made such action research plan following a step-by-step manner: the students were firstly guided on a simple project with strong support; then they were arranged to work on a project in medium level with weakened but suitable guidance; finally, they will be able to design, assemble and debug a product with complex electronic circuits. The relation between project difficulty and provided guidance is shown in the Figure 7.

**Figure 7**

*Relation Between Project Difficulty and Provided Guidance*



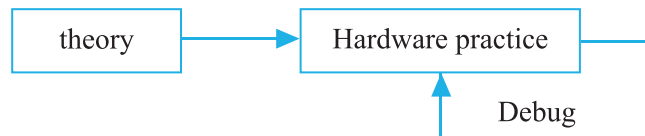


### Promoting Experiential Learning in Engineering Education

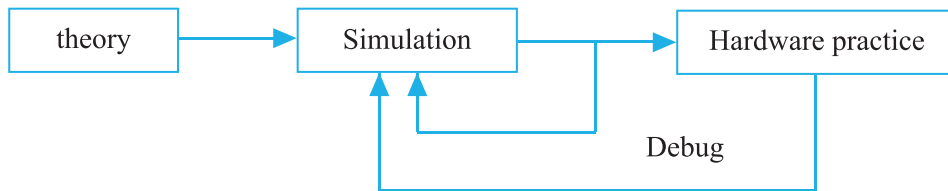
The traditional teaching of MEC104 has mainly two parts: lecture and lab sessions. The teachers will lecture the theories and introduce the electronic elements. Then students will attend lab sessions to practice the knowledge they learned to design electronic circuits and debug the circuits until they work (see Figure 8). In this action research, common to all projects require students to finish the simulation first and then could try to do the experiment with hardware. The debug in simulation platform is highly efficient. Students can have multiple trials in short period and gain experience through the debug in simulations. The two challenges students had at the beginning of the course have been most solved. For example, they found it easy to use and more willing to explore concepts learned in theories to their simulation platform. Students are reported more active in both in-class and after-class learning activities, including group discussions, peer-assisted learning on simulation platform and individual exploration on new functions on TinkerCAD.

**Figure 8**

*Traditional Delivery Method of MEC104*



In summary, the action research plan based on the simulation-based education scheme has improved the traditional “theory-lab” delivery mode, student could obtain intuitive understanding and experience when designing electronic circuits. The practice with simulation platform is safe and iterative, students could have as many trials as they want, encouraging and motivating them to explore new electronic components, design complex circuits and implement complex functions. In the SE-based approach (see Figure 9), students could gain valuable experience using simulation platform, which are limited with traditional teaching method.

**Figure 9***SE-Based MEC104*

### Future Plan

It is demonstrated that introducing virtual simulation platform will improve the performance of students in MEC104, so in future we are going to integrate SE more deeply into the module delivery, e.g., demonstration with simulation should be more involved in lectures. It is pointed out by the collected data that using SE is most helpful in assembling the circuits. In the future, a simple simulation project will be introduced concretely in lecture to help them get familiar with assembling. Using TinkerCAD is also very helpful in guiding the debugging practice, so the debugging skills will be introduced in lectures with the demonstration with simulations.

### Conclusion

In this report, we have proposed an action research plan to investigate the effect of introducing simulation-based education method to the teaching of electronic circuit design. The action research plan includes three steps to gradually guide the students to be familiar with the simulation platform and obtain experience from the platform. The obtained results and marks show that students find the SE method useful in learning the electronic circuit design and the performance of the students is improved using simulation platform.

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## Appendix

### MEC104 Report Marking Guidelines – Open Project

Grade Mark		Quality of Report (10%)	Problem Specification (10%)	Methodology + Trouble Shooting	Design + Implementation (Open Project) (40%)	Testing (10%)
<b>A++</b> 90%–100%	<b>Exceptional work</b>	Clear and structured; all aspects covered; fluent and succinct presentation; logically developed and coherent	Shows critical understanding of functional requirements and knowledge	Complete and concise description of methodologies and techniques involved in the experiment.  Complete and concise description of how trouble shooting is carried out.	Clear and structured; all aspects covered; appropriate design techniques used; design shows exceptional degree of originality and is novel  Delivers novel solutions to problems encountered;	Shows thorough testing, all aspects of system tested; well chosen examples; system works as expected for all examples
<b>A+</b> 80%–89%	<b>Outstanding work</b>	Clear and structured; all aspects covered; fluent and succinct presentation; logically developed and coherent	Shows critical understanding of functional requirements and knowledge	Concise description of methodologies and techniques involved in the experiment.  Concise description of how trouble shooting is carried out.	Clear and structured; all aspects covered; appropriate design techniques used; design shows some originality  Delivers realistic solutions to problems encountered;	Shows thorough testing, all aspects of system tested; well chosen examples; system works as expected for all examples
<b>A</b> 70%–79%	<b>Excellent work</b>	Clear and structured; all aspects covered; fluent and succinct presentation; logically developed and coherent	Shows comprehensive understanding of functional requirements and knowledge with the ability to put the work into context and to critically evaluate selected aspects of the work	Good description of methodologies and techniques involved in the experiment.  Good description of how trouble shooting is carried out.	Clear and structured; all aspects covered; appropriate design techniques used  Delivers appropriate solutions to complex problems encountered	Shows thorough testing, all aspects of system tested; well chosen examples; system works as expected for all examples
Grade Mark		Quality of Report (10%)	Problem Specification (10%)	Methodology + Trouble Shooting	Design + Implementation (Open Project) (40%)	Testing (10%)
<b>B</b> 60%–69%	<b>Competent work</b>	Most clear but may not be structured well; most aspects covered; mostly fluent and succinct presentation; mostly logically developed and coherent	Shows good understanding of functional requirements and knowledge, with no major gaps or omissions, but minor gaps or omissions may occur	Satisfactory description of methodologies and techniques involved in the experiment.  Satisfactory description of how trouble shooting is carried out.	Mostly clear but may not be structured; most aspects covered; appropriate design techniques used  Delivers appropriate solutions to most problems encountered;	Most aspects of system tested; most examples chosen are appropriate; system works as expected for most examples
<b>C</b> 50%–59%	<b>Satisfactory work</b>	Report is satisfactory but may lack in depth or breadth; some aspects omitted; satisfactory presentation; partly logically developed	Shows satisfactory understanding of functional requirements and knowledge, with the ability to integrate information but lacking in depth or breadth	Description of methodologies and techniques involved in the experiment, but not precise.  Description of how trouble shooting is carried out, but not precise.	Design is satisfactory but may lack in depth or breadth; some aspects omitted; design techniques used are mostly appropriate  Delivers satisfactory solutions to some problems encountered	Some aspects of system tested; some examples chosen are appropriate; system works as expected for some examples
<b>D</b> 40%–49%	<b>Adequate work</b>	Unclear report with some faults; quite some aspects omitted; clumsy and repetitive presentation; not logically developed	Shows general understanding of functional requirements and knowledge but very limited in depth or breadth	Description of methodologies and techniques involved in the experiment, but with obvious deficiencies.  Description of how trouble shooting is carried out, but with obvious deficiencies.	Unclear design with some faults; quite some aspects omitted; suitable design techniques used for a good part but with flaws in use or with omissions  Flaws in some solutions to problems encountered;	Some aspects of system tested; Only very few examples are chosen appropriately; system only works for a small portion of the examples
<b>E+</b> 35%–39%	<b>Marginal failure</b>	Displays deficiencies and omissions in a large proportion of the report	Shows limited or fragmented understanding of functional requirements and knowledge, with some aspects displaying fundamental errors and omissions	Either of the key components (content and trouble shooting) is missing	Suitable design methods are used to some extent but with flaws in use or omissions which negatively impacts on the work  Deficiencies in most solutions to problems encountered	Many aspects of system not tested; examples chosen are not appropriate; system does not work for almost all examples

Grade Mark		Quality of Report (10%)	Problem Specification (10%)	Methodology + Trouble Shooting	Design + Implementation (Open Project) (40%)	Testing (10%)
E- 30%–34%	Non-marginal failure	Displays serious deficiencies and omissions in a large proportion of the report	Shows limited or fragmentary understanding of functional requirements and knowledge, with many aspects displaying fundamental errors and omissions		Lack of the use of suitable design methods and/or deficiencies and omissions in a large proportion of the design  Deficiencies in a large portion of solutions to problems encountered	A large portion of system not tested; poorly chosen examples; system does not work for all examples
F 20%–29%	Work shows little effort	Displays serious deficiencies and omissions in most of the report	Shows incomplete understanding of functional requirements and very limited range of knowledge, with numerous errors of interpretation	Not able to demonstrate understanding both of the key components (content and trouble shooting).	Serious lack of the use of suitable design methods and/or serious deficiencies and omissions in most of the design  Unable to deal with most problems encountered;	Almost no testing was described
F- 10%–19%	Work shows little adherence to the tasks	The overall report is unstructured, ill-presented, and very poor	Shows no understanding of essential principles and concepts and the most limited and fragmentary knowledge, work is likely to be unstructured and ill-presented		Little use of any design methods and very poor design  Unable to deal with any problems encountered	Almost no testing was described
G 0%–9%	Nominal or complete lack of work	The report is almost unreadable or does not exist	Virtually devoid of any evidence of understanding of functional requirements and knowledge		No use of design methods or virtually no design is given  Virtually no understanding of material or virtually no realization is given	No testing was described