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Research Article

Development and validation of my online teaching with GeoGebra (MyOT_G+) kit on mathematical reasoning among pre-university students

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ABSTRACT

Traditional rote learning methods often fail to adequately develop reasoning skills in mathematics, particularly among pre-university students. This study addresses challenges in fostering mathematical reasoning abilities, as evidenced by declining TIMSS results and resistance to pedagogical innovations. My online teaching with GeoGebra (MyOT_G+) kit was developed as a technology-enhanced teaching solution to improve students' understanding of propositional logic. Grounded in constructivist theory, the kit integrates GeoGebra software and Venn diagrams for an interactive learning experience, focusing on subtopics such as De Morgan's laws, conditional, converse, inverse, contrapositive, and biconditional statements. Using the design and development research approach and the ADDIE model, the study combined qualitative and quantitative methods. Phase 1 involved interviews with five mathematics lecturers and five pre-university students in Kuala Lumpur to identify instructional needs. Phase 2 focused on designing and validating the MyOT_G+ kit with input from 13 experts. Findings revealed the kit's user-friendliness, adaptability, and ability to reduce cognitive load, facilitating a deeper understanding of mathematical concepts. This study highlights the potential of integrating technology into mathematics education, offering scalable solutions for improving reasoning skills in pre-university contexts. The MyOT_G+ kit provides evidence that interactive, visual tools enhance comprehension of complex topics, with implications for pre-university education and teacher training programs.

Keywords: online teaching, GeoGebra, MyOT_G+ kit, propositional logic, mathematical reasoning

INTRODUCTION

The rapid advancements in technology, particularly during the Fourth Industrial Revolution, have reshaped various sectors, including education. This era, characterized by the integration of big data, artificial intelligence (AI), the Internet of things, and machine learning, emphasizes the need for innovative teaching strategies that prepare students for complex problem-solving and critical thinking (Hussin, 2018; Layco, 2022). As traditional rote learning methods struggle to meet these demands, there is a growing call for technology-enhanced learning (TEL) tools that foster deeper cognitive engagement and reasoning skills.

GeoGebra, an interactive mathematics software, exemplifies this shift by providing dynamic visualizations that support abstract concept comprehension. Its application in teaching propositional logic aligns with the principles of constructivist learning theory, emphasizing student-centered exploration and inquiry (Fariha & Lestari, 2019; Velichová, 2011). My online teaching with GeoGebra (MyOT_G+) kit leverages these capabilities to address challenges in mathematical reasoning, a critical skill underscored by national education frameworks such as the Malaysia education blueprint 2013–2025.

Incorporating emerging pedagogical trends, such as gamification and blended learning environments, can further enhance the engagement and effectiveness of tools like MyOT_G+. These trends emphasize not only the acquisition of knowledge but also the development of key 21st century skills, including creativity, collaboration, and adaptability (Khan et al., 2021). By embedding such innovations, educational tools can meet the evolving needs of Gen Z learners, who thrive in interactive and technology-rich settings.

GeoGebra is one of the dynamic software, which is open-source software for teaching and learning (T&L) mathematics (Fariha & Lestari, 2019; Hernawati & Surjono, 2019; Zulnaidi & Zakaria, 2019). It is developed by Markus Hohenwarter in 2002 (Fariha & Lestari, 2019; Velichová, 2011; Zulnaidi & Zakaria, 2019). GeoGebra is a combination of interactive geometry, algebra, calculus (Fariha & Lestari, 2019; Hernawati & Surjono, 2019; Triwahyuningtyas et al., 2019; Zulnaidi & Zakaria, 2019), and statistics (Fariha & Lestari, 2019; Hernawati & Surjono, 2019). GeoGebra is able to assist students to engage in reasoning (Fatimah, 2019; Olsson, 2018) while learning activities take place, and hence students may practice mathematical literacy skills (Poyner, 2018). The use of technology in T&L mathematics is necessary for all levels, which is not only in elementary and secondary schools but also at the pre-university level. This is due to mathematics in pre-university, in which certain topics are difficult and need to be visualized abstractly to enhance students' understanding of the mathematical concept. GeoGebra is one of the technologies which is also suitable to be used in T&L mathematics at the pre-university level.

In this study, the researcher developed a MyOT_G+ teaching kit, which MyOT_G+ stands for my online teaching with GeoGebra. The term "online teaching" implies that the T&L is conducted virtually. However, this teaching kit is also suitable for use in physical classrooms and is even more interactive. The researcher used the term "teaching" only, instead of "T&L", because the kit is mainly used by lecturers as a teaching aid. For conducting this online class, the researcher chose to use the Microsoft Education 365 suite. Among the applications used in this teaching kit are Microsoft Teams, Microsoft Sway, Microsoft Whiteboard, and Microsoft OneNote (Class Notebook). The term "GeoGebra" is clearly stated in the name of the kit. That indicates that GeoGebra is the main mathematical software used in developing this teaching kit. This research aims to contribute to this discourse by evaluating the effectiveness of the MyOT_G+ kit in enhancing propositional logic understanding among pre-university students. Through a design and development approach, this study seeks to offer insights into how technology can transform mathematics education, fostering both cognitive development and a lifelong love for inquiry.

Frameworks of the Study

A theoretical framework serves as a blueprint for research, guiding how knowledge is structured and investigated (Grant & Osanloo, 2014). This study adopts cognitive and constructivist theories to scaffold knowledge acquisition through three stages: introductory, advanced, and expert. At the introductory stage, behavioral and cognitive approaches provide objective foundations. As knowledge deepens, constructivist approaches enable students to tackle complex problems by discovering, negotiating, and modifying misconceptions (Ertmer & Newby, 2013). The theoretical framework of this study is shown in **Figure 1**.

The MyOT_G+ kit's framework integrates cognitive learning theory at the initial stage, focusing on propositional logic basics such as propositions, conjunctions, disjunctions, and negations. Ausubel's meaningful learning theory is applied to connect new material with students' existing cognitive structures, facilitating retention and comprehension (Zulnaidi & Zakaria, 2019). The advanced stage emphasizes discovery learning, with activities designed to help students independently derive laws such as De Morgan's.

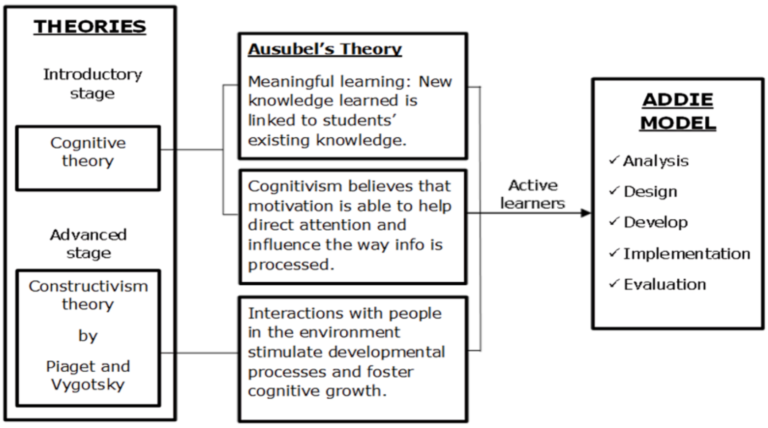

Figure 1. The theoretical framework of study (Source: Authors)

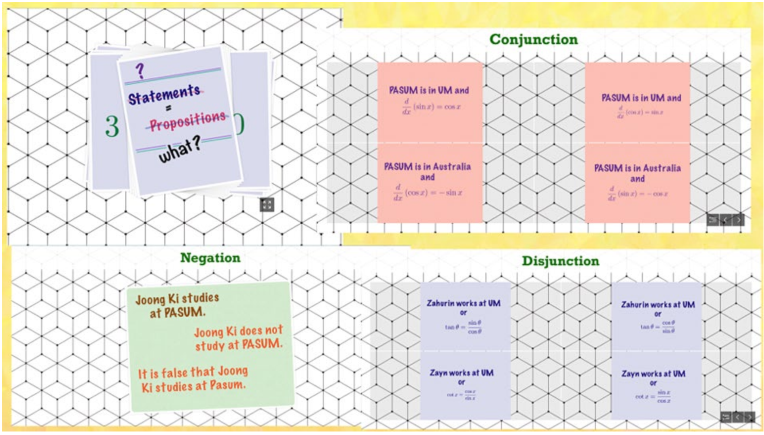

Figure 2. The basic of propositional logic (Source: Authors)

Propositional logic, a fundamental topic often introduced in high school mathematics, poses challenges for students who struggle to understand its relevance and application in both mathematical contexts and everyday life. This disconnect can hinder engagement and deeper comprehension. To address this issue, the MyOT_G+ framework integrates cognitive learning theory at the initial stage of knowledge acquisition. In this approach, both teachers and students actively participate in discussions designed to foster an appreciation and internalization of the topic. By emphasizing the relevance of propositional logic, these discussions aim to bridge the gap between abstract concepts and practical understanding. Following this engagement phase, the lesson progresses with a systematic review of foundational concepts in propositional logic, including propositions, conjunction, disjunction, and negation–content that students were previously introduced to in high school. This pedagogical strategy aligns with Ausubel's theory of meaningful learning, which asserts that new knowledge is most effectively acquired when it is anchored to students' existing cognitive structures. By connecting newly presented material to prior knowledge, the framework facilitates meaningful learning experiences, ultimately enhancing comprehension and retention (Zulnaidi & Zakaria, 2019).

In order to combine the students' existing knowledge with the new knowledge that students will learn in a friendly way, in MyOT_G+ will refresh the basics of propositional logic: definition of propositions, conjunction, disjunction, and negation, only through the human language (refer to **Figure 1**). Students only determine whether the statements are true or false using human logic only. Students will still find it easy to decide on whether true or false. As they are given more complex statements, students will begin to find it challenging to determine the truth of the statement. From then on, students will start to feel the need for mathematical logic. Once they set out to feel the need for mathematical logic, teachers will begin to introduce De Morgan's law. This part has entered an advanced stage of knowledge acquisition. Constructivism theory is applied in this stage. The teacher will start with an activity whereby the students will discover the law independently rather than give it directly to students. First, students need to identify the equivalent statements by only using their human logic, as shown in **Figure 2**.

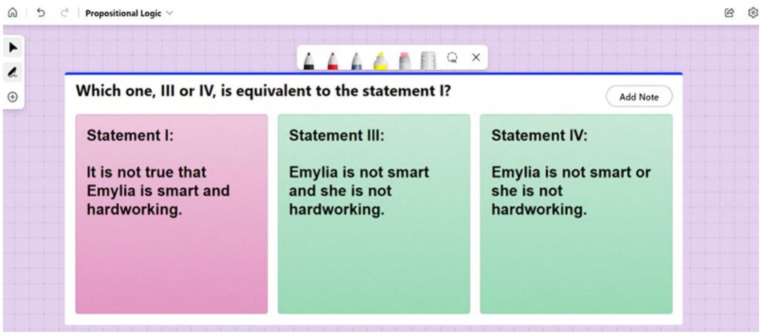

Figure 3. Activity: The exploration of De Morgan's law (Source: Authors)

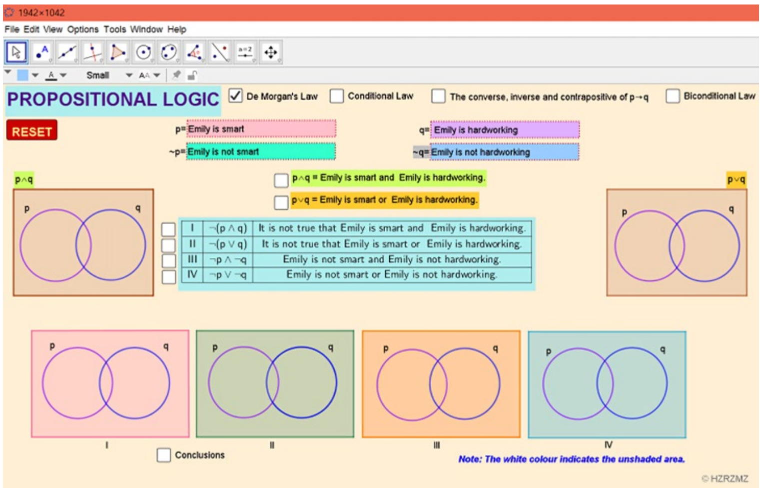

Figure 4. GeoGebra worksheet: De Morgan's law (Source: Authors)

After that, the students will be introduced to mathematical logic. The exploration of De Morgan's law begins with the students being asked to represent each simple statement with one letter, as shown in **Figure 3**. Then the students are asked to draw a Venn diagram for each logical form that has been translated from each statement, the statement I to IV, as in **Figure 4**. From the Venn diagram, students can identify which statement is equivalent to statement I. In the end, students can locate De Morgan's law themselves. Consequently, the students can accept De Morgan's law with more confidence. Then, the activity continues with the exploration of other laws.

The conceptual framework was designed to present the fundamental thinking and structures for this study (**Figure 5**), with the purpose of analyzing the effect of MyOT_G+ on mathematical reasoning among pre-university students on the topic of propositional logic. The conceptual framework is supported by the theoretical framework, and thus it encompasses all the concepts and ideas for this study.

Research Questions

The research questions of this study divided into two phases:

A. Phase 1. Needs analysis phase

1. What areas and topics are problematic in the T&L of pre-university mathematics?
2. How is the implementation of T&L for the topic of propositional logic?
3. Is there a need to develop a MyOT_G+ to enhance understanding of propositional logic?

B. Phase 2. Design and development MyOT_G+ phase

1. To what extent is the content validity of the MyOT_G+ among experts achieved?
2. To what extent is the interface validity of the MyOT_G+ among experts achieved?
3. How reliable is the MyOT_G+ among students?

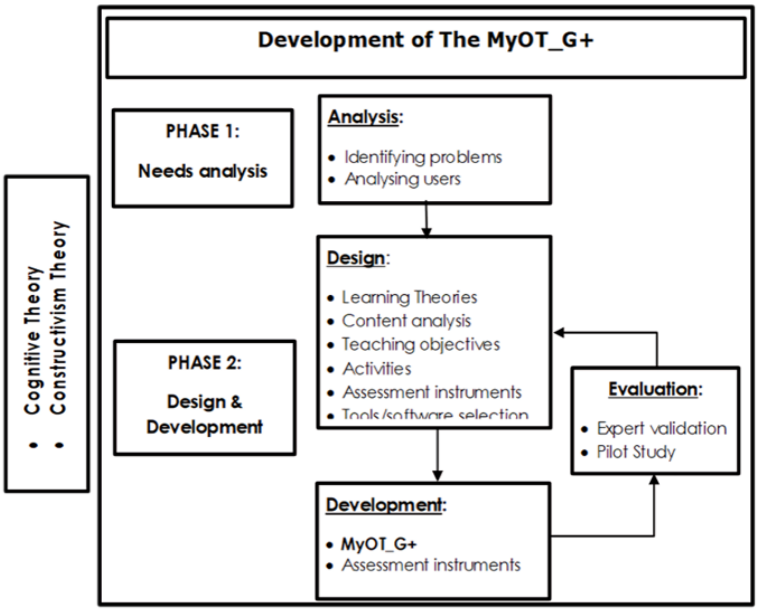

Figure 5. The conceptual framework of study (Source: Authors)

METHODOLOGY

Research Design

This study employed the design and development research (DDR) approach, encompassing the analysis, design and development, and evaluation phases. The ADDIE model (analysis, design, development, implementation, evaluation) underpinned the instructional design framework. Each phase was meticulously documented to ensure replicability and clarity.

Phase 1. Needs analysis

Interviews were conducted with five mathematics lecturers and five pre-university students to identify instructional gaps and areas needing improvement in teaching propositional logic. The interviews employed a structured protocol to ensure consistency and reliability. Thematic analysis was used to extract common themes, focusing on challenges in comprehension and engagement with mathematical reasoning concepts.

Phase 2. Design and development

The MyOT_G+ kit was developed based on insights gained from phase 1. This phase involved collaboration with 13 experts to validate the instructional content, ensuring alignment with cognitive and constructivist learning theories. Tools such as Microsoft Teams and GeoGebra were integrated to create an interactive and engaging learning environment. The development process adhered to the ADDIE model, ensuring a systematic progression from analysis to implementation (Hasbullah et al., 2022).

Richey and Klein (2014) state that most research and development has recently focused on the design and development of technology-based products and tools. Product and tools research stresses the study of products or tools design and specific development projects. In addition, learning outcomes are obtained from developing particular products and analyzing conditions that facilitate their use (Mashoedah et al., 2020). Therefore, the product and tool research cluster aligns with the context of this study. This category comprises three interrelated phases, namely

(1) analysis phase,

(2) Design and development phase, and

(3) Evaluation phase (Mashoedah et al., 2020; Richey & Klein, 2007, 2014).

Each phase in this DDR is appropriate and in line with the instructional design and development model integrated into this study which is the ADDIE model.

Data collection using a structured interview method was analyzed manually. This qualitative data was obtained at the development stage of MyOT_G+. This qualitative analysis was carried out by compiling the recommendations of experts, lecturers and students in the given theme according to the recommendations for improvement of MyOT_G+. However, triangulation is a variety of methods to obtain qualitative data for analysis. It aims to increase the validity of the interpretation of a phenomenon being studied. The researcher used the same questions in the interview protocol on all participants but they are carried out at different times, with the aim of increasing the validity of the answers (data) given by the participants. The triangulation involves 3 levels, involving experts, lecturers, students.

Research Sample

Stage 1. Analysis of module development requirements

There are two categories of interviews in the needs analysis phase for development of the teaching tool:

(1) interviews with mathematics lecturers and

(2) interviews with students.

The research sample was selected via purposive sampling. The participants of this study were selected from among the lecturers in the study population because they have sufficient information about the development and course of the phenomenon that occurs at the study location, namely the selected pre-university. Therefore, this small number of participants was sufficient to provide information to the researcher, which reached the level of no newer or overlapping information. While for interviews with students, the convenience sampling technique was used in the selection of four study participants. The researcher chose this sampling technique for this interview category because all the students at the study location had almost the same level of knowledge and experience. So, the information obtained from the four students is enough to represent the study population among students.

Stage 2. Validity evaluation of the module and implementation of the pilot study

This GeoGebra software module development evaluation study involved 3 instructional design experts, 1 language expert, 10 lecturers, and 30 students. Evaluation by experts and lecturers was conducted through evaluation questionnaires and interviews. While evaluation by students was obtained through the testing of the MyOT_G+. The evaluation of MyOT_G+ began with the evaluation of experts and lecturers. Before filling out the MyOT_G+ evaluation questionnaire, the researcher explained about MyOT_G+ and showed how to use it to experts and lecturers. The researcher gave experts and lecturers 2 weeks to fill out the questionnaire.

Research Instruments

This study involved both qualitative and quantitative instruments, divided into two categories:

(1) Instruments for developing the instructional method (MyOT_G+), including needs analysis instruments for lecturers and students, and validity assessment forms for teaching materials and language.

(2) Instruments for evaluating the effectiveness of MyOT_G+, mainly using pre/post mathematical reasoning ability tests for the topic of propositional logic.

For development, structured interviews with mathematics lecturers and students were conducted to understand challenges in teaching mathematical reasoning. Additionally, the teaching materials were validated through expert reviews for content, interface, and language. The pilot study tested the validity and reliability of both MyOT_G+ and the mathematical reasoning test. The study involved instructional design experts, language experts, lecturers, and students. The pilot test ensured that the instruments could effectively differentiate between high- and low-ability students and evaluated the difficulty and discriminant indexes of test items.

FINDINGS

The purpose of this multi-method study is to develop the MyOT_G+ and investigate its effect on mathematical reasoning abilities for the topic of propositional logic in the pre-university programming syllabus in Malaysia. Technological tools are influential in enhancing students' reasoning skills.

Table 1. The details of study participants (lecturers)

Respondent code	Education	Experience in teaching mathematics	Areas of expertise
L1	PhD in mathematics	20 years in pre-university	Calculus, algebra, and programming
L2	Master's in computer science Postgraduate diploma in mathematics education Bachelor's in electrical engineering	11 years in pre-university	Calculus, algebra, statistics, and programming
L3	PhD in mathematics	20 years in pre-university	Calculus, algebra, and programming
L4	Master's in applied statistics Postgraduate diploma in mathematics education Bachelor's in electrical engineering	15 years in pre-university	Calculus, algebra, statistics, and programming
L5	PhD in software engineering	8 years in MRSM 5 years in pre-university	Calculus, algebra, and programming

Profile Demographic

Phase 1. Need analysis

In this phase, interviews were conducted with lecturers and students to identify the need for the development of the MyOT_G+ kit. Five mathematics lecturers from a pre-university in Kuala Lumpur participated. The selection was based on purposive sampling, focusing on lecturers with more than seven years of teaching experience.

Table 1 presents an overview of the educational qualifications, teaching experience, and areas of expertise of five respondents (L1 to L5), all of whom are mathematics educators with substantial experience in pre-university settings. The respondents possess diverse academic backgrounds, including degrees in mathematics, computer science, applied statistics, and engineering, which inform their teaching practices and subject-matter proficiency.

Phase 2. Design and development

In this section, the researcher systematically examined the virtual T&L platforms available at the selected pre-university. The analysis focused on Google Classroom and Microsoft Teams for Education, as these were the primary platforms provided. Based on a comparative evaluation, the researcher selected Microsoft 365 Education Suite for integration into the MyOT_G+ kit. Key tools from the Microsoft 365 suite utilized in this study include

(1) Teams,

(2) Sway,

(3) Whiteboard, and

(4) OneNote (Class Notebook).

Additionally, GeoGebra was incorporated as a critical software component, facilitating the development of a specialized applet for the topic of propositional logic. The MyOT_G+ kit was designed within a tutorial-based T&L framework, with the GeoGebra applet encompassing six fundamental laws of propositional logic:

(1) De Morgan's law,

(2) conditional law,

(3) contrapositive law,

(4) converse law,

(5) inverse law, and

(6) biconditional law.

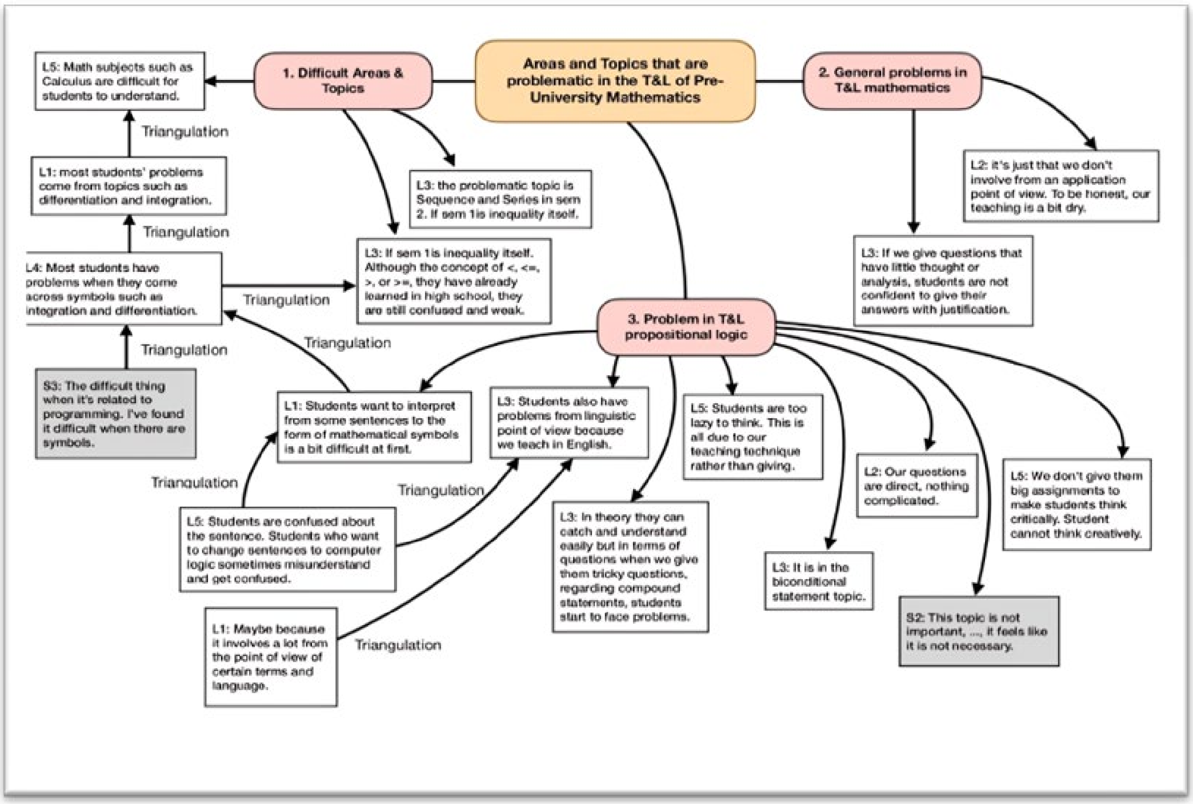

Figure 6. Areas and topics that are problematic in the teaching and learning of pre-university mathematics (Source: Authors)

Besides, as aforementioned, the Microsoft 365 suite was chosen in order to run virtual learning. The lecture slides were designed and developed using Microsoft Sway, instead of Microsoft PowerPoint. One of the reasons Sway was chosen is that GeoGebra applets can be embedded in Sway. While Microsoft Whiteboard was used in lectures for lecturers to explain related matters. All notes and materials, including GeoGebra applet, in the lecture will then be saved in the Microsoft Class Notebook. In addition, the materials for the activities in the tutorial class will be placed in the Class Notebook, in the appropriate section. Class Notebook is the perfect choice to be used in this teaching method. Class Notebook is linked to Microsoft Teams which acts as a meeting platform and virtual classroom. Once the process of development is done, the teaching method will be validated by four experts and ten lecturers, before proceeding to the next phase, evaluation.

Phase 1. Needs Analysis

Areas and topics problematic in teaching and learning pre-university mathematics

The study found that certain areas and topics in pre-university mathematics are challenging for both teachers and students. This includes complex concepts in propositional logic that require innovative teaching tools to enhance understanding and engagement.

The analysis of research question A.1 revealed only one theme, which is (i) areas and topics that are problematic for pre-university mathematics T&L. From the interview session, three codes emerged under the theme, namely:

(1) difficult areas and topics,

(2) general problems in T&L mathematics, and

(3) problems in propositional logic.

Emerging themes and codes are summarized using the schematic diagram in **Figure 6**. Propositional logic topic is under the subject of programming. Since all the interviewed lecturers also teach mathematics, as they were asked which areas and topics in mathematics are difficult, they were only focused on areas and topics in the mathematics syllabus without considering mathematical topics which are also included in the subject of programming. Lecturer L5 stated that calculus is a difficult area in mathematics.

Several lecturers identified key topics in mathematics that pose significant challenges to students. Lecturer L1 and lecturer L4 highlighted differentiation and integration in calculus as particularly problematic, while lecturer L3 pointed to difficulties in algebra, emphasizing issues related to mathematical symbols. In contrast, lecturer L2 did not specify particular topics but discussed broader challenges in T&L mathematics. He noted that pre-university mathematics instruction tends to be rigid and lacks practical applications, contributing to student disengagement.

Lecturer L3 emphasized that students' negative perceptions of mathematics significantly hinder their learning. According to him, students who view mathematics as inherently difficult are less likely to succeed, regardless of the teaching method employed, whether traditional or modern. Additionally, he expressed concerns about students limited critical thinking abilities, particularly in propositional logic, where language barriers further complicate learning. Lecturer L1 and lecturer L5 echoed these concerns, noting that students struggle to translate natural language into mathematical symbols. Lecturer L5 attributed these difficulties to a "spoon-feeding" teaching approach that fosters passivity and limits independent thinking. Furthermore, both L3 and L5 observed that questions related to propositional logic are often perceived as overly simplistic, which may contribute to a lack of engagement. L3 also identified biconditional law as a challenging concept for students based on her teaching experience.

Students' perceptions of propositional logic varied. Students S1, S4, and S5 described the topic as straightforward and manageable. However, student S3 found it moderately challenging, particularly when working with symbols. In contrast, student S2 expressed a different viewpoint, deeming propositional logic unimportant and admitting that he memorized 80% of the material without fully understanding it. This range of perspectives underscores the diverse challenges students face in mastering mathematical concepts.

Implementation of teaching and learning propositional logic

The implementation of T&L propositional logic was evaluated, revealing a gap in effective teaching aids that can facilitate better comprehension and reasoning skills among students. The analysis of research question A.2 exposed three themes, which are

(i) a commonly used approach in the teaching of propositional logic,

(ii) problems when implementing T&L propositional logic, and

(iii) students' wishes in terms of lecturers' teaching for propositional logic.

Theme 1.2 (i). A commonly used approach in the teaching of propositional logic: A commonly used approach in the teaching of propositional logic consists of two main codes, namely:

(1) teaching approach in T&L propositional logic and

(2) software used in T&L mathematics.

Emerging theme and codes are summarized using the schematic diagram in **Figure 7**.

All lecturers acknowledged that they did not employ innovative or unconventional methods when teaching propositional logic. During tutorial sessions, they primarily focused on discussing and solving tutorial questions collaboratively. Additionally, lecturers provided real-life examples to contextualize the topic. Lecturer L5 expressed concern about the prevalent use of a "spoon-feeding" approach in the institution, likening it to traditional school teaching methods. However, she also incorporated real-life examples in her tutorials. In contrast, lecturer L4 adopted a slightly different strategy by intentionally presenting incorrect answers to students. This technique fostered a more interactive environment, encouraging students to correct errors and engage in peer discussions. From the students' perspective, the teaching of propositional logic was largely conventional, lacking innovative methods. Student S2 and student S5 noted that lecturers used real-life examples to explain concepts. Furthermore, students reported minimal use of technology, with lecturers primarily relying on Microsoft PowerPoint for lecture slides and Padlet for class activities. Student S1 and student S2 mentioned exposure to GeoGebra software in other mathematics courses. However, student S1 clarified that GeoGebra was not utilized in the teaching of propositional logic.

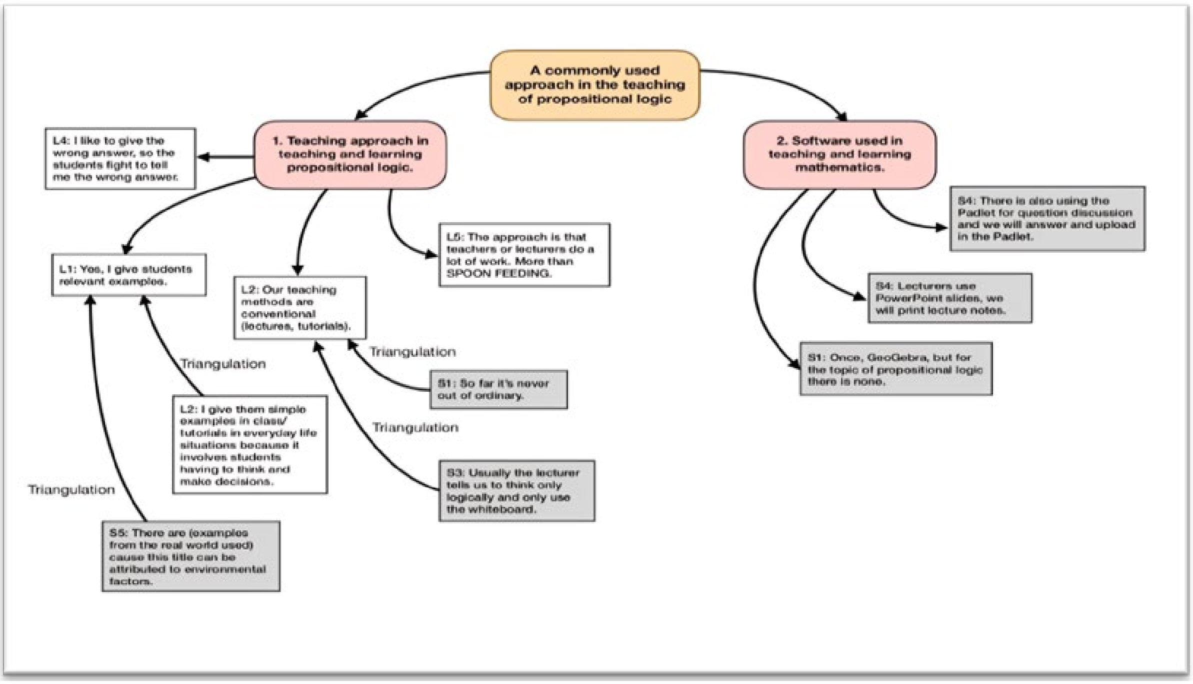

Figure 7. A commonly used approach in the teaching of propositional logic (Source: Authors)

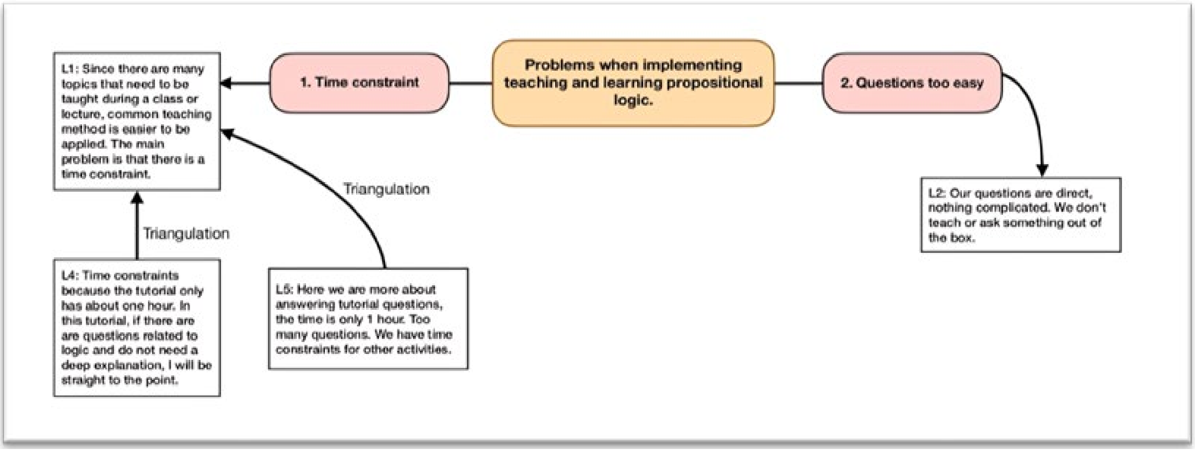

Figure 8. Problems when implementing teaching and learning propositional logic (Source: Authors)

Theme 1.2 (ii). Problems when implementing teaching and learning propositional logic: Problems when implementing T&L propositional logic involves two primary codes, that is

(1) time constraint, and

(2) students' issues.

Emerging theme and codes are summarized using the schematic diagram in **Figure 8**.

Apart from that, lecturers L1, L4, and L5 think that this conventional approach is more favorite and feasible among them because of the time constraints during tutorial classes. In addition, lecturer L2 also thinks that the tutorial questions that they gave to students, for the topic of propositional logic, are a bit too easy and direct. Not testing the students' reasoning skills.

Theme 1.2 (iii). Students' wishes in terms of lecturers' teaching for propositional logic: Students' wishes in terms of lecturers' teaching for propositional logic emerged three codes:

(1) unconventional teaching methods,

(2) technology involvement, and

(3) in-depth explanation.

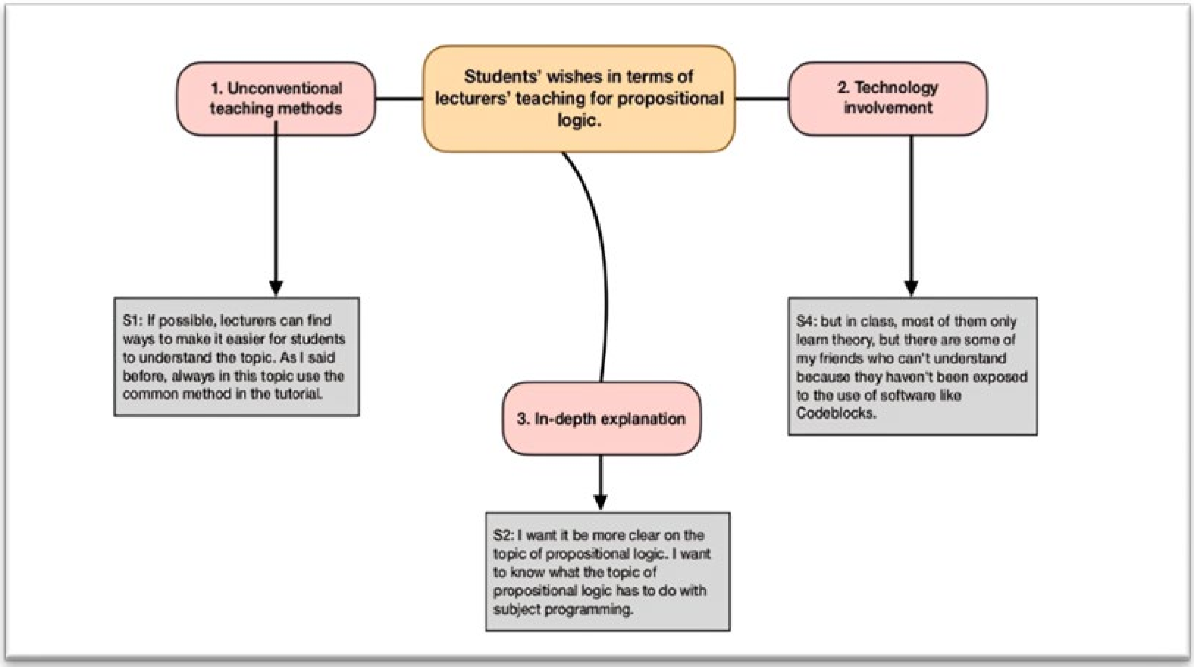

Figure 9. Students' wishes in terms of lecturers' teaching for propositional logic (Source: Authors)

Emerging theme and codes are summarized using the schematic diagram in **Figure 9**.

During the interviews, students were asked about their instructional needs regarding the topic of propositional logic. All participants expressed expectations for a substantial shift in teaching methods, seeking approaches that deviated from traditional practices. Notably, student S4 specifically anticipated the integration of software tools in the instruction of propositional logic. In contrast, all lecturers reported adhering to conventional teaching methods, emphasizing that they did not adopt innovative approaches. The lecturers explained that their tutorial sessions primarily involved collaborative discussions and joint problem-solving activities, supplemented by real-world examples to contextualize the concepts.

Needs for developing MyOT_G+ kit

There is a significant need for developing the MyOT_G+ kit to enhance understanding of the propositional logic topic. Both teachers and students expressed the necessity for an interactive and technologically advanced tool to aid in T&L. The analysis of research question 1.3 exposed two themes, which are

(i) the effectiveness of existing methods, approaches, or teaching aids and

(ii) the use of appropriate software/technology to improve understanding of propositional logic topics.

Theme 1.3 (i). The effectiveness of existing methods, approaches, or teaching aids: The effectiveness of existing methods, approaches, or teaching aids consists of two main codes, namely: namely:

(1) the existing methods, approaches, or teaching aids and

(2) needs Improvement.

Emerging theme and codes are summarized using the schematic diagram in **Figure 10**.

The majority of the lecturers interviewed expressed satisfaction with the adequacy of the current teaching tools. Lecturer L4 specifically noted that the existing methods and equipment for teaching propositional logic were sufficient. However, lecturer L5 acknowledged that while the tools were adequate, there was a need for improvement in the teaching approach. Similarly, lecturer L2 characterized the teaching practices at his institution as predominantly conventional and suggested that pedagogical change was necessary. From the students' perspective, the current teaching of propositional logic was generally perceived as adequate. Nevertheless, both student S1 and student S3 emphasized the need for enhancements in the teaching methods. Furthermore, they proposed incorporating interactive activities, such as educational games, to enhance engagement and learning outcomes in propositional logic instruction.

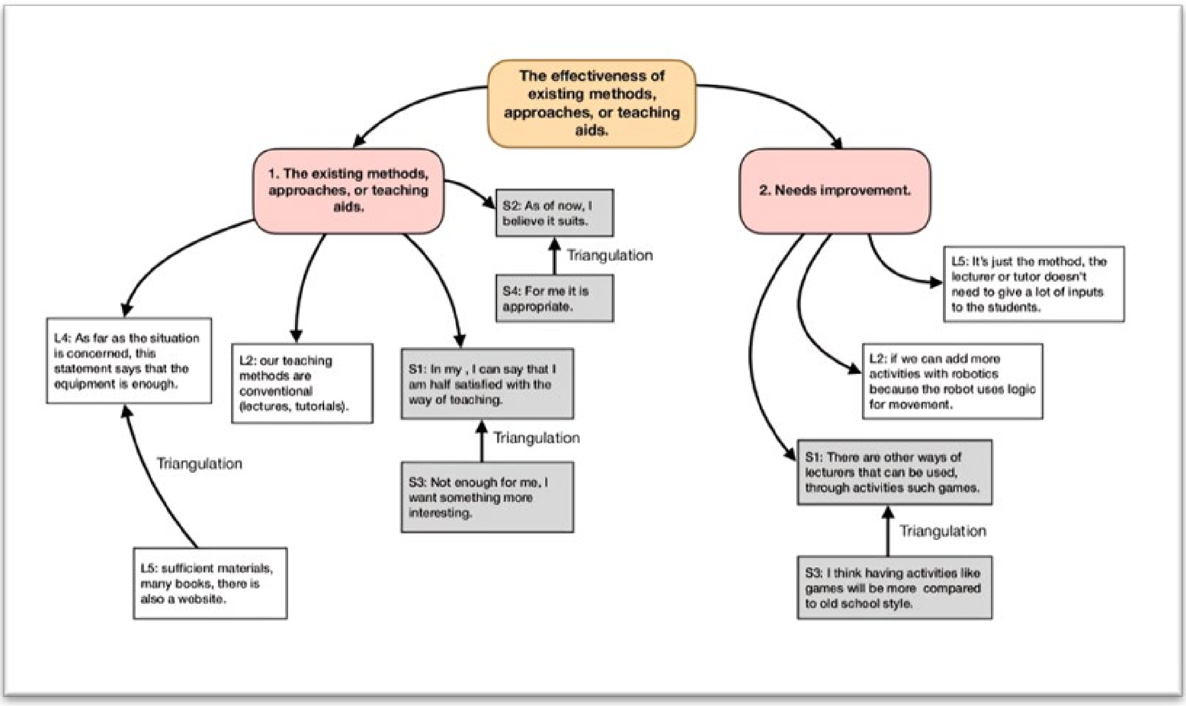

Figure 10. The effectiveness of existing methods, approaches, or teaching aids (Source: Authors)

Theme 1.3 (ii). The use of appropriate software/technology to improve understanding of propositional logic topic: The use of appropriate software/technology to improve understanding of propositional logic topic involves two primary codes, that is

(1) types of appropriate software and

(2) the features of software.

Emerging theme and codes are summarized using the schematic diagram in **Figure 11**.

Lecturer L5 proposed incorporating robotics as a pedagogical tool for teaching propositional logic. In contrast, other lecturers were unable to identify specific software or technological solutions suitable for teaching this subject. When discussing the desired content characteristics for the proposed software, the lecturers emphasized the inclusion of fundamental concepts in propositional logic, such as De Morgan's law, conditional law, and biconditional law. Additionally, lecturer L3 recommended various features to complement the suggested content. However, lecturer L1 expressed reservations about adopting new teaching methods, advocating instead for the continuation of traditional approaches, with an emphasis on incorporating more examples to enhance students' understanding. Students, on the other hand, exhibited differing perspectives on the software's features. Many emphasized the importance of functionalities that demonstrate step-by-step solutions to problem-solving tasks. Similarly, student S4 highlighted the need for the software to provide relevant examples accompanied by detailed answers.

Phase 2. Design and Development

This phase comprises two main parts:

(1) design of MyOT_G+ and

(2) development of MyOT_G+.

Design of MyOT_G+

The MyOT_G+ kit was designed considering cognitive and constructivist theories, ensuring it supports the learning process effectively. The design phase included content analysis, setting teaching objectives, creating activities, developing assessment instruments, and selecting appropriate tools/software.

Content analysis: The pre-university students have learned the topic of propositional logic in secondary school under mathematics and computer science subjects. Since computer science is an elective subject, only

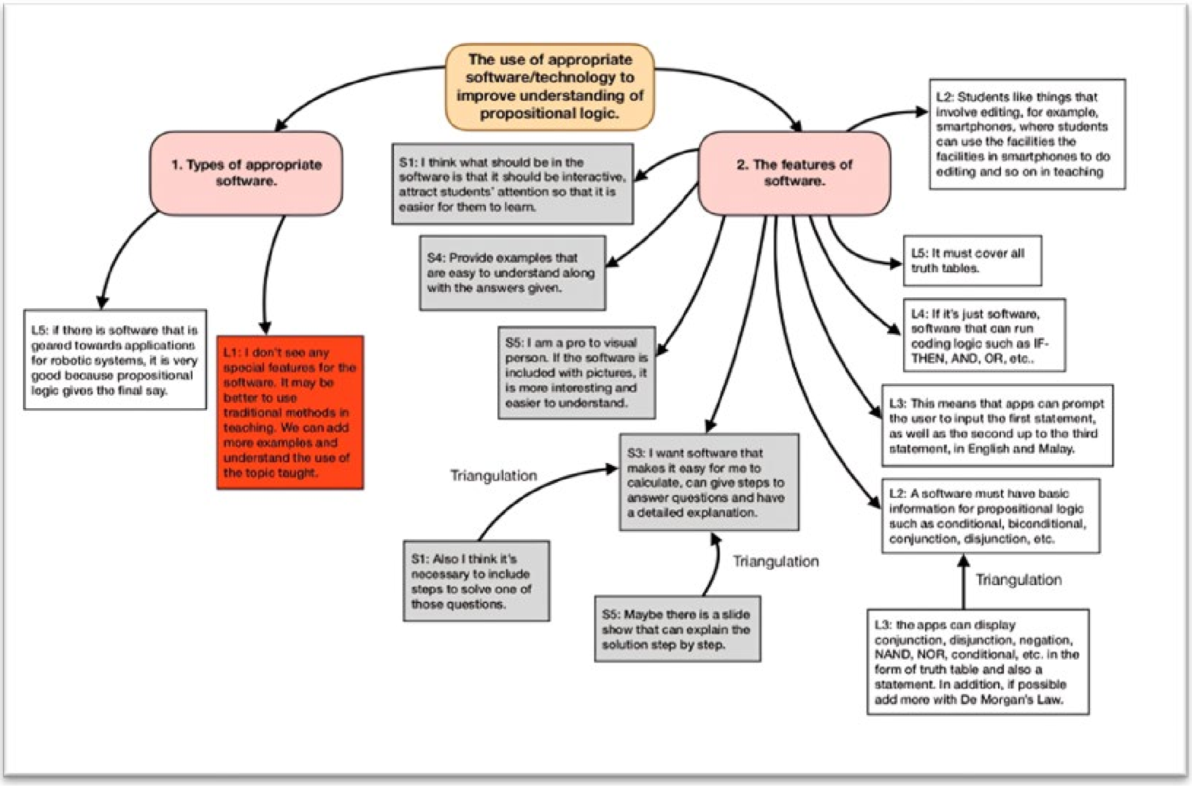

Figure 11. The use of appropriate software/technology to improve understanding of propositional logic (Source: Authors)

mathematics is the core subject, so the researcher chose to analyze the content of propositional logic topic in the mathematics subject only.

Propositional logic is covered by the topic of logical reasoning in mathematics form 4. The definitions of statement, negation, compound statement, conjunction, disjunction, and implication (conditional statement) are essentially covered. Plus, it also covers converse, inverse, and contrapositive of the implication (conditional statement). Additionally, truth tables for conjunction, disjunction, implication, and the inverse, converse, and contrapositive of implication are introduced as well.

Propositional logic at the aforementioned pre-university includes the same content as logical reasoning in mathematics form 4. Additional content at the pre-university is tautologies, contradictions, biconditional laws and the laws of propositional algebra:

(1) idempotent laws,

(2) associative laws,

(3) commutative laws,

(4) distributive laws,

(5) identity laws,

(6) complement laws,

(7) involution law, and

(8) De Morgan's laws.

Based on problem analysis, students often have problems with De Morgan's laws, and biconditional laws. Since biconditional laws is related to conditional laws, it is necessary to include conditional laws, contrapositive laws, converse laws, and inverse laws.

Teaching objectives: The determination of teaching objectives for this topic is based on course learning outcomes documents for programming subjects at the institution concerned. The first learning outcome is related to the topic of propositional logic, which is to identify the technical aspects of computer hardware,

Table 2. Summary of activities in MyOT_G+

Tutorial	Subtopic	Activities
1	Introduction to propositional logic: • Proposition • Negation • Conjunction and disjunction • Truth table and Venn diagram	• Proposition not? Pop quiz • Discussion: Why should we study propositional logic? • NOT-AND-OR game • Conjunction & disjunction: Truth tables & Venn diagram *Tutorial 1 sheets can be referred to Appendix C1
2	Laws of the algebra proposition: • Idempotent law • Commutative law • Identity law • Associative law • Distributive law • Complement law • De Morgan's law	• Exploration of De Morgan's law by using the developed GeoGebra applet • Exploration of simple laws *Tutorial 2 sheets can be referred to Appendix C2
3	• Conditional law • Converse law • Inverse law • Contrapositive law	• Exploration of the four laws by using the developed GeoGebra applet *Tutorial 3 sheets can be referred to Appendix C3
4	• Biconditional law • Truth table • Tautologies and contradictions	• Exploration of biconditional law by using the developed GeoGebra applet • Identify truth tables of all laws • Define tautologies and contradictions *Tutorial 4 sheets can be referred to Appendix C4

computer software, binary number systems, computer codes, truth tables, and logic circuits. Truth tables and logic circuits are advanced topics from propositional logic. Propositional logic is fundamental to both topics. The need for students to really understand propositional logic is very high to ensure that the percentage of learning outcomes is achieved with excellence. The teaching objectives are, as follows:

1. Students will be able to correctly identify each law of propositional logic.
2. Students will be able to correctly differentiate between each propositional logic law.
3. Students will be able to convert propositions accurately into mathematical logic.
4. Students will be able to simplify logical equivalences perfectly.

Activities: In order to achieve the teaching objectives above, the researcher has designed activities, as shown in **Table 2.** The lessons for this topic take place in four tutorial classes, each of which lasts for one hour.

Tools/software selection: As for the selection of tools or software, there are two main parts in the development of MyOT_G+ kit, that is, the class online platform and GeoGebra.

Class online platform: Online education has expanded dramatically over the past few years, especially in 2020, thanks to developing technology and situations that call for learning from home. Schools frequently employ Google Classroom and Microsoft Teams for Education as platforms for online instruction. For online learning, both platforms make communication and file sharing possible. Both of these platforms are also employed globally for educational activities, acting as virtual classrooms.

These two platforms are provided in the said pre-university. The researcher analyzed which online platform is best to use in the MyOT_G+ kit. Google Classroom and Microsoft Teams for Education are comparable programs that permit file sharing and video calling for educational purposes. Both platforms have been gradually modified for 100% online learning even though they were initially intended to be a resource for in-person educational circumstances.

In terms of interface, there is a slight difference between Google Classroom and Microsoft Teams. The user interface of Google Classroom is simple to use. Every class includes a main page called the "stream" that contains all of the announcements for that class, a schedule of upcoming topics and assignments, and a link to the class meeting. Additionally, there is a page for classwork where students can locate and submit tasks. There are also locations where you can view the class roster and grades. Meanwhile, Microsoft Teams for Education's home screen has a bar on the left that links to the following pages:

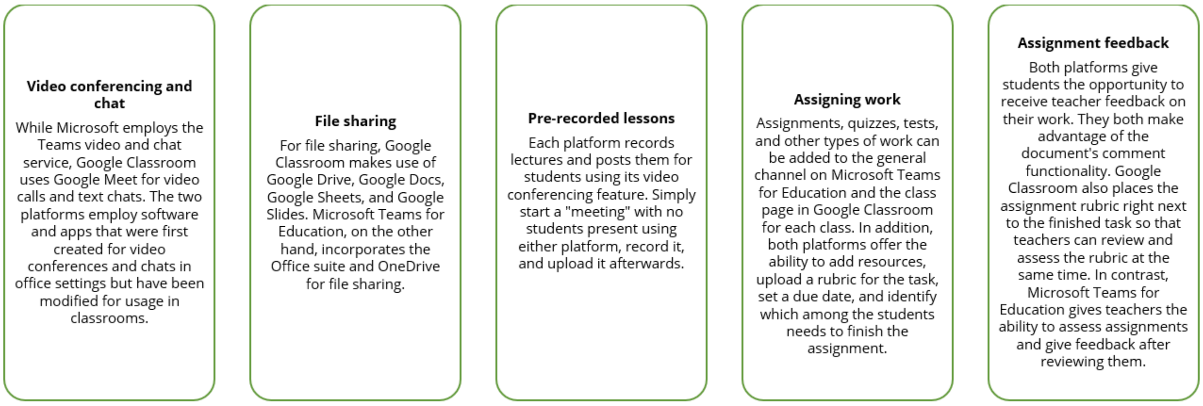

Figure 12. Functionalities on platform in Google Classroom and Microsoft Teams for Education (Source: Authors)

(1) activity,

(2) chat,

(3) teams,

(4) calls,

(5) files, and

(6) apps.

The "team's" page is where students may locate assignments, have different groups for each class, and participate in virtual classes. One platform is not always superior to another. They are simply unique.

Similar functionalities are used differently depending on the platform in Google Classroom and Microsoft Teams for Education. The key components of both platforms are necessary for online learning to be as successful as feasible. Similar to in-person classrooms, these platforms allow students to complete tasks and communicate with their teachers. Both platforms offer a number of useful features, as follows in **Figure 12**.

It is evident that both platforms provide the basic features required to successfully manage a classroom. Nevertheless, there are major differences between Google Classroom and Microsoft Teams for Education that set them apart from each other. The key distinction between the two platforms is that Google Classroom is designed to be the sole website that educators and students use for school, whereas Microsoft Teams for Education acts as a hub for a variety of various tools and programs. Besides, Google Classroom may connect to external apps and combines the Google suite of cloud-based programs. Microsoft Teams for Education, on the other hand, integrates a number of distinct elements, including the existing Microsoft Teams, Office applications, One Note, and third-party apps.

The functional differences between Google Classroom and Microsoft Teams for Education are not significant. However, due to individual learning preferences, the variations may be sufficient to make certain students or teachers choose one over the other.

The summary of comparison between Google Classroom and Microsoft Teams is shown in **Table 3**.

As previously pointed out, both Microsoft Teams for Education and Google Classroom were created with both students and teachers in mind. Teachers will have to choose which platform best suits their unique classes, teaching methods, and functional requirements. A teacher must take the following factors into account when deciding which online learning platform is suitable for their situation (see **Figure 13**).

Following an analysis of virtual classroom platforms, the researchers selected Microsoft Teams for Education over Google Classroom. This decision is based on the above-mentioned selection factors and features for each platform. Students at stated pre-university are between the ages of 17 and 19 and are considered mature students who have already completed secondary school. Furthermore, most students' own laptops or tablets. They are also required to live at the residential college for the duration of their studies. Due to the large number of students, Internet access in the learning area and residential college is inconsistent. As a result, the researcher selected Microsoft Teams for Education for use in the MyOT_G+ kit.

Table 3. Comparison between Google Classroom and Microsoft Teams

Feature	Google Classroom	Microsoft Teams
Ease of use	• Generally far less complicated. • Easier to learn for both teachers and students. • For more mature students, it can be too simplistic.	• There is a steeper learning curve because there are so many different apps and programs inside. • Users can customize their educational experience once they become familiar with the platform.
Collaboration	• All file sharing occurs through cloud-based applications like Google Docs, etc. • This makes collaboration simple and convenient, but it needs to be managed entirely online. • Editing simultaneously is a free feature.	• File sharing can occur through One Drive. • Multiple users can edit Office programs at once, but they must all own the programs in order to do so. • It is more compatible with downloading files for offline use. Therefore, it is suitable for those whose no reliable internet connection.
Platform development	• Initially, the platform was designed with education in mind. • Despite the integration of other apps, the classroom was created with teachers and students in mind.	• The platform was initially designed for business use before being modified for educational use.
Additional features	• The teacher must add browser extensions in order to add features to Google Classroom.	• Teachers can access apps from the class page to add features to Microsoft Teams for Education.

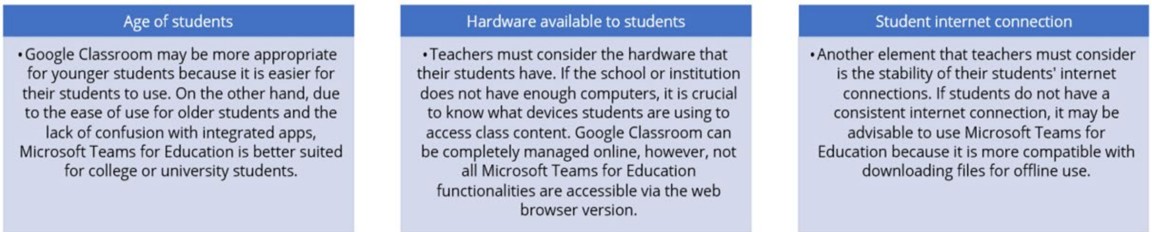

Figure 13. Key factors for selecting an appropriate online learning platform (Source: Authors)

GeoGebra: GeoGebra is another significant piece of software that has been added into the creation of the MyOT_G+ kit. The researcher will create a GeoGebra applet devoted to the subject of propositional logic. Subtopics that are focused in the GeoGebra applet are De Morgan's law, conditional law, converse law, inverse law, contrapositive law, and biconditional law. All these subtopics are worked on in one applet. Therefore, there are five interfaces designed in the applet:

(1) reset mode,

(2) De Morgan's law,

(3) converse, inverse, contrapositive of p to q, and

(4) biconditional law.

The overall design of each interface is, as shown in **Figure 14**.

When in the reset mode, the interface was designed, as shown in **Figure 8**. The user can press the RESET button to get back into that interface. At the top, there are checkboxes for four options:

(1) De Morgan's laws,

(2) conditional laws,

(3) converse, inverse, and contrapositive of p to q, and

(4) biconditional laws.

This applet only provides for two statements. The user can enter the two statements in the input boxes, in which p represents the first statement and q represents the second statement. Another two input boxes are for the negation of p and q. The user needs to input the negation statements. When the reset button is clicked, the statements are retained.

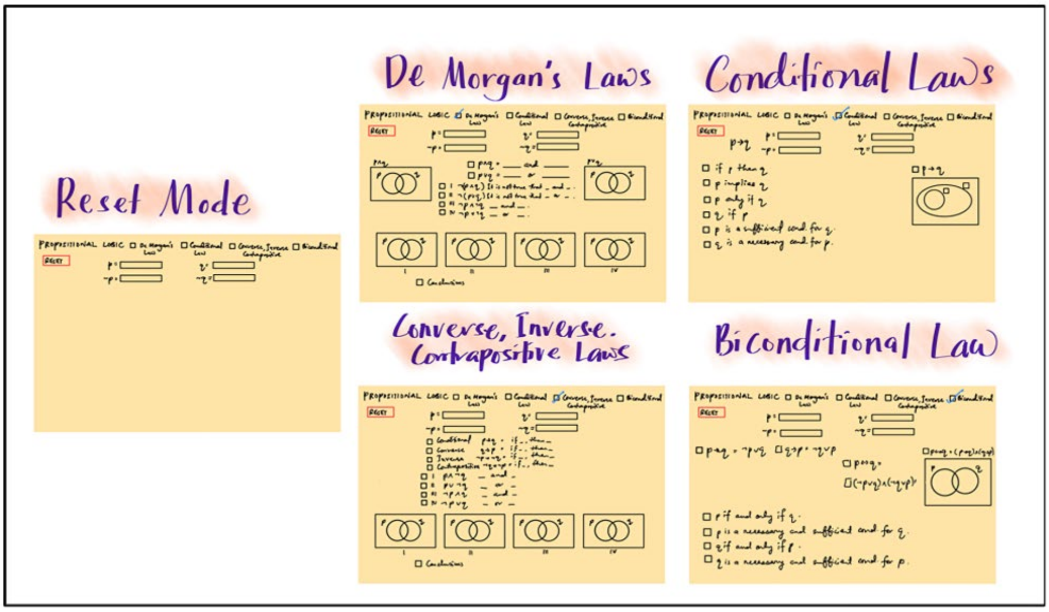

Figure 14. Five interfaces designed in the applet (Source: Authors)

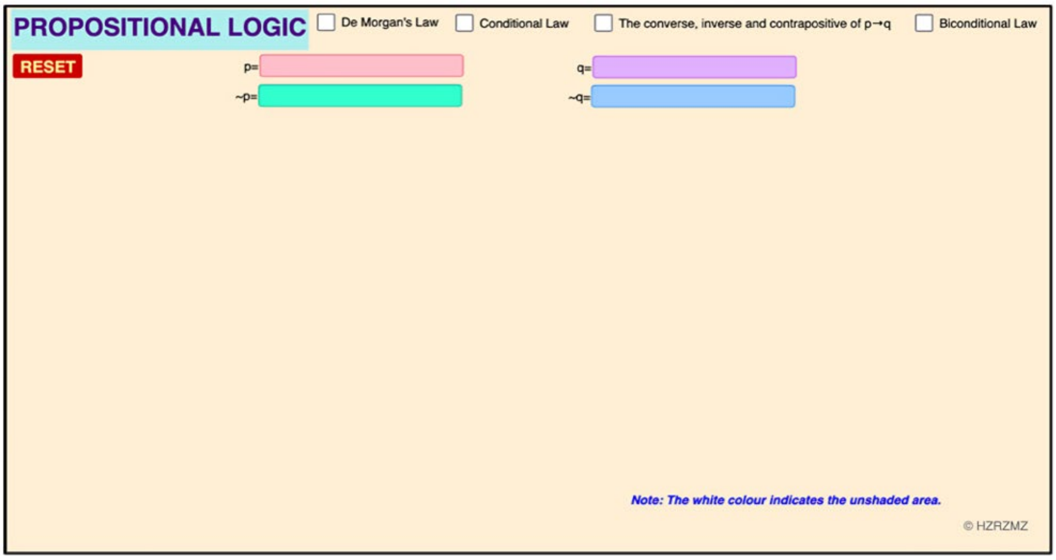

Figure 15. MyOT_G+ interface: Reset mode (Source: Authors)

Development of MyOT_G+ kit

The development phase involved creating the MyOT_G+ kit and the assessment instruments. Expert evaluation was conducted to ensure the tool's effectiveness and suitability. The most prominent part of this stage is the development of GeoGebra applet. The GeoGebra applet is developed according to the design that has been made before. We show the GeoGebra applet that has been developed.

In **Figure 15,** the GeoGebra applet is in reset mode. No laws have been chosen, and the statements for p and q have not yet been input. Meanwhile, **Figure 16** depicts the GeoGebra applet when propositions p, q, and their negations are input, and De Morgan's, conditional law, the converse, inverse and contrapositive of p to q, and biconditional law are selected. Propositions p and q can always be changed to accommodate user preferences. The user can select a different law by first pressing reset button and then ticking the desired law.

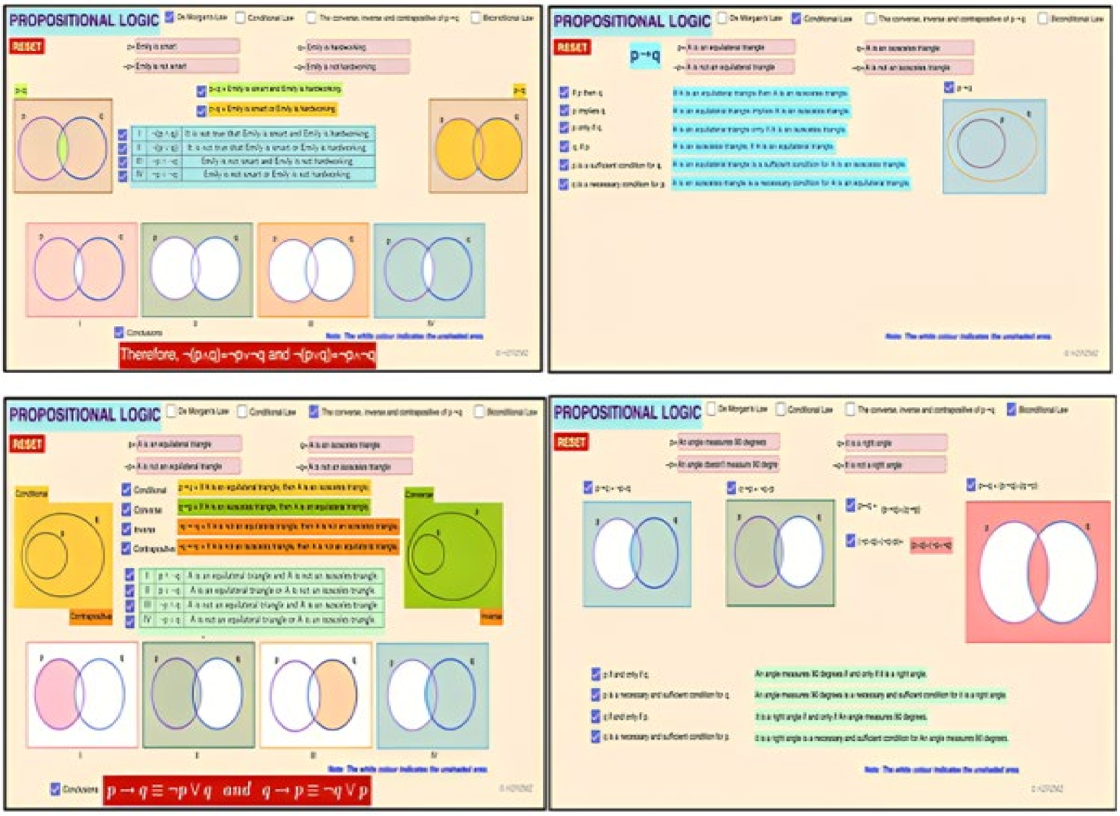

Figure 16. MyOT_G+ interface: De Morgan's law, conditional law, converse, inverse and contrapositive law, and biconditional law (Source: Authors)

Table 4. The content validity of MyOT_G+ kit

Validity	Expert	Score	Total	Percentage agreement (%)
Content	1	28/35	398/455	87.5%
	2	28/35		
	3	28/35		
	4	28/35		
	5	30/35		
	6	29/35		
	7	32/35		
	8	35/35		
	9	34/35		
	10	35/35		
	11	31/35		
	12	28/35		
	13	32/35		

Validation of MyOT_G+

Validation of the MyOT_G+ kit involved feedback from experts, teachers, and students, who generally found it useful, easy to use, and effective in enhancing understanding. After finished the development for 'MyOT_G+ kit', the kit was continued to test the face and content validity among thirteen expert lecturers from UM and UPM. According to Noah and Ahmad (2005), a percentage agreement of at least 70% is acceptable. The data was collected and tabulated in percentages.

RQ 2.1. To what extent is the content validity of the MyOT_G+ kit among experts achieved?

Table 4 shows the validity testing results reveal a high content validity score of 87.5%, suggesting that the MyOT_G+ kit meets essential pedagogical and design criteria. The kit features clearly articulated text and well-displayed images, fostering an intuitive user experience. Its visually appealing game design incorporates a range of question levels aligned with Bloom's taxonomy, ensuring a scaffolded learning approach. Moreover,

Table 5. The face validity of MyOT_G+ kit

Validity	Expert	Score	Total	Percentage agreement (%)
Face	1	30/35	409/455	89.9%
	2	28/35		
	3	28/35		
	4	29/35		
	5	35/35		
	6	33/35		
	7	29/35		
	8	35/35		
	9	30/35		
	10	30/35		
	11	32/35		
	12	35/35		
	13	35/35		

a comprehensive manual has been developed in accordance with the learning objectives, facilitating ease of use for both instructors and students. The kit promotes collaborative learning through group play techniques, which are shown to enhance student engagement. Its design emphasizes user-friendliness, making it accessible and straightforward for students to navigate and interact with. Additionally, the kit demonstrates adaptability, offering tailored learning opportunities in topics related to GeoGebra. It provides clear game objectives, aiding students in understanding and mastering key subtopics through an immersive and engaging format. The MyOT_G+ kit also meets all seven critical elements of game-based learning as outlined by Landers (2014): action language, assessment, challenge, control, environment, game fiction, human interaction, immersion, and goals. These elements work synergistically to create a comprehensive learning environment that fosters both engagement and mastery.

RQ 2.2. To what extent is the face validity of the MyOT_G+ kit among experts achieved?

Table 5 shows the results of the validity testing. For the agreement percentage for face validity is 89.9%, indicating that MyOT_G+ kit has clear text and picture display, appealing game design, various levels of questions based on Bloom Taxonomy, a manual developed per the learning objectives, and group play techniques that can increase learning engagement. Additionally, the MyOT_G+ kit offers a user-friendly experience, making it easily accessible and enjoyable for students. Its versatility is evident in its ability to cater to lessons on GeoGebra, providing clear objectives and facilitating comprehension of GeoGebra subtopics. The game encompasses all seven essential game elements, including action language, assessment, challenge, control, environment, game fiction, human interaction, immersion, and goals (Landers, 2014). In conclusion, the MyOT_G+ kit serves as a valuable tool for game-based and inquiry learning approaches.

DISCUSSION

The results of this study highlight critical insights into the development and implementation of MyOT_G+ kit for enhancing mathematical reasoning, specifically in propositional logic, among pre-university students. While the descriptive analysis provides a comprehensive overview of the tool's efficacy, a more critical and analytical interpretation can strengthen the findings by situating them within broader educational contexts and theoretical frameworks.

The study findings demonstrate that the MyOT_G+ kit significantly improved students' understanding of propositional logic, as evidenced by increased post-test scores. However, these outcomes should be examined beyond statistical significance. The observed improvements may partly result from the interactive and visual nature of GeoGebra, which aligns with cognitive and constructivist learning theories. According to Vygotsky's theory of social constructivism, the interactive environment fosters meaningful learning through engagement and scaffolding. Similarly, Ausubel's theory of meaningful learning suggests that students' ability to connect new knowledge with prior understanding enhances retention and comprehension. Therefore, the MyOT_G+ kit's design, which integrates visual aids and interactive components, is theoretically well-grounded.

Nonetheless, the degree to which these improvements can be generalized across diverse educational contexts warrants further consideration. The study was conducted in a specific pre-university setting with a relatively homogeneous student population. Differences in students' prior knowledge, digital literacy, and access to technology might influence the efficacy of similar interventions in other contexts. Additionally, while the study highlights the positive impact of the MyOT_G+ kit on cognitive outcomes, the affective domain–such as students' motivation and attitudes towards mathematics–requires further exploration.

Additionally, some lecturers do not make a point of mentioning areas or topics that are particularly challenging for their students. However, they identified a broad issue from two distinct perspectives:

(1) the curriculum and instructional strategies and

(2) the students.

The mathematics and programming courses taught in pre-university settings place more emphasis on conceptual understanding than on application. The lecturers are also too intent on particular topics at hand to impart knowledge without relating it to other topics. As a result, this pre-university's T&L are somewhat monotonous. Next, from the aspect of students, there is the issue of mentality toward mathematics. Many students have the mentality that mathematics is a difficult subject. The lecturer who voiced this view thought that the mentality of the students must first be changed, otherwise whatever the teaching method, traditional or modern, does not have any positive effect on the level of student mastery in the subject of mathematics. Besides that, the majority of lecturers also discovered that students have diminished critical and creative thinking skills as well as reasoning skills. Students lack the confidence to provide responses that are supported by reasoning when given questions that need a little thought or analysis. The majority of them would rather await the lecturer's response.

Propositional logic is a topic that is related to the capacity for reasoning. When it comes to the fundamentals of propositional logic, such as conjunction, disjunction, negation, etc., most students have no trouble at all. They acquired all these fundamentals when studying mathematics in high school, namely the topic of logical reasoning. However, when confronted with challenging questions, students begin to struggle and become perplexed. Additionally, sentences in human language are used in propositional logic. Due to the instruction in English, some students have language barriers. Many students translate into Malay, which occasionally causes more misunderstandings. Furthermore, students have to translate sentences in human language into mathematical symbols in propositional logic. This causes problems for many students because the majority of them rote-memorize every rule in propositional logic without real understanding. In addition, according to lecturers, students often have problems with mathematical symbols, other than arithmetic symbols. Apart from that, most students do not comprehend the necessity of learning propositional logic in the fields of mathematics and programming.

The development and presence of computer technology has revolutionized various aspects of life, including education, by providing tools and resources to support learning. One such computer program that has found application in mathematics education is GeoGebra software. GeoGebra is a versatile program designed to assist in the T&L of mathematics, with a particular focus on geometry, algebra, and statistics. Its extensive range of features makes it an excellent medium for visualizing abstract geometric objects quickly, accurately, and efficiently. GeoGebra software as an educational tool for teaching mathematics. GeoGebra facilitates a deeper understanding of geometry among students. Additionally, students tend to exhibit greater enthusiasm when learning geometry through the computer-operated GeoGebra software. The user-friendly interface and interactive features of GeoGebra contribute to a more engaging and enjoyable learning experience for students. In conclusion, GeoGebra software has proven to be a valuable tool in mathematics education. Its capabilities enable students to comprehend geometry more effectively, while also fostering a positive and enjoyable learning environment (Benning et al., 2023; Pebrianti & Handayani, 2022; Tamam & Dasari, 2021).

In this study, all experts agreed to the development of MyOT_G+, in terms of content, face and language. On average, the experts stated that the MyOT_G+ is appropriate and easy to implement in T&L in the classroom. There is also input from a few experts on the face of MyOT_G+. The majority of experts opine that the MyOT_G+ interface is attractive, neat, and not boring. There is an expert who stated that it is the best innovation because students can learn the learning topic from a different angle, where it is not theoretical and rote but through experimenting with the developed GeoGebra applet. In addition, language expert comments that the language used is also clear and precise. Karakose et al. (2023) applied structural equation modeling to examine prospective teachers' attitudes, self-efficacy, and academic motivation. Its approach to analyzing the impact of educational tools could support evaluating MyOT_G+'s effectiveness.

According to Pebrianti and Handayani (2022) developed an online interactive learning resource using the GeoGebra applet for probability education. The ADDIE model is employed as the framework for this development research the validation scores from two expert validators, including material experts, show a high feasibility percentage of 92.5% in terms of content, and a perfect score of 100% in language aspects. The media expert validation reveals a display aspect feasibility of 75%, interaction aspect feasibility of 66.67%, control aspect appropriateness of 75%, and form aspect appropriateness of 75%. Furthermore, the questionnaire responses from the three mathematics teachers demonstrate a highly feasible percentage of 92.5%, and the feedback from the 29 students indicates a highly feasible percentage of 88.04%. However, some studies mentioned GeoGebra software is effective in T&L mathematics since GeoGebra contributed to enhancing students' understanding of mathematical concepts and improved students' interest to learn mathematics (Mainali & Key, 2012; Shadaan, 2013; Yildiz & Baltaci, 2016; Zulnaidi & Syed Zamri, 2017). Açıkgül (2021) developed a learning kit for teaching polygons with the support of GeoGebra software, and we sought to gather feedback from mathematics teachers regarding their opinions on this kit. The study followed a descriptive research model and involved 11 mathematics teachers who voluntarily participated in an in-service training program called 'dynamic math software (GeoGebra)' in Turkey. Based on the feedback received from the mathematics teachers, it was determined that the GeoGebra-supported learning kit effectively addressed learning outcomes, instructional methods, and programming. The teachers' opinions, gathered through their experience with the GeoGebra-supported learning kit during the in-service training, highlighted the changing role of the teacher in the classroom, the benefits for students' cognitive and affective development, the overall teaching quality, as well as the challenges and drawbacks associated with the use of the GeoGebra-supported learning kit. Additionally, the teachers expressed their intention to continue using the GeoGebra-supported learning kit in the future. Aravantinos et al. (2024) explores AI-based educational approaches in primary schools and offers insights into integrating AI tools for teaching, similar to how GeoGebra enhances mathematical reasoning. The methodological strategies discussed can inform the design of MyOT_G+.

However, the GeoGebra applet, which mainly focuses on geometry topics like plane geometry, spatial shapes, geometric transformations, area integrals, derivatives, and quadratic equations, is not extensively utilized for probability. Therefore, there is a need for an online-based interactive learning resource specifically tailored for probability, and the GeoGebra applet can fulfill this requirement. This research aims to develop an online interactive learning resource using the GeoGebra applet for probability education. The ADDIE model is employed as the framework for this development research. The study includes three mathematics teachers and 29 Year 8 students as participants. The research findings indicate positive results. Based on these results, it can be concluded that the GeoGebra applet can effectively serve as an online interactive learning resource for teaching probability to year 8 students (Pebrianti & Handayani, 2022). However, Papadakis (2023) criteria for selecting educational apps for children, highlighting key factors in user engagement and educational impact. These principles can guide the refinement of your interactive GeoGebra applet and teaching strategies.

The integration of technology in mathematics education plays a crucial role in shaping the curriculum and enhancing students' learning experiences. This paper introduces emerging trends in technology and their impact on learning, focusing on the use of GeoGebra, which holds significant potential for the future development of e-learning in college mathematics. GeoGebra is a dynamic mathematics software that is freely available, open source, and compatible with multiple platforms. It boasts a vibrant international community of users who actively support each other by sharing teaching materials and providing technical assistance. Leelavardhini (2018) showcase the application of GeoGebra in teaching 3D-geometry, providing concrete examples to illustrate its effectiveness and versatility. Karakose et al. (2022) delves into digital addiction and its implications for academic performance. Insights into technology use and its effects on student engagement and achievement can contextualize the implementation of MyOT_G+.

Meanwhile, the teaching of Euclidean geometry often suffers from ineffective instructional methods employed by in-service teachers and low proficiency levels among learners. This study aimed to investigate the GeoGebra integrative skills of in-service mathematics teachers in the context of geometry instruction. The findings of the study indicated a positive impact of the intervention on the instructional strategies of in-service teachers, with a high level of statistical significance. Furthermore, there was a medium to large effect size observed in both the pre- and post-intervention stages. Following the training, participants expressed that integrating GeoGebra into geometry instruction provided mathematics teachers with the opportunity to adopt learner-centered approaches, teach geometry with confidence, and effectively capture and maintain learners' attention and engagement in the classroom (Marange & Tatira, 2023). Tülübaş et al. (2023). Focusing on the relationship between digital addiction and academic achievement, this study's findings on digital literacy and learning outcomes can help address potential challenges in using MyOT_G+ effectively.

The implications of this study extend beyond the immediate context of propositional logic instruction. The successful integration of GeoGebra in the MyOT_G+ kit exemplifies the potential of TEL tools in fostering mathematical reasoning. Future research should explore the scalability of the MyOT_G+ kit in different mathematical topics and educational levels. Additionally, longitudinal studies could assess the sustained impact of such tools on students' reasoning skills and overall mathematical proficiency.

Further studies might also investigate the interplay between teacher training and the effective use of TEL tools. Professional development programs focusing on digital pedagogy could enhance teachers' confidence and competence in integrating tools like GeoGebra into their instructional practices. Finally, expanding the scope of research to include affective outcomes, such as student engagement and motivation, could provide a more holistic understanding of the MyOT_G+ kit's impact, while the MyOT_G+ kit demonstrates significant potential for improving mathematical reasoning, a more nuanced understanding of contextual and individual variables is necessary to fully realize its benefits. By addressing these limitations and exploring new avenues for research, the educational community can leverage TEL tools to foster deeper and more meaningful learning experiences.

CONCLUSION

In conclusion, this study aimed to design, develop, and evaluate the MyOT_G+ kit as a tool for enhancing pre-university students' understanding of propositional logic. Utilizing a mixed-methods approach within the DDR framework, the research provided both quantitative and qualitative insights into the effectiveness of the MyOT_G+ kit. The development of the kit integrated GeoGebra's dynamic visualizations and interactive features, offering a comprehensive, scaffolded learning environment aligned with the learning objectives of propositional logic. Quantitative findings demonstrated significant improvements in students' comprehension, as evidenced by statistically significant gains in pre- and post-test scores. These results underscore the kit's potential as an effective instructional tool. Qualitative data further enriched these findings, revealing students' positive perceptions and highlighting the kit's impact on engagement and conceptual understanding. The study's outcomes have important implications for educational practice. The MyOT_G+ kit represents a valuable resource for teaching propositional logic, fostering interactive and engaging learning experiences. Educators can leverage this tool to enhance instructional practices, while researchers and curriculum developers can draw on the insights gained to inform the integration of technology in mathematics education. The study also contributes to the broader discourse on TEL by demonstrating the utility of GeoGebra in online teaching contexts and advocating for the DDR framework as a robust methodological approach for future tool development and evaluation. Nonetheless, the findings must be interpreted with caution due to certain limitations, notably the restricted generalizability of results to different educational levels or cultural contexts. Further research is recommended to assess the applicability and effectiveness of the MyOT_G+ kit across diverse populations and settings. As digital learning environments continue to evolve, ongoing exploration of innovative tools, such as GeoGebra, will be essential in advancing effective pedagogical strategies and fostering deeper student engagement in mathematics education.

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Ethics declaration: The authors declared that this study was approved by the Institutional Review Board on behalf of the University of Malaya Research Ethics Committee. All participants in this study provided informed consent before their involvement. As the study focused on pre-university students, parental or guardian consent was obtained for participants under the age of 18, along with student assent. Participants were informed about the purpose of the research, the voluntary nature of their participation, and their right to withdraw at any time without any consequences. Confidentiality and anonymity were ensured by assigning unique identifiers instead of personal information, and all collected data was securely stored and used solely for research purposes. The study adhered to the ethical guidelines set forth by the Institutional Review Board on behalf of the University of Malaya Research Ethics Committee.

Declaration of interest: The authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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