SubNetSmart Application: Enhancing Vocational College Students' Achievement in IP Addressing Curriculum through Experimentation

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***Abstract*—The SubNetSmart was developed to assist students in grasping subnetting concepts especially for students who have problems with subnet calculations. Students' subnetting skills have improved through engaging and problem-based activities which adhered to the principles of self-directed learning and were also aligned with the Vocational College Standard Curriculum (KSKV). A distinctive feature of this app is that students would receive immediate scores and feedback after completing the tasks. SubNetSmart's development follows the five phases of the Analysis, Design, Development, Implementation and Evaluation (ADDIE) instructional design model. Incorporating the constructive alignment model and core principles of curriculum design, it emphasized clear learning objectives, personalized experiences, and integrated assessments. SubNetSmart also has a built-in teacher contact feature that enabled students to reach instructors or facilitators directly for support. The results from a quasi-experimental pre-test–post-test nonrandomized design with explanatory mixed-method approach showed a significant difference in results between the control and treatment groups. The post-test scores proved that students using SubNetSmart outperformed students in the control group. Additionally, the Levene test has confirmed that there was no significant difference between groups at the initial stage. Hence, this validated the comparable starting conditions. Feedback from student surveys showed that most participants found the lessons easy to understand and successfully applied IPv4 class identification and valid Internet Protocol (IP) range calculations. Qualitative findings further revealed that students perceived SubNetSmart as an effective cognitive scaffolding tool that enhanced conceptual understanding, calculation accuracy, and self-directed learning through its interactive, case-based, and adaptive features. In conclusion, the triangulation of quantitative and qualitative findings confirms that SubNetSmart functions as a theoretically grounded instructional system that effectively bridges the gap between theoretical knowledge and practical competency in Technical and Vocational Education and Training (TVET) networking education.**

***Keywords*—digital curriculum, vocational college standard curriculum, SubNetSmart, ADDIE model, curriculum alignment, interactive learning**

I. Introduction

The dynamic job market in the technical and vocational fields requires the support of a digital curriculum that can strengthen the skills and knowledge of the latest technology of vocational students, especially in the field of Information technology and networking [1]. The digital transformation of education enables students to engage in authentic simulated learning through interactive platforms [2]. In fact, it is important in helping to understand complex courses (such as Subnetting) through visual representation. This is in line with the Ref. [3] which recognizes that an effective digital curriculum can play an important role in bridging the gap between traditional education and the skills required in the industrial workforce. Therefore, the use of digital resources and tools will improve the vocational students' learning experience and thus, impact the employability of these students.

The Internet Protocol (IP) addresses enable communication across the internet or a Local Area Network (LAN). According to Okoh *et al.* [4] and Wang *et al.* [5], effective management of IP addresses is essential to maintain seamless data exchange between connected devices. On the other hand, subnetting optimizes the operation of IP addresses and protects network performance. Subnetting, according to Alzakwani *et al.* [6], is the process of dividing a large IP network into smaller, more manageable networks or subnets. This will allow more efficient use of the IP addresses, improve network performance and security. Subnetting also reduces traffic congestion and segregates network segments. In addition, it also plays a critical role in shaping systematized, flexible, and secure network infrastructures. This is to ensure that network administrators can allocate IP addresses efficiently and implement applicable security procedures for different segments of the network. As a result, traffic management has become more efficient, and network resources can be accessed systematically. This finding is consistent with Putra *et al.* [7] who argued that the evolution of network management and big data-driven systems optimizes IP address management and supports the complex demands of modern infrastructure. However, subnetting can be a challenge for students who study networking because they need to have a concrete grasp of the concepts and the fundamental networking principles. In this situation, the development of educational tools is important to support students in grasping and mastering these concepts. Conversely, the SubNetSmart is developed to assist students in comprehending the complexities of IP addressing and subnetting. SubNetSmart offers a self-paced and interactive learning experience. It helps students navigate subnetting concepts and develop a solid foundation in

networking.

This study aimed to examine the effectiveness of SubNetSmart applications guided by the following study questions:

(1) What are the pre-test and post-test scores of students in the control and treatment groups?
(2) Is there a significant difference in post-test scores between the control and treatment groups after controlling for pre-test scores?
(3) How do students respond to the experience learning using SubNetSmart application in IP Address and Subnetting course?
(4) How do students perceive the effectiveness of the SubNetSmart app in supporting their learning of IP addressing and subnetting?

II. Literature Review

A. Technology-enhanced Learning in TVET: Current Evidence, Limitations, and Research Gap

Learning through the integration of technology in Technical and Vocational Education and Training (TVET) has gained scholarly attention and is growing over the past decade. This is driven by the urgent need to complement the competencies of graduates in line with the needs of the industry in producing a workforce and graduates who are industry-competent and relevant in the digitalization-era employment landscape [8]. This is in line with the global agenda that demands digital transformation in the TVET system to meet the needs of the future economy and workforce [8, 9]. A comprehensive bibliometric synthesis of 58 empirical studies conducted between 2020 and 2026 proves that pedagogical approaches that through technology empowerment generally improve learning outcomes in TVET, with mobile learning emerging as a highly prominent modality to support competency-based education [10]. Similarly, Zou *et al.* [11] point out that the strategic integration of digital tools including interactive simulations, customization platforms, and gamification environments has improved student engagement, conceptual understanding, and academic achievement across technical disciplines. These findings collectively show that Technology Enhanced Learning (TEL) has great potential in addressing the challenges of teaching and learning complex technical content in the context of TVET.

Despite these contributions, a critical examination of the existing literature reveals a number of substantive limitations that constrain the generalizability and applicability of previous findings. First, although extensive studies have shown the positive impact of digital tools on learning outcomes, the majority have relied on general-purpose platforms that are not specifically designed for the technical demands of the TVET curriculum, resulting in misalignment between instructional design and occupational efficiency standards [10, 12]. The absence of domain-specific applications especially for complex network concepts such as IP addresses and subnetting represents a critical gap in the existing TEL landscape, as these topics require specialized scaffolding mechanisms that generic platforms are not equipped to provide. Second, the primary focus on quantitative outcome measures means a nuanced qualitative dimension of the learning experience. These include students' perceptual responses to digital scaffolding, confidence development, and self-directed learning behaviors remain inadequately explored [11, 12]. Third, there have been previous studies that have used single-method designs with limited control for existing group differences, thereby weakening causal conclusions about the effectiveness of interventions [13]. Fourth, the theoretical foundations of existing TVET digital tools are often implicit rather than explicit, with some proven applications based on established instructional design frameworks such as constructive alignment, which systematically coordinates learning outcomes, teaching activities, and assessments [14]. Fifth, the application of adaptive and self-paced learning features in TVET specific digital environments is still underexplored, although there is strong evidence that personalized learning pathways significantly enhance students' technical skill acquisition and autonomy [15, 16].

These limitations collectively point to research gaps that can still be addressed with this study. For example, there is still a lack of empirically validated, theory-based digital learning applications in the field of TVET designed specifically for IP addressing and subnetting instruction, integrating cognitive scaffolding, immediate correction feedback, case-based learning, and self-directed learning pathways within a constructive alignment framework, and evaluated through rigorous blended methods through quasi-experimental design. Hence, this gap is what this study aims to address through the development and empirical evaluation of SubNetSmart. Unlike previous tools that addressed networking concepts peripherally in the broader computing curriculum, SubNetSmart is purpose-built using ADDIE's instructional design model to specifically scale the conceptual demands and IP and subnetting addressing procedures for TVET students for Form Four students' Information Technology programs. The application operates on the principle of constructive alignment by systematically aligning learning outcomes, step-by-step teaching scaffolding, simulation-based visualization, case-based scenarios, and iterative assessments with immediate feedback thereby addressing the theoretical, pedagogical and methodological gaps identified in previous research. Therefore, this study contributes to the field by providing quantitative and qualitative evidence that focuses on the effectiveness of SubNetSmart, advancing an understanding of how domain-specific digital scaffolding can be designed and evaluated in a competency-based TVET learning environment.

B. Issues Regarding IP Address and Subnetting

Due to the complexities in IP address and subnetting concepts, students have problems to understand the works of subnetting and IP addressing. This may be attributed to subnetting which involves a strong grasp of the binary calculations, to determine subnet masks, and identify network classes. Specifically, Archer *et al.* [17] claimed that students frequently find it problematic to relate theoretical knowledge with real-world applications which leads to sub-optimal assessment performance. Students' ability is suppressed and thus unable to perform crucial networking due to the detachment between theory and practice. Students

are able to configure the IPs if they are proficient in both mathematics and foundational networking concepts. This statement concedes with statements by Dixit *et al.* [18] that many students struggle with the calculations thus inhibiting their ability to accurately design and implement the subnetting schemes. Having problems in both mathematics calculations and networking concepts cause frustration and lack of confidence in students to solve advanced networking problems. Another issue is that students go through limited practical application of the theoretical concepts in classroom instruction. Students often face difficulties when applying this knowledge to the real-world scenarios such as configuring and troubleshooting networks although they are have understood the fundamentals. The gap between understanding the theories and applying them hinders students from fully developing the hands-on skills required in professional networking roles [19].

Lastly, limitation of resources such as inadequate access to high quality, interactive resources for hands-on learning aggravate the learning challenges although the basic materials are provided by educational institutions [20]. Lacking in comprehensive, engaging tools constrain opportunities for experiential learning, further deterring students' ability to translate theoretical knowledge into practical expertise [21]. Therefore, the issues of learning IP address and subnetting highlight the need for innovative teaching approaches and enhanced learning resources that relate to the conceptual, mathematical, practical, and resource-related barriers faced by students in mastering IP addressing and subnetting.

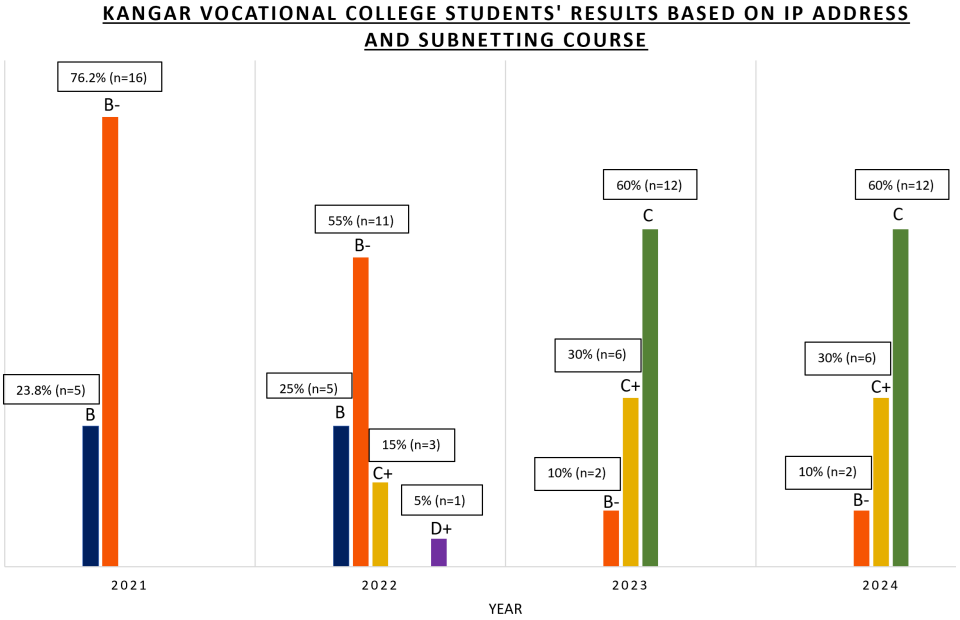


Fig. 1. College vocational students' results.

The issues mentioned above are in line with the analysis of the exam results presented in Fig. 1 which shows an overview of the grades distribution for students over four years between 2021 and 2024. In 2021, 76.2% obtained a B—grade while 23.8% scored a B grade which indicated a high overall performance with most students performing well above average. Subsequently in 2022, there was more variation in grades. While the majority still obtained a B—(55%), there were also notable percentages of students getting B (25%), C+ (15%), and even D+ (5%). This suggested some diversification in student performance. However, the performance shifted in 2023, with 60% of students obtaining a C grade and 30% a C+ grade. Only 10% of students managed to achieve a B− grade, indicating a drop in overall performance compared to the previous years. The distribution of grades in 2024 was identical to that of 2023, with 60% of students obtaining a C grade, 30% obtaining a C+ grade, and 10% obtaining a B− grade.

Based on interview feedback from 44 students who had attended the IP address and subnetting course regarding the problems they faced during this course. Based on the interviews, three themes were formed, namely (i) information availability, (ii) incomplete information and (iii) others. In the first theme, information availability, all students said there was no source to get information related to KSK1033 online "*limited information on the internet*" (R1), "*not many resources*" (R13, R15, R29, R6, R11). In addition, there were students who thought that the challenge was to get hands-on lab simulation in the real-world situation; "*Limited access to hand-on lab simulation or real-world networking*" (R43). There were also students who talked about the challenges of getting reference materials related to this course "*The main challenge I faced was the lack of reference material*" (R41). The second theme, incomplete information, refers to insufficient information "*less information*" (R35), "*there is no detailed information on internet*" (R9), Students also found it difficult to get materials that were similar to the learning modules "*I had a hard time finding material that fit the module"* (R39) "*lack of reference materials*" (R4), "*hard to find the correct notes*" (R31), "*not enough references*" (R33), It was difficult to get notes that were equivalent to the course learning outcomes "*less notes that meet course learning outcome (CLO) KSK1033*" (R39). Sometimes students encountered relevant but inaccurate and incomplete learning materials "*the material I was looking for was sometimes inaccurate or incomplete*" (R44). The results of the interviews also found that there were students who said that there were no apps, or online materials that could help

their learning, for example "*no apps as help to get knowledge about KSK1033*" (R22), "*lack online module reference for 1033*" (R23), "*insufficient online resources*" (R2), "*many available materials were either too advanced or did not match with the CLO*" (R8). The third theme showed students' suggestions to strengthen IP Address and Subnetting learning. Among them stated "*I need to be fast in learning*" (R28), Sub-topics were broken down for easy follow-up "*break down the complex topic*" (R44), numbers-oriented learning such as calculation of IP address to increase their memory of calculations "*It's hard to me to memorize the numbers*" (R37). Learning must be based on the concept of theory to practice so that students understand the connection between the two "*sometimes the theory taught is hard to relate to how it is practiced*" (R7).

C. The Framework of the SubNetSmart

The SubNetSmart application was designed with the purpose of assisting students facing difficulties in IP address and subnetting, particularly those who are not proficient in the overall topics of IP address and subnetting. SubNetSmart has been developed with the copyright number CRLY2025P00443. The unique concept of self-directed learning in SubNetSmart which was built based on the ADDIE Model included 12 case-based learning (problem-solving tasks) with entertaining learning activities. The interactive assessment provided the score automatically when the students completed the tasks. The provided activities were aligned with the Vocational College Standard Curriculum (KSKV) and the Competency Standard Assessment Document (DPSK) for Semester one in Malaysian Vocational Certificate (SVM). SubNetSmart is an educational application specially designed to enhance students' IP address and subnetting skills, of which through the innovative features make this course more accessible and entertaining for students. The main objectives of developing the SubNetSmart application are: (i) To increase students' achievement in the IP address and subnetting course, (ii) To facilitate personalized learning experiences by adapting contents to students' individual comprehension abilities and providing opportunities for repeated practice for students to master the concepts at their own pace, (iii) To heighten students' motivation and engagement through gamified assessments with progressive difficulty levels, accompanied by positive reinforcement and real-time performance feedback, (iv) To nurture collaborative learning through the integration of communication platforms that permit seamless interaction and prompt feedback between teachers or facilitators and students, improving comprehension and achieving educational goals, (vi) To ensure alignment with curriculum development principles by designing the app's structure based on established models, focusing on clear learning outcomes, structured content, engaging activities, and effective assessments.

A distinctive feature of SubNetSmart is that it combines the interactive learning approach with the elements of gaming and thus generates enjoyable learning environments for students. To provide a more engaging learning experience, SubNetSmart also uses interactive animations, images, video and audio elements. Moreover, it allows students to interact directly with teachers by means of the Telegram platform whenever they encounter learning difficulties. SubNetSmart development process involves five phases such as analysis, design, construction, implementation, and product evaluation. The assessment, alternatively, is organized based on difficulty levels to help students improve in their understanding of subnetting calculations and problem-solving. Using a digital format, SubNetSmart is believed to cater to the needs of the younger generation because it can be accessed anytime and anywhere. The SubNetSmart structure has (i) learning outcomes, (ii) learning content, (iii) learning activities, and (iv) learning assessment. This is to ensure comprehensive educational experience for students. SubNetSmart also benefits teachers and parents. Teachers and parents can assess students' skills and monitor their achievements through the achievement profiles generated by the application.

D. Cognitive Scaffolding and Its Integration with Constructive Alignment Model

Cognitive scaffolding, which has its roots in Vygotsky's Proximal Developmental Zone theory, refers to structured instructional support that is temporarily provided to enable students to complete tasks beyond their current capabilities independently, with such support gradually withdrawn as the student's mastery increases [22]. In the context of digital learning, cognitive scaffolding operates through mechanisms such as step-by-step guidance, instant feedback, visualization and the progressive arrangement of tasks according to the level of difficulty. Recent systematic studies have found that cognitive scaffolding strategies consistently improve student learning outcomes across a variety of technical domains, including conceptual comprehension, problem-solving skills, and higher-level thinking [23, 24]. These findings reinforce the position of cognitive scaffolding as a critical pedagogical mechanism in supporting mastery of complex technical content, particularly in digital learning environments. However, cognitive scaffolding alone is not enough without systematic coordination between learning outcomes, instructional activities, and assessments. This is where Constructive Alignment [14] complements cognitive scaffolding by providing a design framework that ensures that each element of learning supports each other coherently. The integration of these two principles in SubNetSmart is not just stacked theoretically but operates synergistically: cognitive scaffolding determines how instructional support is delivered to students at each stage of learning, while constructive alignment ensures that it is always oriented to learning outcomes that are consistently set and evaluated. In SubNetSmart, this alignment is expressed through the design of case-based activities that target the application of IP addressing and subnetting concepts in real-world industry contexts, coupled with immediate feedback and repetitive assessment exercises that align with TVET competency standards. This integrated approach responds to the limitations of past studies that showed that most TVET digital applications do not show explicitly integrating these two dimensions in their instructional design [10, 16].

SubNetSmart's instructional design integrates the principles of cognitive scaffolding and constructive alignment in an integrated manner, where cognitive scaffolding determines how learning supports are delivered,

while constructive alignment ensures that the support is always oriented towards the set learning outcomes [14, 22]. In line with this principle, each assignment in SubNetSmart is designed with a clear learning objective and directly linked to the core concepts of IP addressing and subnetting, ensuring alignment between learning and assessment activities [25]. Cognitive scaffolding operates explicitly through the gradual transition of tasks from simpler tasks to more challenging tasks, this condition not only reduces the cognitive load of students but also instills a sense of achievement that encourages perseverance in the face of difficulties [23]. This scaffolding mechanism is further strengthened through dynamic modification of difficulty levels based on individual performance, supporting a diversity of learning styles and speeds among TVET students [26]. In addition, the integration of interactive multimedia elements including animation, video, visualization, and network simulation serves as a representation scaffolding that helps learners build accurate mental models of abstract concepts of subnetting [16, 27]. Finally, scaffolding support in SubNetSmart is gradually withdrawn as students achieve mastery, allowing them to take control of their learning independently, a condition that is consistent with the principles of self-directed learning and the development of lifelong learning skills [15, 28].

E. Self-directed Learning

In line with Zulpykhar *et al.* [21], the opportunity to identify their own needs, set their own goals, and assess their own self-achievement, SubNetSmart offers students the responsibility to be more engaged in their learning. SubNetSmart aligns with the principles of Self-Directed Learning in that it is personalized, interactive, and practices self-based learning. It encourages self-directed learning through its interactive problem-solving tasks. These tasks, according to Knowles [29], provide students with the autonomy to learn at their own pace which fosters a sense of ownership over their learning journey. SubNetSmart also provides immediate feedback which is consistent with the statement by Zimmerman [30] that this will enable students to track their progress and adjust their learning strategies accordingly. SubNetSmart also promotes personalized learning paths by providing adaptive learning modules where the contents are structured according to the student's level of comprehension. Through this approach, Plooy *et al.* [31] said that students can master concepts according to their abilities.

According to Abdirahma [32], activities such as gamification quizzes, and network configuration exercises can enhance active learning, which is an essential element of Self-Directed Learning. Thus, in SubNetSmart, interactive and practical learning are emphasized through scenario-based exercises which allow students to understand subnetting in real-world applications. In addition, automated feedback in SubNetSmart allows students to assess their understanding on an ongoing basis. This is in line with the statement by Knowles [29] that immediate corrections (to subnetting calculations and IP configurations) help students identify errors as well as improve learning strategies without having to wait for external guidance. SubNetSmart can provide a resource-based learning environment i.e., a planned step-by-step tutorial on how to access a variety of digital learning materials such as interactive videos and case-based learning. This approach supports different learning styles, making Self-Directed Learning more effective and inclusive [33].

SubNetSmart is a tool for students to set their own learning goals and in this study these goals involved mastering subnetting for IPv4 address classes A, B, and C. SubNetSmart aligns with the principles of Self-Directed Learning as it offers adaptive, interactive, instant feedback, diverse learning resources as well as progress monitoring. It is through these features that students are able to master subnetting skills autonomously and effectively. This is in line with Clark and Mayer [34] who stated that control and analytics panels allow them to track progress as well as identify areas that need more attention.

F. ADDIE Model Background

According to Refs. [35, 36], the digitalization of education has brought about changes in the teaching and learning process. This causes the use of technology to be an important part of everyday life and in the development of professional skills. To capture students' interest, innovation in education involves technologies that can create interactive learning applications and games. The main features to consider are: (i) user interfaces with interactive graphics that provide maximum functionality, and (ii) use of audio, visual elements, and suitable 2D graphics. Notably, the ADDIE model is well known for designing effective learning experiences. Nagel and Zlatkin-Troitschanskaia [37] said that as a flexible framework for addressing complex situations, ADDIE is well-suited for developing educational products and various learning resources. Branch [38] added that the educational philosophy behind this application of ADDIE emphasizes that intentional learning should be student-centered, innovative, authentic, and inspirational. Evidently, the SubNetSmart application has followed all stages of the ADDIE Model. It started with a detailed analysis phase and a design approach related to the Constructive Alignment Model. Then, graphics, 2D animations, audio, video components, and structured textual content were added in the development phase. During the implementation and evaluation phases, a prototype was introduced and users were given tutorials on the application's functionality. The users were given the opportunity to evaluate its different features.

G. Digital Curriculum Alignment

Digitalizing the curriculum is important to stimulate dynamic learning outcomes [1]. This statement has impacted on the design and development of the curriculum. In SubNetSmart, the teaching resources followed the guidelines set by the Vocational College Standard Curriculum. This is to ensure that students receive relevant and effective learning experiences. Additionally, the assessment method used in the app was also aligned with the specific learning objectives of KSK1033 to provide accurate and unbiased measurement of student progress. Fig. 2 illustrates the interfaces of SubNetSmart showing the main page where students register, create a student profile and set a password before starting the learning process. The SubNetSmart design followed the constructive alignment model which according to Ref. [39], it emphasizes the importance between learning objectives, learning activities, and assessments to improve teaching effectiveness.

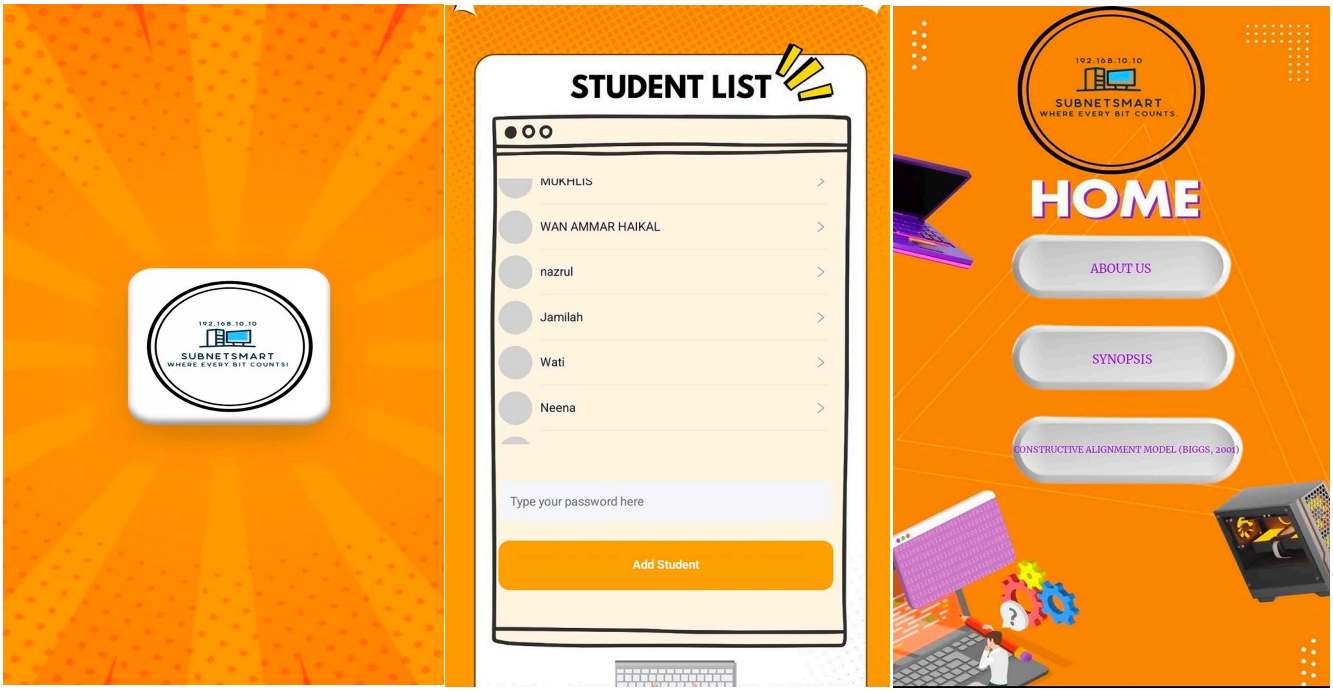


Fig. 2. SubNetSmart interfaces.

H. Learning Outcomes

According to Lawrence [40], learning outcomes are clear statements of what students should know, understand, and be able to do after completing their learning. Usually structured based on Bloom's Taxonomy, learning outcomes ensure that learning objectives are aligned with the desired outcomes. Learning outcomes (Refer Fig. 3) also play a significant role in planning learning content, teaching strategies, and assessments. In structuring digital content, Biggs and Tang [41] stated that learning outcomes aid in the design of a more directed and focused digital curriculum. In the process of evaluating learning effectiveness, [42] claimed that determining learning outcomes allows educators to assess students' achievement and tailor digital materials according to individual learning needs. In addition, Plooy *et al.* [31] opined that in facilitating technology adaptation, clear learning outcomes allow Learning Management Systems (LMS) to be adapted to support students' needs more effectively.

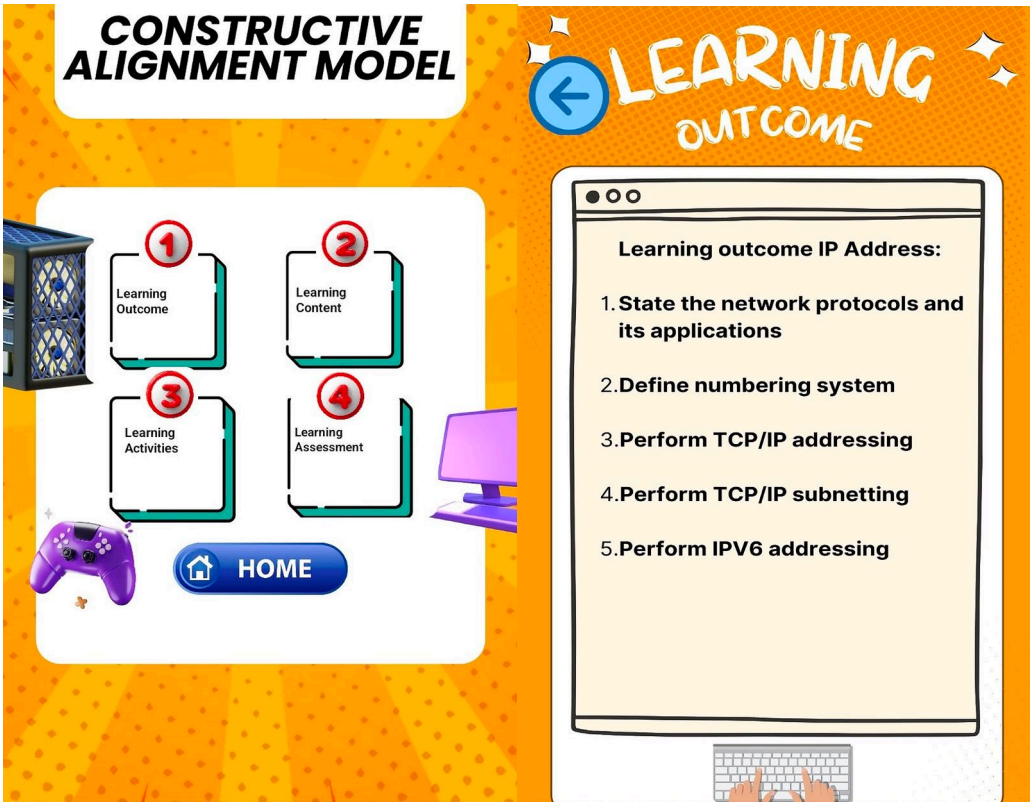


Fig. 3. Constructive alignment and learning outcomes.

The importance of learning outcomes in this context includes (i) driving students towards Independent Learning:

providing students with direction on what they need to achieve in each digital module [29], (ii) increase motivation and engagement: increasing in motivation when students understand the learning goals and how they relate to their future skills [34], (iii) aids in self-monitoring and reflection: using learning outcomes to assess their own development and identifying areas that need improvement [43]. Hence, SubNetSmart was built to achieve the following learning outcomes: (i) State the network protocols and its applications, (ii) Define numbering system, (iii) Perform TCP/IP addressing, (iv) Perform TCP/IP subnetting, (v) Perform IPV6 addressing.

I. Designing Learning Content, Learning Activities and Assessment

The contents in SubNetSmart (Refer to Fig. 4) were following the characteristic mentioned by Kolb [43] which are clarity and accuracy of information. The learning materials developed clearly explained the concepts of IP addressing and subnetting, including IPv4, IPv6, and subnet masks. In fact, the use of practical examples and real-world scenarios in SubNetSmart were created in accordance with the statement by Stallings [44] that is to help students understand the application of these concepts in computer networks. The second feature followed the stance by Kurose and Ross [45] which is an orderly, staggered structure. The learning contents were organized according to the level of difficulty, starting with basic concepts such as from binary conversions to introducing subnet calculations. In addition, the learning content also contains assessment sections such as interactive quizzes to improve students' understanding. The third feature was based on the idea by Forouzan [46] that the use of visuals and interactivity combined with the use of infographic elements, network diagrams, and interactive simulations help students visually understand the topology and breakdown of subnets. Simulations showing how IP Addresses are used in network communication improve understanding of abstract concepts [33]. The fourth feature as suggested by Tanenbaum and Wetherall [47] is that the scenario-based learning experiences involving network problem-solving allow students to understand the usefulness of subnetting in the real world. The fifth feature set during the curriculum design for SubNetSmart was interactivity and self-assessment. Interactive quiz elements and network simulations using scenario-based learning allow students to test their comprehension independently [31]. This is also confirmed by Roig *et al.* [48] that the learning of Vocational Education and Training (VET) students differs between programs. Yet hands-on activities supported by technology virtually help VET students' understanding.

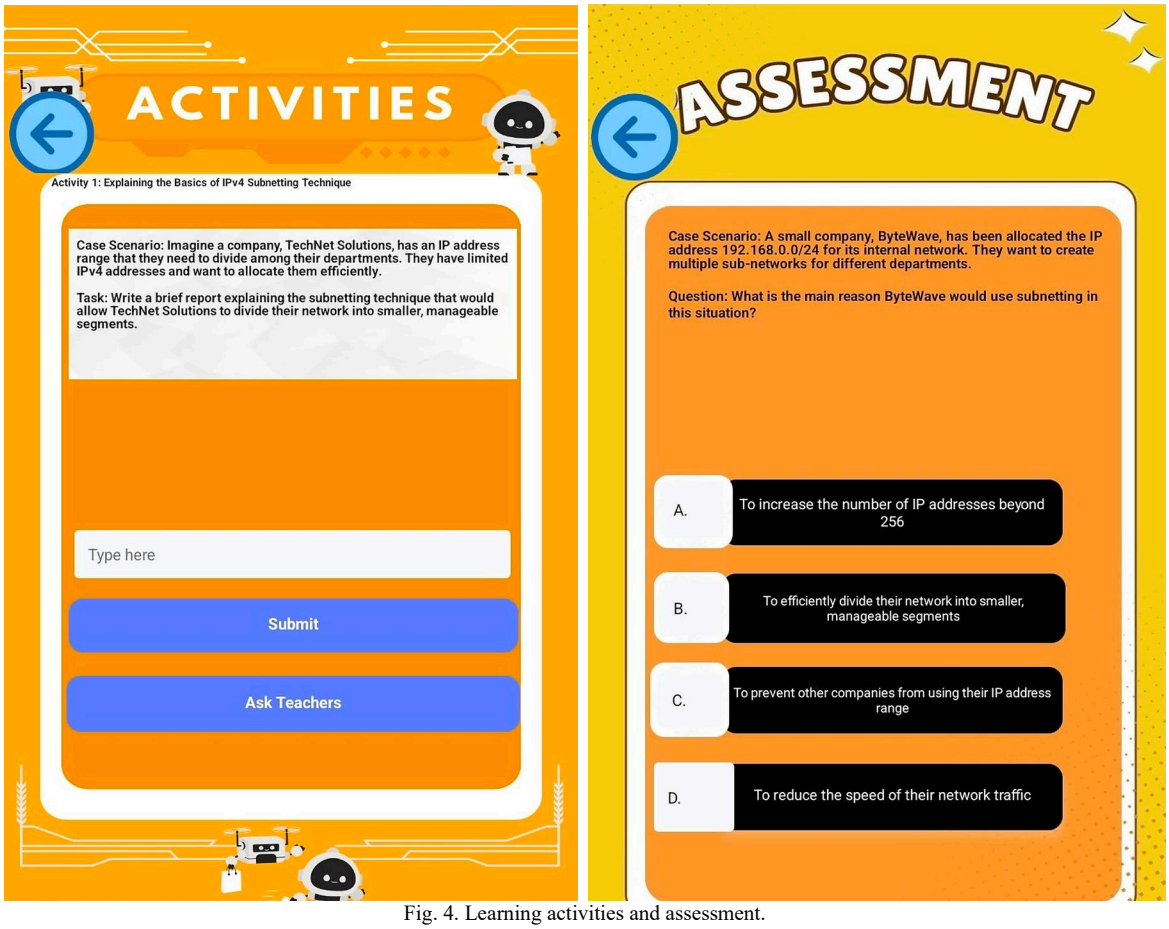


Fig. 4. Learning activities and assessment.

J. Rationale and Design Justification

Based on the gaps identified in past studies, there is a lack of domain-specific digital applications that combine cognitive scaffolding, immediate feedback, case-based learning and self-learning pathways in a coherent constructive alignment framework for TVET contexts. Therefore, SubNetSmart has been systematically designed using the ADDIE model to meet these needs directly [10, 14]. In contrast to previous studies that evaluated the

effectiveness of common digital tools without explicit alignment between pedagogical design and vocational competency standards, this study contributes uniquely through three dimensions: first, theoretical contributions through empirical validation of the integration of cognitive scaffolding and constructive alignment in the TVET digital learning environment. Furthermore, the incorporation of the principles of Self-Directed Learning as the third theoretical pillar ensures that SubNetSmart is designed not only to deliver content, but to foster student autonomy through self-progress, iterative assessment practices, and personalized learning paths that allow students to monitor and control their own learning trajectory independently of the guidance of a live instructor [15]; second, methodological contribution through the use of a strict quasi-experimental mixed-method design with ANCOVA, effect size analysis and qualitative triangulation [49]; and third, practical contributions through the development of domain-specific applications that are empirically proven to enhance TVET students' achievement in complex IP addressing and subnetting topics, thus offering instructional design models that can be replicated across other technical disciplines in the TVET ecosystem [16, 50]. Overall, it can be explained that Constructive Alignment coordinates learning outcomes, activities and assessments, Cognitive Scaffolding structures staged instructional support and Self-Directed Learning builds student autonomy and control.

III. Methodology

The methodology discusses research design, sampling design, data collection procedures, instrumentation, and test analysis.

A. Research Design

This study adopted an explanatory mixed methods approach, in which a quasi-experimental pretest–posttest nonrandomized control and treatment group design was used in the quantitative phase. Quasi-experimental research is a study design used to assess cause-and-effect relationships when random distribution is not feasible [51]. Unlike true experiments, in quasi-experiments, participants are not randomly assigned to treatment or control groups. This is often the case in situations where random distribution is impractical or unethical [52]. Involved in this study were two groups of students from two vocational colleges. The two groups were assigned as the control and treatment groups. Creswell [52] assert, triangulating multiple data sources within a mixed-methods framework enhances both the internal validity and the interpretive depth of findings beyond what either method could achieve independently.

B. Sampling Design

In this research, intact group convenience sampling design was used [53]. This refers to the selection of participants from existing groups, based on ease of access. This method is often used when researchers select an existing group, such as a class or organization, for their study [54]. The use of intact group convenience sampling in this study is in line with common practice in educational research, particularly in contexts where random assignments cannot be implemented due to institutional constraints and the need to maintain the integrity of the existing lecture system [40, 55]. Quasi-experimental design is generally adopted in educational settings since the implementation of randomized control trials is impractical and even impossible in most situations, due to the need to avoid disruption to the learning process and institutional operations [49, 55]. Convenience sampling is one of the designs of non-probability sampling that is widely used in educational research, where the selection of study participants is based on their accessibility and willingness to participate [53, 56]. This approach is considered appropriate and reasonable in studies involving intact classes, if the study findings are interpreted in the right context and scope considering the limitations of relevant generalizations. In this study, 60 form four vocational college students (16-year-old male and female students), from A and B vocational college were assigned to the control and treatment groups. The sample size of 60 participants, consisting of 30 participants in the control group and 30 participants in the treatment group, was adequate and met the minimum requirements set for experimental design studies. General guidelines in experimental research set a minimum of 30 participants per group to ensure statistical comparative robustness [57, 58]. This requirement is also in line with practice in clinical trials, where a minimum of 30 participants per treatment group makes a minimum total of 60 participants found to be sufficient to detect significant differences between groups with a satisfactory level of statistical power. In addition, the Roscoe's [58] guidelines specifically state that for studies involving comparative analysis between subgroups, a minimum of 30 respondents per group should be considered. The logical basis behind this rule $n \geq 30$ is based on the Central Limit Theorem (CLT), which asserts that sampling distribution of the mean will approach the normal distribution when the sample size reaches that level [53, 59]. Thus, when the sample size of each group meets the requirement of $n \geq 30$, the normality assumption is considered met, thus allowing researchers to use parametric statistical tests in a valid and controlled manner [53, 58, 60]. This threshold is further supported by Memon *et al.* [56], who affirm that convenience sampling in quantitative research is methodologically defensible provided that each group meets the minimum sample size criterion. Pre-intervention equivalence between groups was additionally confirmed through Levene's Test for Equality of Variances ($p > 0.05$), substantiating group comparability at baseline prior to the intervention [60].

C. Design Data Collection Procedure

This quasi-experimental study methodically employed structured data collection procedures to ensure its accuracy and relevance such as (i) in the first week, a pre-test was given to the control and treatment groups to collect baseline score data for IP Address and Subnetting prior to the implementation of the intervention to ensure that both groups had equivalent scores. (ii) From the second week to the fifth week, learning sessions using modules were conducted at the vocational college (control group) and using the SubNetSmart application for the treatment group. Prior to the intervention, teachers who were the instructors for the treatment group underwent a comprehensive training session on the use of SubNetSmart. The study implementation

process considered the consistency and fidelity of treatment implementation across both groups. Structured intervention protocols were developed and strictly adhered to throughout the study period. The treatment group was involved with SubNetSmart and the control group started the learning session in the second week after the pre-test was administered until the fifth week. The learning process lasted four weeks, with clear learning objectives, a sequence of instruction, and assessment activities aligned with a constructive alignment framework [14]. Implementation fidelity was monitored through instructor observation notes and structured lesson checklists administered at each session. The control group received conventional lecture-based instruction that included the same content within the same time frame. The consistency of this procedure ensures that any differences observed in post-test outcomes can be attributed to the nature of the teaching approach rather than variations in content coverage or teaching time [61]. (iii) During the sixth week, the post-test data collection was conducted for both the experimental and control groups. It is important to ensure consistency in data collection between groups and throughout the study period to reduce measurement bias and errors [40, 62]. (iv) Finally, a survey was conducted using Google Forms to obtain student feedback related to the use of SubNetSmart in learning to support course learning outcomes. This survey aimed to measure students' understanding in (i) Explaining the Basics of IPv4 Subnetting Technique, (ii) Describing the Importance of Subnetting Across Various IPv4 Network Classes, and (iii) Calculating Subnet Masks and Addresses for IPv4 Classes A, B, and C. To minimise the threat of instructor bias, the control group implemented standard learning modules set by the vocational education authorities, while the treatment group used SubNetSmart as an additional teaching medium. This standardized module ensures uniformity of content coverage, teaching objectives, and pedagogical sequence across both groups, thus reducing the variability stemming from differences in instructor delivery. This approach is consistent with recommended practices for controlling teaching confusion in multigroup quasi-experimental designs [49, 61]. Thus, the differences observed in post-test performance between the control and treatment groups can be attributed more confidently to SubNetSmart interventions than to variations in content or instructional delivery.

A qualitative approach was also adopted in this study to explore participants' perceptions of usability as well as learning experiences related to the SubNetSmart application. Purposive sampling strategy was used to select 15 participants from the treatment group who had experience using the application and were able to provide rich information that was relevant to the objectives of the study. Before the interview session is conducted, the participants had successfully learned using the SubNetSmart application and completed the learning activities provided to ensure that the responses given are based on real interaction and experience with the application. Semi-structured interviews that lasted for 30–40 min were then conducted to gain an in-depth understanding of the participants' experiences, perceptions of the applicability of the application, as well as their views on the effectiveness of the application in supporting subnetting learning. The interview was recorded with the consent of the participants to ensure the accuracy of the data obtained. The interview recordings were then transcribed verbatim and analysed using thematic analysis based on the procedure proposed by Braun and Clarke [63], which involved the process of familiarizing themselves with the data, initial code generation, pattern identification, theme development, theme review, as well as the refinement of the final theme. Throughout the analysis process, transcripts and coding results were reviewed repeatedly to ensure consistency, credibility and reliability of the study findings. Data collection continued until the information reached a data saturation level when no more significant new information or insights emerged from subsequent interviews. Ethical considerations were also observed throughout the study by ensuring that participants were informed about the purpose of the study, the nature of voluntary participation, and the confidentiality of the information provided. To protect the identity of the participants, all identifying information was removed from the transcript and the use of pseudonyms was practiced during the reporting of the study results.

D. Instrumentation

The pre-test and post-test instruments consisted of eight structured questions (totalling 30 marks), which were adopted and adapted from the Malaysian Examinations Board, Ministry of Education Malaysia, ensuring that the items reflect the national standard content benchmarks for IP addresses and subnetting. Each question is allocated between 3 and 6 marks, reflecting progressive cognitive demands consistent with the three stages of Bloom's Taxonomy namely Knowledge (items 1–3), Comprehension (items 4–6) and Application (items 7–8). This is explicitly in line with the learning outcomes of the study, namely: (i) the ability to identify and calculate network addresses, subnet masks and host ranges; (ii) the ability to interpret IP addressing schemes; and (iii) the ability to use subnetting procedures to troubleshoot network problems. Students are required to complete the instrument within 90 min under standard conditions in both groups. The validity of the content was carefully established through a review of an expert panel involving five experienced vocational educators, each with at least five years of teaching experience in IP addressing and subnetting in vocational colleges, which verified the appropriateness, clarity, level of difficulty, and alignment of each item with the specified learning outcomes [64]. Reliability between raters was confirmed at 0.81, indicating strong agreement among raters and attesting to the consistency and reliability of scoring procedures [14]. The use of national standards instruments further strengthens the validity of the content and generalizability of the findings in the context of Malaysian TVET, as the items have been previously benchmarked against the national competency standards set for network education. Inter-rater reliability was established through independent scoring by two experienced raters using a structured marking scheme, yielding a Cohen's Kappa coefficient of 0.81, indicating strong inter-rater agreement [65]. Content validity was systematically demonstrated through expert panel review employing a Content Validity Index (CVI), with all retained items confirmed to align with the specified learning

outcomes and Bloom's Taxonomy cognitive levels [64].

The interview protocol was developed based on the objectives of the study and focused on aspects such as ease of use, usability of learning features, engagement, learning support, and overall user experience. The semi-structured interview format allows researchers to maintain uniformity between interview sessions while also providing flexibility to ask follow-up questions for further clarification and explore emerging issues in more depth. To answer the Fourth Study Question, three sub-questions were developed, namely first: How did SubNetSmart application help you understand IP addressing and subnetting more effectively? Second: What differences did you notice when learning with the SubNetSmart app instead of your usual classroom lessons? While the third is What parts of the SubNetSmart app did you find most useful? Explain why. The interview protocol has gone through a content validation process involving two experts with more than 15 years of experience in the field of qualitative research and education. The validity of the content of the interview protocol was determined through an iterative expert review in two rounds until consensus was reached. The evaluation process focused on several key aspects, namely the alignment of the questions with the objectives of the study, the relevance and representativeness of the constructs explored, the clarity and appropriateness of the language used, the order and flow of the questions, as well as the protocol's ability to generate in-depth and meaningful data from the study participants. The legality process is carried out in two rounds. In the first round, a panel of experts evaluated the entire interview protocol and submitted suggestions for improvements related to the content, structure, and formulation of the questions. Based on the feedback, several amendments have been made to improve the accuracy and clarity of the instrument. Subsequently, the improved protocols were re-evaluated in the second round by the same panel of experts to obtain the validity of the content and were certified as valid and can be used for actual research purposes.

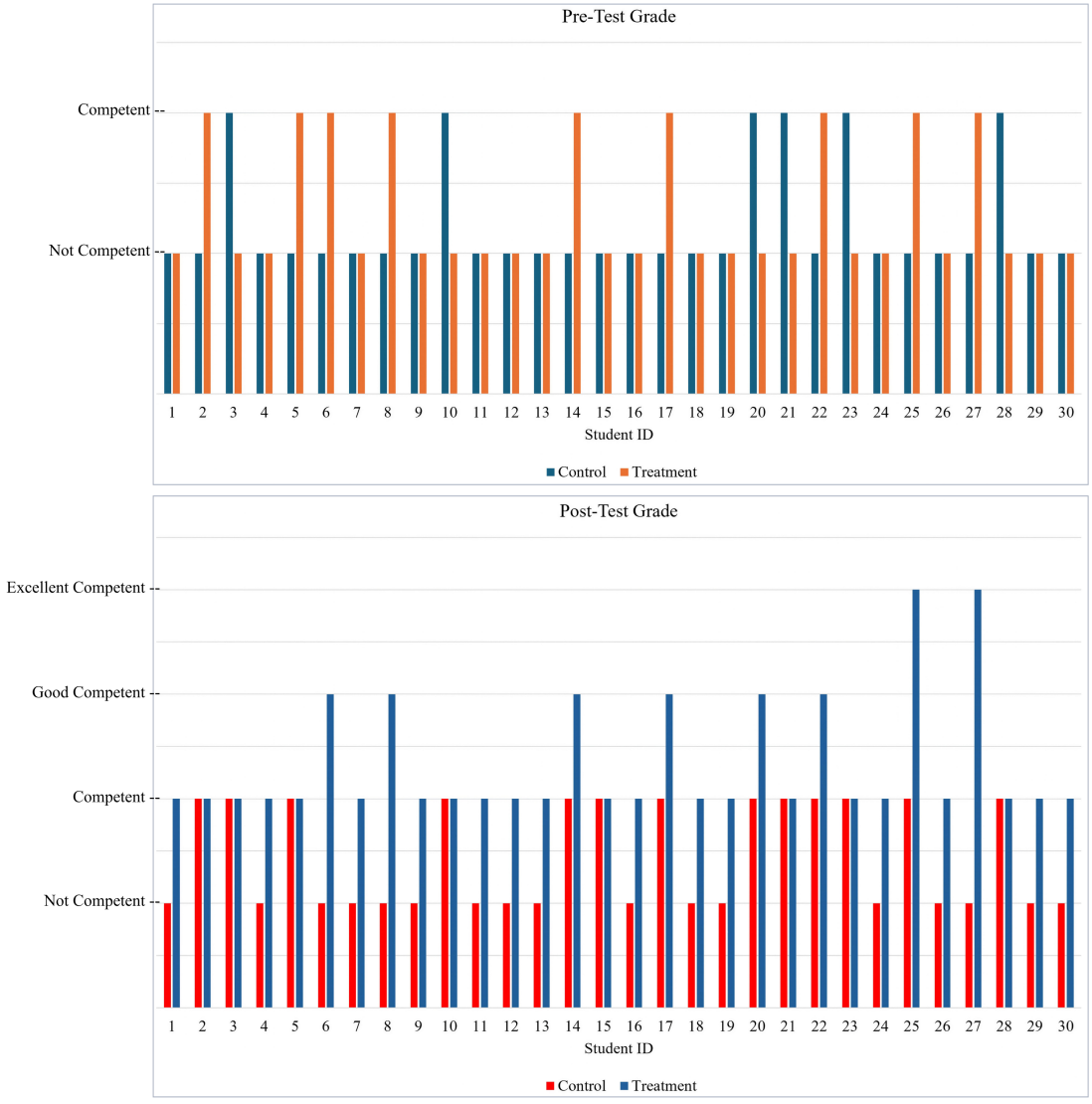


Fig. 5. Pre-test and post-test students' profile.

E. Test Analysis

After data collection, statistical analysis was performed to assess the effects of the intervention. Descriptive statistics were used to summarize the data and provide a general overview of sample characteristics, such as mean, standard

deviation, and frequency distribution [62]. While the Covariance (ANCOVA) analysis was used to control the differential variable (covariate) that may influence the leaning variable. ANCOVA allows researchers to assess the effects of interventions while controlling the covariate that influences the accuracy of conclusions on causal relationships [66]. Several steps have been taken to strengthen the internal validity of this study. First, the threat of bias of sample selection was reduced through pre-test equivalence verification, where the Levene Test confirmed the homogeneity of variance ($p > 0.05$) and a mean pre-test difference of no significance proving the equality of the two groups before the intervention was implemented. Second, ANCOVA is used as the main analytical tool to control for covariate variables, i.e., pre-test scores, thus reducing the influence of early differences on post-test outcomes and strengthening the causal inference of interventions. Third, the threat of maturity is controlled by ensuring that both groups receive an equal teaching period and are exposed to the same learning content. Fourth, historical impact is minimized through the implementation of interventions within a semester under consistent institutional conditions. Collectively, these measures strengthen the internal validity of the study and increase confidence in the causal inferences associated with SubNetSmart interventions [49, 55].

Qualitative data obtained through semi-structured interviews were analyzed using thematic analysis. All interview recordings have been transcribed verbatim to ensure data accuracy. The analysis process began with repeated reading of the transcript to allow the researchers to understand the entire data in depth. Next, the initial coding process was conducted by identifying significant units of meaning and providing the code systematically. The codes that have similarities are then grouped into specific categories before being formulated into a main theme that describes the patterns of meaning in the study data. To improve the validity and reliability of the analysis, repeated discussions between researchers were conducted to check the consistency of the codes and themes. The final themes were revised with reference to the original data to ensure the accuracy of the interpretation of the views of the study participants [63].

IV. Findings

A. What Are the Pre-test and Post-test Scores of Students in Control and Treatment Groups?

Fig. 5 shows the score profile of the control and treatment groups in the pre-test and post-test. The pre-test of both groups showed that there were two achievement grades, namely incompetent and competent. Meanwhile, based on the post-test graph, it showed an improvement to excellent competent grades of 7% ($n = 2$) and good competent 20% ($n = 6$) and the remaining 73% ($n = 22$) in competent grades for treatment group. On the other hand, in the control group, there were students who were still in the not yet competent grade 57% ($n = 17$) and competent 43% ($n = 13$).

B. Is There a Significant Difference in Post-test Scores between the Control and Treatment Groups after Controlling for Pre-test Scores?

Table 1 presents the descriptive analysis data. The mean for the Treatment Group was 72.30 ($\sigma = 9.966$), while the mean for the Control Group was 58.80 ($\sigma = 5.845$). This indicated that the Treatment Group achieved a higher mean compared to the Control Group.

Table 1. The mean and standard deviation for the post-test of the control and experimental groups

Group	Mean	St. Deviation	N
Control	58.80	5.845	30
Treatment	72.30	9.966	30
Control	65.55	10.580	60

Table 2 shows the Levene's Test for this study. The researcher conducted Levene's Test to ensure that the Control and Treatment Groups were homogeneous before proceeding with any tests. Based on Table 2, the data indicated [$F(1, 58) = 0.224$, $p > 0.05$], where the result was not significant. This confirmed that both groups were homogeneous before the experiment began.

Table 2. Levene's test

F	df1	df2	Sig.
1.508	1	58	0.224

Note: Test the null hypothesis that the error variance of the dependent variable is equal across groups. Design: Intercept +Pre-test+Group

Table 3 refers to the homogeneity of regression slopes was tested by introducing a Group *Pretest interaction term into the model. The interaction was statistically significant, $F(1, 56) = 8.242$, $p = 0.006$, partial $\eta^2 = 0.128$, indicating that the relationship between prior knowledge (pretest) and achievement (post-test) differed between the control and treatment groups. Rather than invalidating the ANCOVA, this finding provides an additional theoretically meaningful insight: SubNetSmart differentially strengthened the pretest-posttest relationship within the treatment group, suggesting that the intervention benefited students with varying levels of prior knowledge to different degrees. This is consistent with cognitive scaffolding theory, wherein structured digital learning environments are posited to be particularly effective for learners with lower prior knowledge [22].

Table 3. Homogeneity of regression slopes (dependent variable: post-test)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4561.089[a]	3	1520.363	41.659	0.000	0.691
Intercept	179.076	1	179.076	4.907	0.031	0.081
Group	173.950	1	173.950	4.766	0.033	0.078
Pretest	1140.404	1	1140.404	31.248	0.000	0.358
Group * Pretest	300.793	1	300.793	8.242	0.006	0.128
Error	2043.761	56	36.496			
Total	264413.000	60				
Corrected Total	6604.850	59				

Note: R Squared = 0.691 (Adjusted R Squared = 0.674)

Table 4. ANCOVA test on instructional approaches tests of between-subjects effects (dependent variable: post-test)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4260.297[a]	2	2130.148	51.787	0.000	0.645
Intercept	96.672	1	96.672	2.350	0.131	0.040
Pre-test	1526.547	1	1526.547	37.113	0.000	0.394
Group	1802.075	1	1802.075	43.811	0.000	0.435
Error	2344.553	57	41.133			
Total	264413.000	60				
Corrected Total	6604.850	59				

Note: R Squared = 0.645 (Adjusted R Squared = 0.633)

Table 4 presents the data for the ANCOVA test on instructional approaches. Based on the data in Table 4, the post-test scores for both the control and treatment groups showed a significant change [F (2, 57) = 43.811, $p < 0.05$]. The study hypothesis was correct, and the Null Hypothesis was rejected. This demonstrated that teaching using SubNetSmart Interactive Applications has enhanced students' achievement in IP Address and Subnetting course. The partial eta squared value ($\eta^2 = 0.435$) has been explicitly interpreted as a large effect according to Cohen's established benchmarks [67], indicating that the SubNetSmart intervention accounted for 43.5% of the variance in post-test achievement after controlling for pre-test differences.

Fig. 6 illustrates the estimated post-test marginal mean for both groups after controlling for the pre-test score at the grand mean value ($M = 56.18$). The treatment group achieved a higher estimated marginal mean ($M = 71.3$) compared to the control group ($M = 60.0$), visually confirming the significant effect of the SubNetSmart intervention on student achievement in the IP addressing and subnetting courses after controlling for the pre-test effect on the grand mean covariate value (pre-test = 56.18).

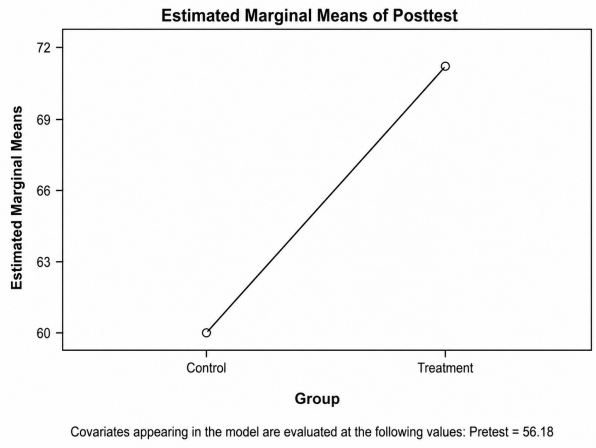


Fig. 6. Estimated marginal means of posttest.

C. How do Students Respond to the Experience Learning Using SubNetSmart Application in IP Address and Subnetting Course?

The Google Form in the SubNetSmart application collected various perspectives and remained open to feedback for this study. A total of 30 users participated in the survey. The survey consisted of 3 sections, each containing several questions. Users were provided with a 5-point rating scale for each question, with options ranging from 1. Strongly Disagree, 2. Disagree, 3. Neutral, 4. Agree to 5. Strongly Agree for the SubNetSmart application. Fig. 7 shows the items to measure learning outcome 1: Explaining the basics of IPv4 subnetting technique. Fig. 7 shows the respondents' ability to explain the concept of network protocols (mean = 4.4); with 60% ($n = 18$) of respondents agreed while 40% ($n = 12$) of respondents strongly agreed. For the statement of being able to differentiate between network protocols (mean = 4.27), 73% ($n = 22$) agreed and 27% ($n = 8$) strongly agreed. Meanwhile, for the statement explaining the purpose of the network protocol (mean = 4.33), 67% ($n = 20$) agreed and 33% ($n = 10$) strongly agreed. The median values which were consistent across all three statements further supported the high level of understanding on the basics of IPv4 Subnetting Technique and proved that they have successfully achieved course outcome one. The standard deviation values suggested moderate variability in the responses with values ranging from 0.450 to 0.498. This indicated that most respondents strongly agreed that they have comprehended the learning content. However, there were some variations in their level of comprehension to explain the basics of IPv4 subnetting technique.

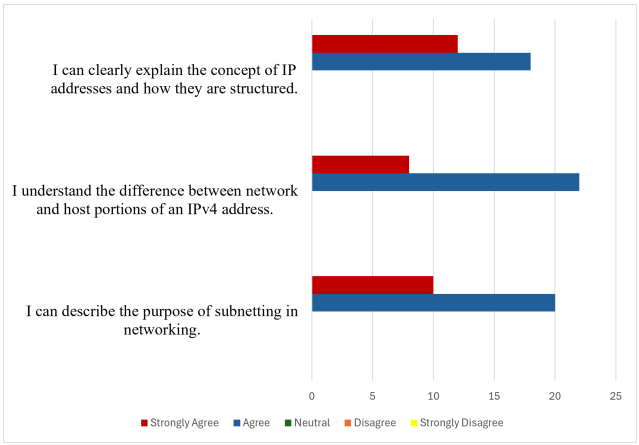


Fig. 7. Items to measure learning outcome one (explaining the basics of IPv4 subnetting technique).

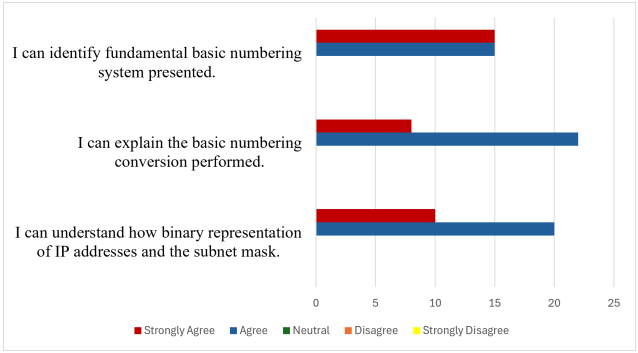


Fig. 8. The items measure learning outcome two (describing the importance of subnetting across various IPv4 network classes).

Fig. 8 shows the respondents' ability to identify the fundamentals of the basic numbering system (mean = 4.5)

where 50% (n =15) of respondents agreed, while 50% (n = 15) of respondents strongly agreed. For the statement of being able to explain the basic numbering conversion performed (mean = 4.27), 73% (n = 22) agreed and 27% (n = 8) strongly agreed. Meanwhile, for the statement of being able to explain how binary representation of IP addresses and the subnet mask (mean = 4.33), 67% (n = 20) agreed while 33% (n = 10) strongly agreed. The consistent median values for each three statements showed a high level of understanding in describing the importance of subnetting across various IPv4 network classes and thus proved that they have achieved course outcome two. The standard deviation values suggested moderate variability in the responses with values ranging from 0.450 to 0.509. This indicated that most respondents strongly agreed they have comprehended the learning content. There were some variations in their level of comprehension to describe the importance of subnetting across various IPv4 network classes. The overall analysis demonstrated that respondents have a strong and consistent self-perceived proficiency in understanding basic numbering systems and the binary representation of IP addresses. The high mean and median values along with moderate standard deviation values indicated a generally high level of comprehension regarding learning outcome two.

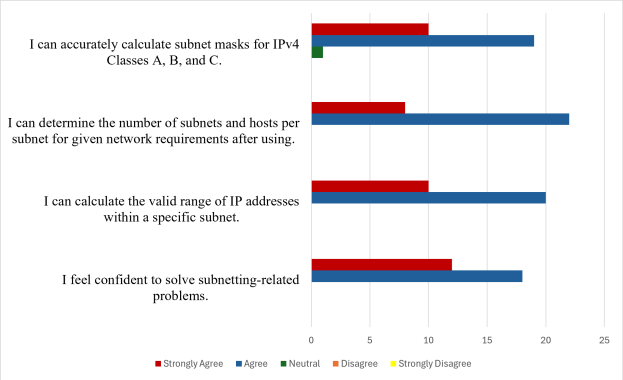


Fig. 9. The items measure learning outcome three (calculating subnet masks and addresses for IPv4 classes A, B, and C).

Based on Fig. 9, the mean value shows the respondents' ability to accurately calculate subnet masks for IPv4 (mean = 4.3) with 63% (n = 19) agreed, 33% (n = 10) strongly agreed and the remaining 3.33% with a frequency of n = 1 respondent answering neutral. For statements determining the number of subnets and hosts (mean = 4.27), 73% (n = 22) chose to agree and only 27% (n = 8) strongly agreed. The third statement "I can calculate the valid range of IP addresses within a subnet" showed 67% (n = 20) of the respondents agreed and 33% (n = 10) answered strongly agree with a mean value of 4.33, and finally, for the fourth statement "I feel confident to solve subnetting-related problems" (mean = 4.4), a total of n=18 respondents agreed with a percentage of 60%, while 40% (n = 12) respondents strongly agreed. The median values for each four statements showed the high level of students' comprehension and proved they have successfully achieved course outcome three related to calculating subnet masks and addresses for IPv4 Classes A, B, and C. The standard deviation values, ranging from approximately 0.450 to 0.534, suggested moderate variability in the responses. This indicated that most respondents have shown high comprehension of the learning content. The overall analysis demonstrated that respondents have a strong and consistent self-perceived proficiency in calculating subnet masks and addresses for IPv4 Classes A, B, and C. The high mean and median values along with moderate standard deviation values indicated a generally high-level comprehension of the body of knowledge.

D. How do Students Perceive the Effectiveness of the SubNetSmart App in Supporting their Learning of IP Addressing and Subnetting?

Qualitative data analysis to answer the fourth research question is as follows. Thematic data analysis through interviews showed that there were three main themes that emerged, namely (i) Cognitive Scaffolding Facilitates Conceptual Mastery, (ii) Interactive Learning Promotes Meaningful Learning Experiences and (iii) SubNetSmart Features Facilitate Meaningful Learning. Referring to Fig. 10 showing the first theme, Cognitive Scaffolding Facilitates Conceptual Mastery, there are six sub-themes discussed by the participant, namely (i) Improved Accuracy in IP Address Calculations, (ii) Step-by-Step Learning Support, (iii) Increase confidence in solving Networking Problem, (iv) Better Conceptual Understanding of Networking, (v) Visualisation and Interactive learning and (vi) Case-Based Learning Increase Understanding.

(i) Improved Accuracy in IP Address Calculations; (ii) Step-by-Step Learning Support Interview: Participants perceived that the use of SubNetSmart has helped them improve accuracy in IP address calculations as well as resolve calculation errors more effectively. "*The SubNetSmart app helped me understand the subnetting calculations more clearly because the steps were organized systematically. Previously, I was confused when determining a valid broadcast address and host range" (P1).* The activities provided in SubNetSmart help students understand the calculation of IP addresses and networks in different IP classes "*The activity in the SubNetSmart application helped me calculate the number of hosts and network addresses for different IP classes"* (P2). In fact, automatic feedback helps students identify errors in calculations and makes it easier for them to understand the concept of subnetting more accurately "*Automated feedback from the SubNetSmart app helps me identify errors in calculations more quickly and improves my understanding of subnetting concepts"* (P12). Participants described learning through SubNetSmart helps to show the relationship between the subnet mask value and the number of hosts that exist in the network where there were some students who previously had difficulty understanding this relationship "*The SubNetSmart app helped me understand the relationship between the subnet mask value and the number of hosts available in the network. Previously I had a hard time understanding this situation"* (P13). SubNetSmart helps students provide correct calculation answers if there are mistakes made by students. This allows students to learn from mistakes to be more efficient and calculate more accurately "*The SubNetSmart app helped me improve the speed and accuracy of my subnetting calculations. I made fewer mistakes by using SubNetSmart"* (P15).

Some students stated that before learning to use SubNetSmart most of them were confused and always made mistakes in calculating IP addresses and host ranges. In fact,

they take a long time to calculate manually in class. Among their responses were: "*Previously, I was confused when determining a valid broadcast address and host range. SubNetSmart explains each process step by step, which reduces my errors during calculations" (P1).* Other students added *"Before using the SubNetSmart application, it took me a long time to complete the subnetting calculation manually. After practicing with the SubNetSmart app, I was able to calculate the range of subnets more efficiently and accurately"* (P6). On the other hand, the use of SubNetSmart which provides repetitive assessment exercises has helped students make calculations more accurately and efficiently. The systematic guidance found in this application also supports the overall improvement of students' understanding. *"Repeatable assessments allow my ability in calculations to be marketable and accurate"* (P5), *"The guided exercises in SubNetSmart application helped me reduce these errors"* (P3) and *"The SubNetSmart application improved my understanding of binary conversion in subnetting calculations through systematic guided. Previously, I was often confused when converting decimal numbers to binary forms"* (P7).

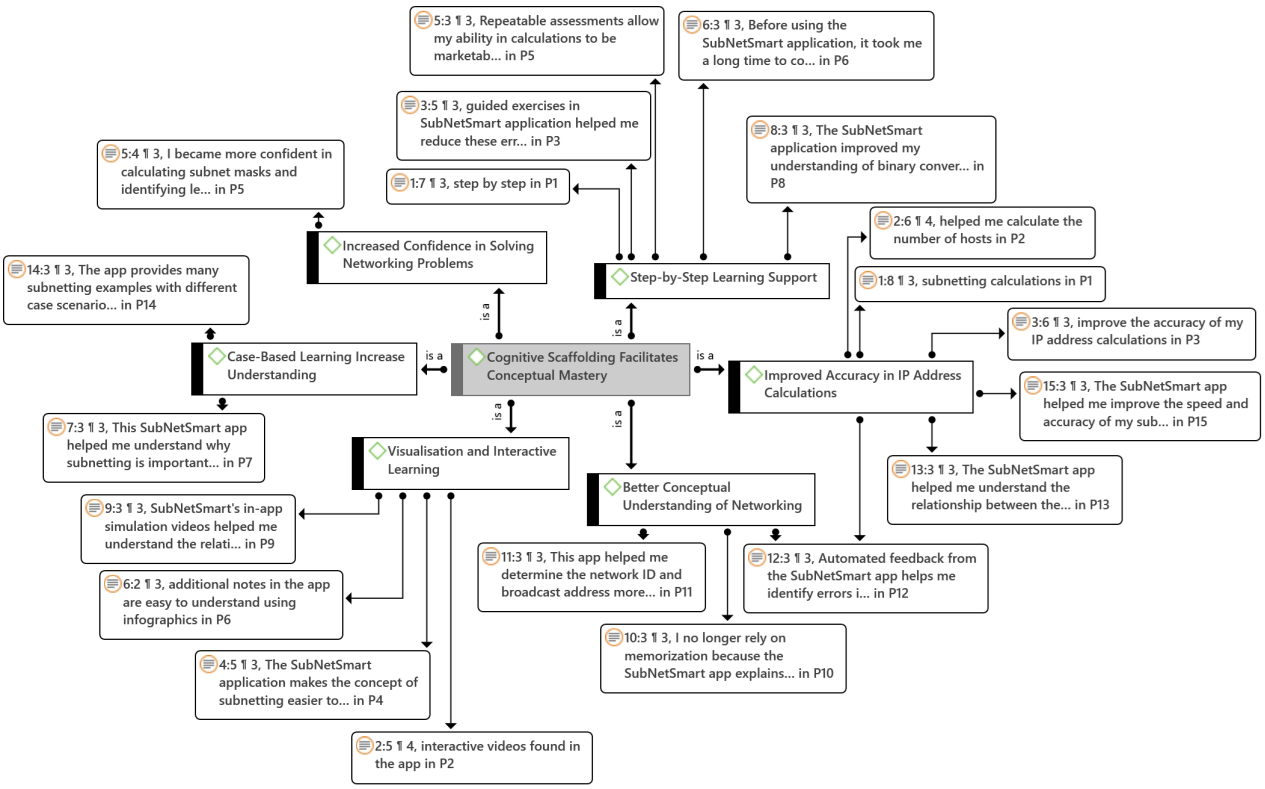


Fig. 10. Cognitive scaffolding facilitates conceptual mastery ATLAS.ti model.

(iii) Increase Confidence in Solving Networking Problem; (iv) Better Conceptual Understanding of Networking: Analysis of the interview data revealed that the use of SubNetSmart has increased students' confidence in solving networking problems because the app explains the logic behind subnetting calculations in an easy-to-understand way. "*I became more confident in calculating subnet masks and identifying legitimate hosts after using the SubNetSmart app"* (P5). In addition, participants also reported an increase in their overall understanding of networking concepts, where the automatic feedback provided by the app helps them identify calculation errors instantly, thus strengthening their understanding in stages. *"I no longer rely on memorization because the SubNetSmart app explains the logic behind subnetting calculations. This significantly improved my conceptual understanding."* (P10), *"This app helped me determine the network ID and broadcast address more precisely. Previously, I was often confused by these two concepts."* (P11) and *"Automated feedback from the SubNetSmart app helps me identify errors in calculations more quickly and improves my understanding of subnetting concepts."* (P12)

(v) Visualisation and Interactive Learning; (vi) Case-Based Learning Increase Understanding: Analysis of the interview data indicated that the use of interactive videos, visual design and infographics helped students understand concepts and remember accurate calculation formulas "*Before using the app, I memorized formulas without fully understanding the concept. After using the SubNetSmart app, I understood how subnet segmentation actually works through the interactive videos found in the app"* (P2). Other participant described *"The SubNetSmart application makes the concept of subnetting easier to understand because the diagrams and visual explanations clearly show the relationship between the network address, the subnet mask, and the host address"* (P4). In fact, using videos allows students to understand more easily the concepts and relationships between routing and subnetting *"SubNetSmart's in-app simulation videos helped me understand the relationship between routing and subnetting. I became more aware of how packets are transmitted in different networks"* (P9). The provision of additional notes in the form of infographics available in SubNetSmart also helps to improve and accelerate students' understanding "*This is because the additional notes in the app are easy to understand using infographics"* (P6). Participants

emphasized that case-based learning enhanced their understanding of IP addressing and subnetting by connecting theoretical concepts to real-world scenarios through contextualised problem-solving tasks *"This SubNetSmart app helped me understand why subnetting is important in a real network environment. I understand how network administrators split networks to avoid IP wastage through the case-based learning activities provided in the SubNetSmart application"* (P7). The use of case-based scenarios provided diverse and contextualised examples that systematically deepened students' conceptual understanding by exposing them to varied real-world problem contexts: *"The app provides many subnetting examples with different case scenarios, which strengthened my understanding of network computation"* (P14). Overall, main-theme one shows that cognitive scaffolding facilitates conceptual mastery through improved IP computational accuracy, staging support, confidence in network problem-solving, as well as strengthening conceptual understanding through visualization, interactivity, and case-based learning.

Fig. 11 shows the second main theme, "Interactive Learning Promotes Meaningful Learning Experiences". These findings reflect students' perceptions of the differences between learning using SubNetSmart versus conventional teaching methods in the classroom. Through this main theme, five sub-themes were formed that were discussed by students regarding their experience of learning using the SubNetSmart app. The sub-themes formed are (i) Case-Based Interactive Learning, (ii) Self-Paced Learning, (iii) Interactive and Enjoyable learning Environment, (iv) Active Learning Engagement (v) Creating a Supportive Learning System.

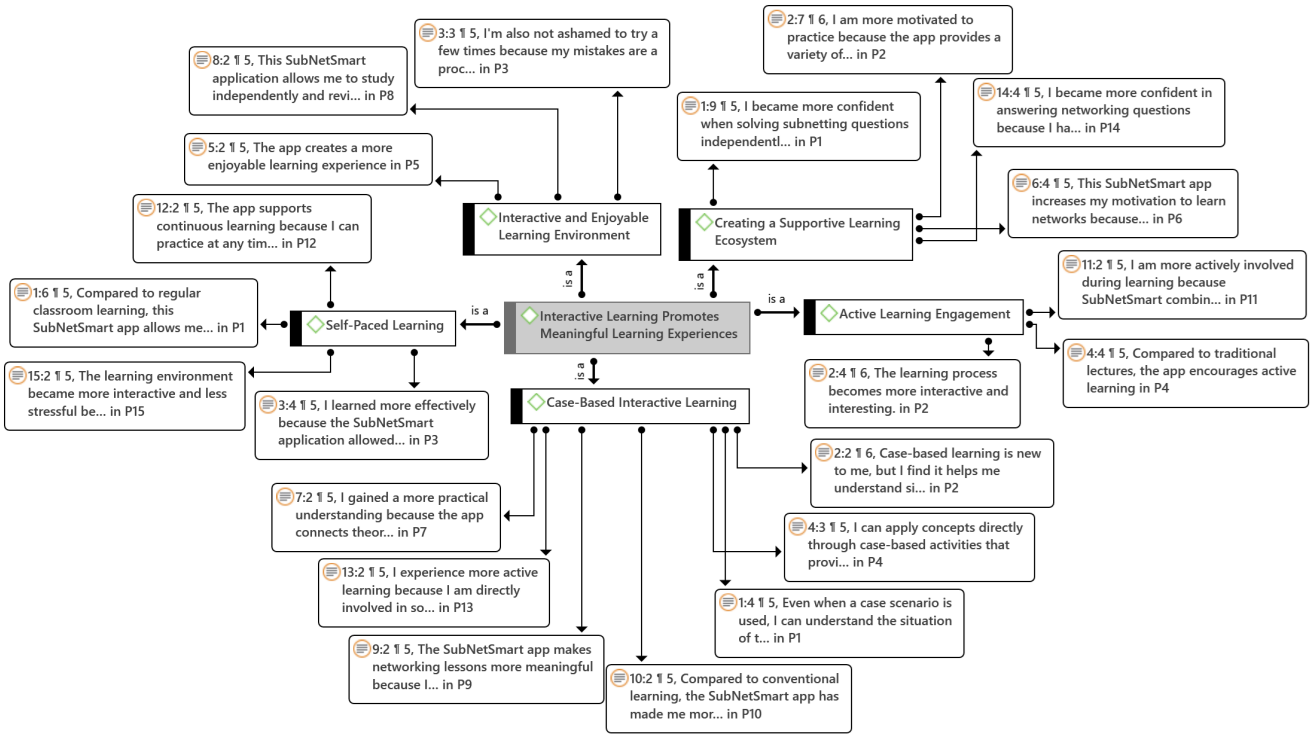


Fig. 11. Interactive learning promotes meaningful learning experiences ATLAS.ti model.

(i) Case-Based Interactive Learning; (ii) Self-Paced Learning: Study participants consistently stated that the case-based interactive learning available in SubNetSmart helped them understand the situation in a given case and apply the knowledge to solve problems in the context of a real work environment. Among the feedback obtained from the participants were as follows: *"Even when a case scenario is used, I can understand the situation of the case and try to apply the knowledge I have learned to solve the problem in a given case"* (P1). Other students also added "*Case-based learning is new to me, but I find it helps me understand situations and try to solve problems as if I were in a real workplace"* (P2). Students also expressed a positive tendency towards case-based activities as this approach allows them to apply their knowledge directly in solving the problems presented, as opposed to traditional learning methods that rely solely on reading notes: "*I can apply concepts directly through case-based activities that provide problem situations instead of just reading notes"* (P4). Students agree that the case-based approach is more practical as it is able to connect theoretical concepts with real network scenarios, thus making the learning process more meaningful and relevant*: "I gained a more practical understanding because the app connects theoretical concepts with real network scenarios through case-based learning activities"* (P7). Learning through SubNetSmart becomes more meaningful when students are able to understand the use of IP addresses in real computer networks through contextual cases provided in the application, thus bridging the gap between theoretical understanding and practical practice: *"The SubNetSmart app makes networking lessons more meaningful because I can understand how IP addresses work in a real computer network when I solve case-based problems"* (P9). Case-based learning in SubNetSmart encourages active learning in solving network problems independently, as opposed to conventional teaching methods that are more passive and focused on the delivery of information by instructors in the classroom "*Compared to*

conventional learning, the SubNetSmart app has made me more active in solving network problems independently through case-based activities" (P10) and other students add "*I experience more active learning because I am directly involved in solving case-based network calculations rather than passively listening to explanations"* (P13).

While the second sub-theme is Self-Paced Learning. Through this sub-theme, students found that compared to conventional learning methods in the classroom, SubNetSmart allows them to conduct exercises repeatedly at their own pace without having to rely entirely on lecture notes: "*Compared to regular classroom learning, this SubNetSmart app allows me to practice over and over again without relying solely on lecture notes" (P1)* and students relate to case-based learning which is *"Even when a case scenario is used, I can understand the situation of the case and try to apply the knowledge I have learned to solve the problem in a given case"(P1).* SubNetSmart enables self-directed learning where students are free to try a question over and over again until they have mastered the correct calculation method, without any trial limits that hinder their learning process: *"I learned more effectively because the SubNetSmart application allowed for self-learning. I can repeat difficult questions until I fully understand the calculation method*" (P3). Learning through SubNetSmart is flexible and continuous, allowing students to access the app anytime and anywhere without being tied to a set learning schedule: *"The app supports continuous learning because I can practice at any time outside of classroom hours and can review how to calculate independently"* (P12). This creates a more interactive and conducive learning environment, thus reducing the stress that students commonly experience in conventional formal learning environments. *"The learning environment became more interactive and less stressful because I could learn at my own pace"* (P15).

(iii) Interactive and Enjoyable learning Environment; (iv) Active Learning Engagement: Learning through SubNetSmart, which is interactive in nature, also supports active student engagement as the non-judgmental application environment encourages students to try again and again without shame, thus allowing them to learn from their own mistakes and build a stronger understanding gradually: *"I'm also not ashamed to try a few times because my mistakes are a process that makes me better understand what is supposed to be done.*"(P3). Other students also added: *"Compared to traditional lectures, the app encourages active learning"* (P4). Interactive learning becomes more engaging*: "The learning process becomes more interactive and interesting"* (P2) and the app supports active learning *"Compared to traditional lectures, the app encourages active learning"* (P4). Furthermore, students are actively involved in learning *"I am more actively involved during learning because SubNetSmart combines theory with interactive activities*" (P11). In addition, the SubNetSmart application allows students to be independent and review difficult topics many times without stress: *"This SubNetSmart application allows me to study independently and review difficult topics several times without stress*" (P7). Students think that SubNetSmart makes the learning process more enjoyable because they have the opportunity to test their comprehension instantly based on the learning outcomes that have been set, thus providing immediate feedback on their level of mastery*: "The app creates a more enjoyable learning experience as I can test my understanding immediately after learning each topic based on learning outcomes"* (P5).

(v) Creating a Supportive Learning System: After using SubNetSmart, students reported increased motivation in learning networking topics as well as having greater confidence and drive to solve computer network-related problems independently: *"I am more motivated to practice because the app provides a variety of networking exercises with different levels of difficulty"* (P2). In fact, other students said *"This SubNetSmart app increases my motivation to learn networks because learning activities are more interactive than classroom explanations alone"* (P6). In addition, students expressed higher confidence in answering subnetting-related questions independently, as a result of the intensive and repetitive training conducted through the SubNetSmart application: *"I became more confident when solving subnetting questions independently"* (P1). Furthermore, *"I became more confident in answering networking questions because I have practiced a lot of exercises using this SubNetSmart app"* (P14).

Fig. 12 is the ATLAS.ti Model for SubNetSmart "Features Facilitate Meaningful Learning". Based on the findings of interviews with participants, the data showed that students addressed three main themes, namely (i) Enhanced Understanding of Subnetting Concept, (ii) Perceived Usefulness of Learning Features, and (iii) Self-Directed and Independent Learning. The students' feedback further revealed that three sub-themes were formed from the first main theme, namely Enhanced Understanding of Subnetting Concept, as follows:

(i) Assessment activity improved calculation skills; (ii) Real-World Networking Example: The results of the analysis of the interview data found that: *"The assessment activity that provides the answer scheme causes a misunderstanding better where my subnetting calculation error is"* (P5). In fact, binary exercise is the most effective feature of the application in helping to improve students' calculation skills systematically and in stages: *"The binary conversion exercise is the most useful feature to improve my calculation skills"* (P7). The participant think that the real-world examples provided in SubNetSmart also play an important role in improving their understanding of the practical application of subnetting in real-world situations in the workplace: *"The real-world networking example helped me understand the practical use of subnetting in organizations*" (P7).

(iii) Guided video tutorials; (iv) Assessment improved problem-solving skills: Students feel that guidance through video tutorials is the most effective feature in helping them understand the subnetting calculation process and method more accurately and systematically: "*The guided tutorial video feature is very effective because it explains each subnetting process clearly."* (P10). While other students added *"The subnetting calculation video was interactive and helped me in improving the accuracy while the calculation was made"* (P13). The fourth sub-theme revealed that students found that the multi-level exercises provided in SubNetSmart helped improve their problem-solving skills in stages and comprehensively: *"Networking exercises with*

different levels of difficulty improved my problem-solving skills" (P11). Thus, the findings of qualitative data through the four sub-themes formed from the analysis of interviews with students have strengthened and confirmed the findings of the first main theme, namely Enhanced Understanding of Subnetting Concept, thus providing strong and consistent narrative evidence of the effectiveness of SubNetSmart in improving students' conceptual understanding.

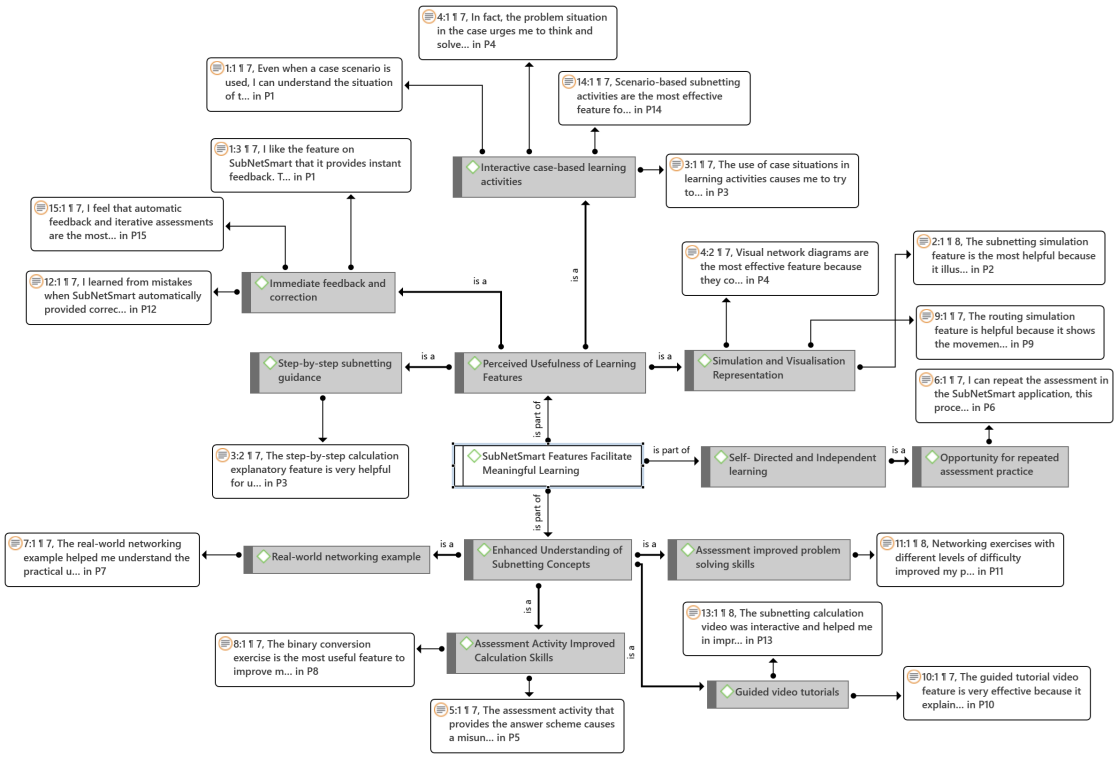


Fig. 12. SubNetSmart features facilitate meaningful learning ATLAS.ti model.

Next, the second main theme identified was the "Perceived Usefulness of Learning Guidance", where students discussed their perceptions of the usefulness of the learning guidance provided by SubNetSmart. The qualitative data obtained through the interviews revealed the formation of four sub-themes as follows:

(i) Step-by-step subnetting guidance; (ii) Simulation and Visualisation Representation: Study participants reported that their learning experience became more structured and easier to understand when SubNetSmart provided step-by-step calculation guidance. *"The step-by-step calculation explanatory feature is very helpful for understanding the complex subnetting process"* (P3). The second sub-theme found that the majority of study participants discussed the effectiveness of visualization and simulation features in SubNetSmart which includes network simulations, infographics, and diagrams as elements that are able to bridge the gap between theoretical understanding and practical application. *"Visual network diagrams are the most effective feature because they connect theory with practical network situations"* (P4). The incorporation of movement simulation was found to significantly enhance students' conceptual comprehension of the subject matter. *"The routing simulation feature is helpful because it shows the movement of data between subnetworks"* (P7) and others participant added *"The subnetting simulation feature is the most helpful because it illustrates how IP addresses are divided into smaller networks"* (P2). In addition, visual network representation has also been found to play a role in bridging the gap between theoretical understanding and practical application "*Visual network diagrams are the most effective feature because they connect theory with practical network situations"* (P4).

(iii) Interactive Case-Based Learning Activities; (iv) Immediate Feedback and Correction: The interview data also revealed the narratives of the study participants related to the third sub-theme. Most participants reported an improved learning experience when SubNetSmart provided case-based scenarios. In this regard, participants noted that the case-based approach allows them to apply the knowledge gained into a more meaningful context. *"Even when a case scenario is used, I can understand the situation of the case and try to apply the knowledge, and I have learned to solve the problem in a given case"* (P1). Participants also reported different learning experiences, where a case-based approach was found to encourage critical thinking among students to address and solve the problems presented: *"The use of case situations in learning activities causes me to try to think about solving the problem in the case. It is quite different from the previous learning"* (P3), In addition, other participants also pointed out that case-based learning encourages them to solve problems that are closely related to the content of the lessons learned. "*In fact, the problem situation in the case urges me to think and solve problems based on the content of the lessons learned"* (P4). Furthermore, participants also noted that the case-based activity feature was found to be more effective in strengthening their understanding compared to learning through lectures alone: "*Scenario-based subnetting activities are the most effective feature for improving my understanding because they are not the same as just listening to lectures*" (P14). In this regard, some participants also

discussed the fourth sub-theme, namely "Immediate Feedback and Correction", which is a feature of SubNetSmart that provides immediate feedback on the calculations performed. This feature also displays the correct calculation for each incorrect response, thus helping participants to identify and correct their mistakes more effectively: *"This feedback was very useful because I was able to identify calculation errors immediately and correct them before moving on to the next question and this feedback was very useful because I was able to identify calculation errors immediately and correct them before moving on to the next question."* (P1). This has been found to help participants identify and understand the mistakes made, thus enabling them to make improvements in the learning process: *"I learned from mistakes when SubNetSmart automatically provided correct answers. This is very useful to me because it explains why my answer is incorrect"* (P12) and other students add *"I feel that automatic feedback and iterative assessments are the most useful features for mastering the concepts of IP addressing and subnetting"* (P15). Overall, the majority of participants responded positively to this feature, as it was found to make a significant contribution in improving the effectiveness of their learning process: *"I like the feature on SubNetSmart that it provides instant feedback"* (P1).

The last major theme in the study was "Self-Directed and Independent Learning", which included participant discussions on the sub-theme "Opportunity for Repeated Assessment Practice". Interview findings revealed that study participants actively discussed their experiences regarding the opportunity to perform repetitive assessment exercises in a SubNetSmart learning environment. *"I can repeat the assessment in the SubNetSmart application, this process is very helpful as it strengthens my understanding of the concept of IP addressing*" (P6). The qualitative data findings revealed the study participants' feedback on the features found in SubNetSmart, which was found to make a significant contribution in improving their understanding of learning content related to IP addressing and subnetting.

V. Discussion

The results of the pre and post-test profiles of the control and treatment groups showed that the post-test profile increased to good competent and excellent competent grades. In fact, the treatment group that experienced learning through SubNetSmart scored more prominently than the control group that used modular instruction. A study by Philippas [66] examines the impact of technology integration on student learning outcomes through a comparative study. Through the analysis of existing literature, empirical data, and case studies, it is shown that the potential benefits of technology integration in the educational environment have an impact on student achievement and engagement [66]. The findings of the grade distribution profiles of both groups showed an equivalent grade distribution in only two categories, namely "incompetent" and "competent". This similarity was confirmed by the Levene Test ($p > 0.05$), which reinforced the validity of the comparison between groups and allowed any post-test differences to be legally associated with the SubNetSmart intervention. Post-test treatment groups show 100% of students achieve at least a competent level. The acquisition of excellent competent (7%, $n = 2$) and good competent (20%, $n = 6$) grades indicates that SubNetSmart not only helps weak students achieve the minimum level but also enables high-performing students to pass the threshold of basic competencies. This upward migration of grades demonstrates the effectiveness of adaptive and application-staged learning designs in supporting differentiated learning outcomes, in line with the principles of mastery learning which assert that continuous feedback and repetitive practice allow students to grow at their own rate of mastery [68, 69]. On the other hand, 57% ($n = 17$) of control group students still remained in incompetent grades after the intervention, indicating that conventional teaching methods are insufficient to address conceptual understanding gaps in complex topics such as IP addressing and subnetting. The consistency of incompetent grades in the majority of control group students is critical in the context of TVET, where the mastery of minimum competencies is an industry requirement that cannot be compromised [16, 70]. Overall, the transition of grade distribution from a pre-test two-category profile to a post-test multi-category profile in the treatment group proves that SubNetSmart helps improve student scores.

This study makes a significant empirical contribution to the field of Educational and instructional technology by proving that learning applications specifically designed based on domains are able to improve students' conceptual understanding and procedural skills in abstract and complex IP addressing and subnetting topics. In contrast to conventional approaches that rely on lectures and static exercises alone, the applications developed in this study integrate interactive learning experiences that support active engagement, immediate feedback, and self-learning in line with the principles of the Cognitive Theory of Multimedia Learning which asserts that an effective learning environment is one that facilitates the process of selecting, organizing, and integrating information actively by students [17, 71]. A technology-based active learning environment significantly enhances students' understanding of learning, teaching techniques, and technology use, as well as fosters positive attitudes toward technology and maintains learning motivation [71, 72]. From an instructional design perspective, this study shows how the principles of student-centered design, scaffolding, structured feedback, and authentic problem-solving can be systematically woven into digital learning environments in line with Merrill's [73] findings that learning is reinforced when students engage in real-world problem-solving, new knowledge is demonstrated, applied, and integrated into existing experiences students. The importance of scaffolding in this digital environment is also empirically supported by Thomann and Deutscher [74] who through systematic analysis and meta-analysis of 68 experimental studies found that scaffolding through prompts in digital learning has a modest but significant positive effect on learning achievement. Next, the study expands on the existing literature on how domain-specific instructional technologies can bridge the gap between theoretical comprehension and mastery of practical skills, coinciding with the finding that adaptive learning technologies that tailor content to students' individual needs as well as provide real-time feedback

positively influence student engagement throughout the learning process [33, 72]. Overall, this study offers a valuable practical framework for researchers and practitioners in designing meaningful learning applications based on the principles of contemporary pedagogy, particularly for technical subjects that demand simultaneous mastery of conceptual and computational competencies. ANCOVA's test results prove that the achievement of the IP Address and subnetting course is better when using the SubNetSmart interactive application with a large size effect influence than the SubNetSmart application. These findings are in line with a study by Consoli *et al.* [75] which found that that technology integration in the classroom has a positive relationship with student achievement. ANCOVA findings showed significant group primary effects on post-test achievement after controlling for pretest scores, $F(1, 57) = 43.811$, $p < 0.001$, partial $\eta^2 = 0.435$. This large effect size [67] showed that the use of SubNetSmart applications accounted for 43.5% of the variance in post-test achievements, proving the pedagogical effectiveness of these applications in the teaching of IP addressing and subnetting courses. The treatment group ($M = 72.30$, SP = 9.97) showed significantly higher achievement than the control group ($M = 58.80$, SP = 5.85), showing that technology-based teaching through carefully designed digital applications is able to improve student achievement in technical and vocational education. These findings are in line with a study by Zhang *et al.* [76], which reported that the use of digital technology significantly improves the learning achievement of vocational students, with students' learning experiences and active engagement acting as important mediating mechanisms. Before the main ANCOVA was carried out, the prerequisite assumptions were reviewed. The Levene test confirmed the similarity of the error variance between the groups, $F(1, 58) = 1.508$, $p = 0.224$, indicating an equivalent score variability between the two groups. However, the homogeneity test of regression slopes revealed a statistically significant pre-test group*interaction, $F(1, 56) = 8.242$, $p = 0.006$, partial $\eta^2 = 0.128$, which suggests this assumption is not fully met. Rather than seeing it as a mere methodological limitation, these significant interactions are actually meaningful findings that are in line with the framework of the Aptitude-Treatment Interaction or ATI [77]. Specifically, differences in regression slopes between groups suggest that SubNetSmart exerts varying effects on post-test achievement depending on the student's existing level of knowledge. Students who obtained lower pre-test scores benefited more from the intervention than their peers who had a stronger knowledge base. This pattern is supported by the findings of Möser *et al.* [78] in a study of digital problem-based learning, in which students with lower pre-existing knowledge achieved about four times higher knowledge gains than high-skilled students, even though both groups eventually achieved equivalent levels of performance. The researchers attribute these different efficacies to increased engagement and more active group interaction among low-skilled students when placed in a structured digital learning environment. A similar mechanism is proposed in this study: the cognitive scaffolding embedded in SubNetSmart includes step-by-step subnetting simulations, immediate corrective feedback, and adaptive problem development providing invaluable learning support to students with a limited knowledge base, in line with the principle of Proximal Developmental Zones proposed by Vygotsky [22].

This interpretation is also supported by Thomann and Deutscher [73], who through systematic review and meta-analysis of 68 experimental studies found that digital scaffolding and cognitive boosters had a significant positive impact on learning achievement (Cohen's d = 0.39), with more significant benefits observed in students who needed higher teaching support. The interaction findings in this study suggest that the scaffolding mechanism in SubNetSmart is most effectively activated for students operating in their Proximal Development Zone, thus reinforcing achievement among those with weaker prior knowledge. It should be recognized that the presence of significant Pre-test Group*interactions is a limitation in conventional interpretations of ANCOVA's main effects, since the assumption of regression slope parallelism is not fully met. Nevertheless, given that the group size is balanced ($n = 30$ per group) and these interactions have strong theoretical clarity, the ANCOVA findings are maintained and interpreted with caution, in line with methodological guidance which suggests that ANCOVA remains relatively robust under such conditions when group sizes are equivalent [79].

From a methodological and statistical perspective, the findings of this study are strong and are not affected by the issue of sample size which is often misinterpreted in educational experimental studies. Although the total number of participants consisted of 30 for the control group and 30 for the treatment group, the sample size of 60 participants was sufficient for a quasi-experimental design involving ANCOVA, particularly when the magnitude of the treatment effect obtained was large. As pointed out by Refs. [60, 80], statistical power is not determined by sample size alone, but is also significantly influenced by effect size, measurement accuracy, and study design accuracy. Thus, studies with smaller sample sizes but producing large treatment effects still have sufficient statistical power to make valid inferences [81]. In this study, the results of the insignificant Levene test ($F = 0.224$, $p > 0.05$) confirmed the homogeneity of variance between the control and treatment groups at an early stage, thus meeting important assumptions of ANCOVA and strengthening the internal validity of the study. The use of ANCOVA was the most appropriate analytical option as the study design involved only one dependent variable; MANCOVA is theoretically only relevant when there are two or more dependent variables that correlate with each other in the same design [80, 82]. Furthermore, a partial value of eta squared ($\eta^2 p = 0.435$) showed that the intervention explained the 43.5% variance of post-test scores after the pre-test score was controlled showing a magnitude of an effect that was categorized as large and had substantial practical significance [75, 83]. From the point of view of external validity, the use of two different vocational colleges for the control and treatment groups also reduces the threat of treatment diffusion, i.e., the risk of interaction between participants and the sharing of treatment information that is common when both groups are placed in the same institution [84]. Therefore, the design of this study simultaneously controlled for external validity

threats through the separation of study sites and controlled for internal validity threats using ANCOVA that standardized the initial differences between participants. When quantitative findings showing these major effects are supported by qualitative data that are rich, consistent, and explain the mechanisms of learning change in depth, the strength of the study's inferences becomes more convincing than relying on statistical analysis or sample size alone [52].

The findings of the student feedback survey after experiencing learning using SubNetSmart showed that all three learning outcomes were achieved when the majority of students agreed that they have more understanding and competent to (i) show the ability to explain the concept of network protocols, (ii) describe the importance of subnetting across various IPv4 network classes, (iii) calculate subnet masks and addresses for IPv4 Classes A, B, and C. These findings are in line with a study by Stallings [44] which found that the quality of technology integration in the classroom has a positive relationship with student achievement and motivation. This is in line with digital education and digital education policies which are an important essence in the agenda of the Kingdom around the world during the COVID-19 pandemic [85]. The survey findings showed that students gave a mean score above 4.00 for all three learning outcomes, indicating a high level of agreement that the use of the SubNetSmart application has helped them achieve the set learning outcomes. Although this measure is based on students' self-perceptions, the strength of the findings lies in their clear alignment with the qualitative evidence obtained. Analysis of the interviews revealed that students not only reported an increased understanding of subnetting concepts but were also able to explain in detail how the features of the application, especially step-by-step guides, network simulations and visualizations, immediate feedback, repetitive assessment exercises, as well as case-based learning activities have supported their learning process concretely. The correlation between high quantitative ratings and specific qualitative descriptions suggests that students' positive perceptions are not superficial or simply reflect satisfaction with the use of technology but rather are supported by meaningful and clearly articulate learning experiences [33, 71]. From a methodological perspective, the convergence between these two data sources is a core feature of the design of the explanatory mixed method approach where quantitative and qualitative data are collected separately before being integrated for comparison and cross-validation purposes. This approach systematically enhances the credibility and depth of interpretation of study findings [86, 87]. Therefore, the high mean score of learning outcomes in this study can be interpreted as a reasonable and convincing indicator of the mastery of knowledge and skills acquired through the SubNetSmart application, particularly when supported by qualitative findings that consistently demonstrate improved conceptual understanding, problem-solving skills, and self-learning in the context of IP addressing and subnetting. This is in line with the findings of recent studies confirming that instant feedback and personalized guidance through digital apps provide students with a deeper understanding of their learning progress and promote metacognitive awareness [87, 88]. Data integration in mixed methods studies, according to [86] aims to combine, connect, or converge findings to build more comprehensive and reliable conclusions than relying on a single data source.

Qualitative findings show that form four vocational college students in the field of Information Technology TVET perceive SubNetSmart as an effective learning tool in assisting in mastering the concepts of IP addressing and subnetting through cognitive scaffolding mechanisms. The thematic analysis identifies two main complementary themes, namely (1) Cognitive Scaffolding Facilitates Conceptual Mastery and (2) Interactive Learning Promotes Meaningful Learning Experiences, which together explain how the pedagogical features of these applications support structured, active, and student-centered learning. The first theme encompasses six main subthemes: improving the accuracy of IP address calculations, step-by-step learning support, increased confidence in network problem-solving, deeper conceptual understanding, visualization and interactive learning, and case-based learning. Collectively, these subthemes illustrate how SubNetSmart functions as a cognitive scaffolding that helps students connect theoretical knowledge with practical applications. Students report that this step-by-step guide in the app breaks down complex subnetting procedures into clear and manageable steps, thus reducing cognitive burden and errors in determining network addresses, subnet masks, and host ranges. These findings support the view that technology-based cognitive scaffolding can improve the accuracy of the execution of technical tasks and strengthen the mastery of vocational skills [16, 69]. Additionally, the instant feedback provided by the app allows students to instantly identify and correct mistakes, which directly contributes to increased self-confidence and self-efficacy in completing network tasks. These findings are in line with the study of Xia *et al.* [69], which showed that technology-based scaffolding can improve students' self-efficacy in the context of technical problem-solving.

The second theme includes five sub-themes, namely case-based interactive learning, self-paced learning, interactive and enjoyable learning environment, active learning engagement, and creating a supportive learning system. Students appreciate the flexibility of self-paced learning which allows them to repeat tutorials and exercises without time constraints, an aspect that is particularly relevant in the context of TVET given the diversity of academic backgrounds and skill levels of students. The study of Plooy *et al.* [31] confirms that access to flexible digital resources supports self-directed learning and increases students' intrinsic motivation. Meanwhile, interactive elements and case-based scenarios encourage active engagement, where students are required to analyze network needs, determine appropriate subnets, and make decisions based on authentic situations that resemble real industrial environments. This approach is in line with the pedagogical principles of TVET which emphasizes practice-based learning and knowledge transfer to the employment context [69]. The combination of these characteristics forms a learning ecosystem that supports student autonomy without relying entirely on lecturers, in line with the findings of Mdodana-Zide [39] related to digital learning systems that support autonomous learning management.

These qualitative findings are also reinforced through the three dimensions identified in the third theme leading to

Fig. 12: SubNetSmart Application Features Facilitates Meaningful Learning, namely (i) enhanced understanding of subnetting concepts, (ii) perceived usefulness of learning features, and (iii) self-directed and independent learning. The first dimension, the most dominant in student feedback, shows that understanding is formed not through one particular feature, but as a result of interactions between various complementary pedagogical elements including staged assessments, visual simulations, instant feedback, and real-world network examples. According to Peña-Acuña *et al.* [16], the combination of visualization, immediate feedback, and procedural support is among the most significant factors in improving the understanding of complex technical concepts in a digital learning environment. The second dimension shows that students see each feature of the application not just as a technological function, but as a learning tool that has clear pedagogical value. This is in line with the Technology Acceptance Model related to the main factors of continuous acceptance and use of a technology. The third dimension shows that SubNetSmart successfully supports the development of self-paced learning through repeated assessment practice opportunities, enabling students to identify weaknesses and improve them independently, which is a key driver of lifelong learning and autonomy of learning in TVET education [15, 68]. Overall, the triangulation between the themes of cognitive scaffolding and meaningful learning reveals a coherent learning mechanism, where the characteristics of SubNetSmart act as a pedagogical medium that simultaneously supports the construction of conceptual knowledge, active engagement and autonomy of learning. These findings reinforce the importance of integrating constructive alignment-based digital applications in TVET education to ensure that students not only master the concept of subnetting theoretically but are also able to apply it effectively in real-world employment situations in line with the competency needs of today's information technology and networking industries.

The triangulation of the findings of this mixed-method study provides coherent and convincing empirical evidence regarding the effectiveness of SubNetSmart. Quantitatively, the results of the insignificant Levene Test ($p > 0.05$) confirmed the equality of variance between the groups at the pre-test stage, proving that the two groups were equivalent before the intervention was conducted. A significant improvement in the treatment group's post-test scores, when analysed through ANCOVA by controlling for pre-test differences, produced statistically significant results with large effect sizes (partial $\eta^2 = 0.435$), suggesting that the SubNetSmart intervention contributed to a 43.5% variance in student achievement. These quantitative findings are consistently reinforced by qualitative data, where students explicitly report increased conceptual understanding, computational accuracy, self-confidence, and active engagement through the pedagogical features of the application. The alignment between these three sources of evidence showed group equality, significant impact of interventions, and meaningful learning experiences. This collectively confirms that SubNetSmart is not just a digital tool, but a learning system based on constructive alignment that is effective in enhancing the technical competence of TVET students in the field of Information Technology.

This study contributes to the development of knowledge in the field of TVET educational technology by proving that the effectiveness of technical learning applications does not depend on content delivery alone, but results from the dynamic interaction between cognitive scaffolding, interactive learning experiences, self-directed learning, adaptive learning, and personalized learning pathways. In contrast to previous studies that examined these constructs separately, the mixed-method findings of this study show that the arrangement of application features based on the principle of Constructive Alignment [14] creates a learning mechanism that links conceptual mastery, active involvement and development of technical competencies simultaneously. Collectively, this study proposes a new conceptual model for computer network learning in TVET, namely Constructive Alignment Features → Cognitive Scaffolding → Interactive Learning Experience → Meaningful Learning → Technical Competency Development, which can be used as a basis for the development of technical learning applications in the future. Meanwhile, the pedagogical contribution of this study focuses on the teaching model of subnetting based on constructive alignment, case-based learning, cognitive scaffolding, simulation, immediate feedback and self-paced learning. One of the contributions to the industry is through case-based learning activities that produce skills that are close to real work situations such as network planning, subnet allocation, troubleshooting and decision making. Furthermore, it is a contribution to the field of TVET by providing a digital teaching model for TVET technical specialties that is in line with the needs of Industry 4.0 and Education 5.0. In terms of methodological contribution, this study shows how the explanatory mixed-method design can be used to confirm not only whether an intervention is effective, but also why and how the intervention results in learning changes.

VI. Conclusion

Overall, the findings of this mixed-method study provide strong empirical evidence that the use of SubNetSmart in IP addressing and subnetting learning has a significant and meaningful impact on the achievement of form four students in the Information Technology TVET programme. ANCOVA's results record a large effect size, which shows that these application-based interventions are not only statistically effective, but also practically significant. These findings are corroborated by consistent qualitative data, revealing that SubNetSmart holistically improves conceptual understanding, self-confidence, computational skill mastery, as well as a more interactive, adaptive and student-centered learning experience through elements of self-directed learning and personalized learning pathways. Among the main strengths of SubNetSmart is its emphasis on self-directed learning which allows students to control their own pace of progress and learning trajectory. Clear learning objectives and carefully coordinated assignments through a case-based scenario approach ensure that students are able to apply theoretical knowledge into meaningful practical contexts. In addition, the integration of interactive assessment elements with various levels of difficulty has been proven to play a role in maintaining students'

motivation and active involvement throughout the learning process, thus supporting the development of technical competencies in a gradual and systematic manner. However, this study did not escape some limitations that need to be taken into account in interpreting the findings. First, the limited sample size of 60 participants from just two vocational colleges is a major constraint, potentially limiting the generalisation power of the study findings to a wider and more diverse TVET context. Smaller sample sizes also increase the risk of Type II errors, i.e. the likelihood of failing to detect the true effects inherent in larger populations. Second, relatively short intervention durations may not be sufficient to assess the effects of long-term learning comprehensively. Third, the use of convenience sampling limits the generalizability of the findings to a more representative population. From the point of view of policy implications, these findings suggest that TVET institutions strengthen the integration of constructive alignment-based digital learning applications as part of formal pedagogical strategies, particularly in complex technical courses such as computer networks, to effectively and systematically support the development of industry competencies. This is also in line with UNESCO's agenda to strengthen the digital transformation of education and the achievement of Sustainable Development Goal 4 (Quality Education) through access to inclusive, quality and technology-based learning. For future studies, several further research directions are proposed. First, future studies should involve a larger sample size and include various TVET institutions across different geographical regions to improve the generalization ability of the findings. Second, a longer intervention period is recommended to allow for a more comprehensive assessment of the effects of long-term learning. Third, the integration of learning analytics in advanced studies has the potential to provide a deeper understanding of the relationship between adaptive learning behaviors, student engagement patterns, and technical achievement in an increasingly complex digital environment. Finally, a comparative study across different digital learning platforms is also recommended to determine the most effective instructional design features in the context of technical and vocational education.

Institutional Review Board Statement

The study obtained the permission from the Technical and Vocational Education Training Division, Ministry of Education Malaysia while the protocol was approved by the Ethics Committee with reference number: KPM.600-2/2/28 (12). This study involved vocational students and was conducted with the full permission of the college director and the respective teachers. Informed verbal consent was obtained from all participating teachers and students, and all data was kept as anonymous to protect participants' confidentiality. Several teachers and students who contributed substantially to the research are also included as co-authors. The research adhered to institutional guidelines for ethical conduct and respected the principles of voluntary participation, confidentiality, and academic integrity.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Nurulwahida Azid was responsible for study conception, research design, quantitative and qualitative data analysis interpretation and academic writing ethics. Muhammad Noor Abdul Aziz and Tee Tze Kiong wrote the discussion, edited the manuscript based on the journal format and rewrote it to reduce similarity index. The development process and features of SubNetSmart writing were drafted by Muhammad Mukhlis Ridzuan. The results of the students' issues were collected and analyzed by Shafiyah Sukri, Jamilah Yusof and Isnormaniza Ithnain. All authors read and approved of the final manuscript.

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