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PAPER

AI-Powered Smart Classrooms for C-PBL: Enhancing Mobile and Virtual Learning Technologies

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ABSTRACT

The AI-powered smart classrooms for C-PBL to enhance mobile and virtual learning technology, or C-PBL mobile and virtual learning are based on the integration of artificial intelligence and virtual reality technologies with problem-based learning and cooperative learning with an attempt to enhance students' analytical thinking and curiosity. Thereby, students are encouraged to do activities in small groups and use analytical thinking skills to distinguish problems in a systematic manner, which is believed to enable them to create their own bodies of knowledge from the problem-solving process in those situations or problems. The results of this research are consistent with the hypotheses, as it is found that the C-PBL mobile and virtual learning system is considered a learning tool that can be practically applied in cooperative problem-based learning processes through virtual smart classrooms in order to promote students' analytical thinking and curiosity in learning. Meanwhile, it is believed that the C-PBL mobile and virtual learning system herein also enables students not only to create their own bodies of knowledge after doing small-group activities in virtual environments but also to receive brand-new knowledge as to their own abilities from experiential learning. However, there are still some research gaps in this study that need to be further addressed in the future. For instance, future studies should explore a wider scope of application by doing surveys with more varied populations and broader educational environments so as to confirm the validity and clarity of study results. Therefore, the findings in this study are considered merely the findings derived from a pilot study and can be used as just a guideline for future development.

KEYWORDS

AI-powered smart classrooms, cooperative problem-based learning, C-PBL mobile and virtual learning, mobile learning, virtual smart classrooms, analytical thinking, curiosity

1 INTRODUCTION

Technological and social changes in the 21st century have resulted in the need for indispensable skills for adaptation and self-development in different aspects,

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which will enable modern students to use and expand their knowledge based on flexibility and the ability to access knowledge sources via the internet. At the same time, appropriate technologies are required in order to urge students to create new bodies of knowledge and organize their own learning. Not only that, students should be encouraged to take part in teaching and learning and have interactions with others, which is considered a style of learning that can respond to Education 4.0 [1]. Once considering the development of the Thai education system by 2027, it is important that students of all ages should be developed to their full potential while possessing morality, ethics, and necessary skills. Besides, they must be ready for lifelong learning and able to adapt themselves to the New Normal ways of life and manage to use technologies in order to support new learning styles that can promote 21st-century learning, focusing on interactive learning, participatory learning, and active learning [2]. In addition, there is also an emphasis on the instruction management that can promote students to develop life skills and practically apply them in their future careers, aiming to equip students with the qualifications that are consistent with the demand of workplaces, communities, labor markets, and even self-employment [3]. For this reason, learning via online platforms has been applied to education systems with an aim to adjust instruction processes and facilitate learning activities in such a way that they would be consistent with more diverse contexts. It is expected that this can provide opportunities for learners to access knowledge, collaborate with others, and create new bodies of knowledge regardless of time and place [4].

Recently, online learning in higher education has grown rapidly, and a number of higher education institutions have begun to offer online courses in order to fulfill students' needs for easy access and high flexibility [5]. Several formats of instruction management have been developed, and all of them focus on students' engagement and practices that can enhance work skills. It is believed that the teaching methods in which teachers set up different atmospheres, conditions, or situations according to specific groups of students [6] can assist students in seeing the problems that may arise. In other words, the problem situations established by teachers will encourage students to think analytically and systematically and then enable them to work practically [7]. Teachers may use a cooperative problem-solving process, in which students search for knowledge in order to find out solutions and have a clear understanding of the problems; meanwhile, teachers are acting as facilitators with minimal participation in that process [8]. It is said that this is the instruction method that allows students to make decisions on what they really want.

1.1 The significant effects of technologies on cooperative problem-based learning in digital society

Nowadays, classroom activities are usually organized with the aid of virtual classroom technologies combined with artificial intelligence, which is better than traditional classrooms [9]. This is because this method is said to provide students with more learning opportunities and more engagement in formal educational experiences. A variety of educational technology tools have been used to record lectures, analyze performance, and monitor students continuously in real time in order to make sure that all students have access to educational resources and receive equal support [10]. The virtual smart classroom will be designed with the instruction management that covers all subjects, and the main objective thereof is to stimulate students to seek knowledge and, meanwhile, create their own bodies of knowledge. In addition, the classroom of this kind can also encourage students to practically do analytical thinking, synthesis thinking, and creative thinking; solve problems; and process the data and knowledge by themselves. Furthermore, the virtual smart classroom also helps promote learning skills, communication skills, and information and communication technology skills, all of which can be applied in students' daily lives [11].

Additionally, the integration of different technologies in the instruction management can also enhance the communication skills and teamwork skills of students [12]. This is consistent with cooperative learning, which refers to the collaboration in small groups of students who are working together in order to improve learning skills of their own and of their teammates and to achieve the results that benefit both themselves and the team members [13]. The cooperative learning herein refers to the learning management in which students with different abilities work together in small groups, exchange their learning or knowledge derived from the assigned problems [14], [15], summarize their knowledge into learning contents, and then achieve their mutual goals [16]. In the meantime, teachers are responsible for giving advice, assistance, and suggestions on additional information sources or applying any strategies that can help students gain knowledge from the said activities. Also, teachers can choose any learning management formats that are appropriate to the learning contents [15]. Thus, it can be said that cooperative learning can stimulate students' intrinsic motivation, improve attitudes towards learning, enhance learning efficiency, and enable them to achieve their learning goals. Several earlier studies have also indicated that cooperative learning can improve learning efficiency and also add more fun to the learning [17].

According to the aforementioned details, it is expected that the integration of education technology with problem-based learning and cooperative learning will help promote students' analytical thinking, and this enables them to consider, review, and distinguish the importance, relationships, and principles in order to receive the sub-issues of facts in various aspects [18], [19]. Moreover, the learning of this style is believed to help students search and link relationships of different bodies of knowledge together, search for different backgrounds of things in their work [20], and then analyze them so as to find out the real causes of what has happened in a systematic manner. Nonetheless, this must be coupled with students' curiosity since it is considered an indispensable skill highly needed in the future. Curiosity will not only provoke students to explore, question, and seek knowledge, but also promote their creativity, critical thinking, and problem-solving skills during the learning processes [21]. Curiosity is also like a mental state that stimulates students to search for information, and it will fade out once the said information is acquired [22]. Classified as CQ (curiosity quotient), curiosity is said to open up opportunities to learn from others and from the outside world, to talk and build relationships with others, and to bring about new and exciting experiences [23], [24]. Once curious about different things, students will be able to learn throughout their lives.

1.2 Contribution of mobile learning technology to students' engagement in virtual learning

Thanks to the constant development of information technology, mobile learning technology has been widely used in higher education, and this eventually results in the so-called personalized learning. To illustrate, personalized learning is a learning format intended to provide specific learning content and methods according to the needs, interest and learning progress of each student. Thus, personalized learning has become an important trend in modern education [25]. In addition, the traditional graphical user interfaces (GUI) have been replaced by the emerging touch screen devices, such as tablets, offering a new way for children, even the very young ones, to interact with digital technologies with no need of such external input devices as a mouse or a keyboard. It is believed that the use of natural ways to interact with touch screen devices allows users to express themselves naturally, which can further promote communication, collaboration, and students' engagement [26]. So, it can be said that all of the aforementioned technologies have been applied to facilitate interactive teaching and learning in place of the traditional classroom learning.

Recently, individualized learning has become such a significant research trend in the field of education that mobile devices have also become indispensable learning tools. This is because these gadgets can effectively fulfill students' needs for individualized learning, enhance their engagement, promote collaboration, enable them to create bodies of knowledge, and allow access anytime and anywhere with mobile interactivity [27]. The main feature or benefit of mobile learning is that it is not limited to a specific place; for instance, students are able to learn anytime and anywhere by means of mobile interactivity. This concept provides students with new freedom for learning and, meanwhile, increases their engagement and accessibility to the learning sources. In addition, the mobile device adaptability that can make it more flexible to satisfy specific needs is another key feature of this mobile learning. The concepts of mobile learning can be divided into three main categories: (1) mobility of learning, which is the ability to use digital devices to deliver learning materials to users via wireless connectivity; (2) mobility of the learner, which refers to the ability to learn and communicate with other learners anywhere and anytime via specific delivery channels; and (3) mobility of technology, which means the ability to deliver learning materials, communicate, and learn via mobile technologies [28].

Additionally, mobile technologies also have a vital role in the social adjustment of adolescents. Although these technologies may cause social isolation and anxiety in some circumstances, they are still considered valuable tools for building social networks, accessing support systems, and improving digital literacy skills, all of which are highly essential for living in today's modern world [29]. The results of studies indicate that the use of mobile technologies has increased significantly since 2018, with a shift from general eLearning applications to specialized AI applications, particularly in mobile learning (M-learning) environments. It is said that these applications make education more adaptable, customizable, and flexible with the aid of AI-powered M-learning platforms [30]. Also, push notifications have been widely employed in AI-powered chatbots. These are the samples of applying AI in education, leading to individualized learning experiences that help improve the efficiency of administration along with more creative teaching strategies.

In mobile learning environments, students' learning behaviors are not limited to the classroom learning because they are able to interact with almost everything through their mobile devices and platforms. These interactions include browsing the learning resources, participating in online discussions, submitting assignments, receiving feedback on quizzes, and many more [25], all of which can be conducted via mobile interactions under virtual learning. This can stimulate learners to respond and interact with virtual environments and have more engagement in learning. Due to the unique characteristics, interactive devices have been widely applied together with various techniques in order to respond to the needs of learning and daily life.

The New Normal education has emphasized the significance of digital environments so as to move towards Thailand 4.0. Digital technologies have forced people in society to adapt themselves to digital environments, which clearly reflects today's learning methods. Once taking into account educational perspectives, digital technologies have significantly changed learning behaviors since they can be used as tools to expand educational opportunities and promote lifelong learning for all ages and all professions regardless of time and place [31]. Virtual learning environments have been introduced and applied in instruction management, especially in terms of learning design and digital platform learning, and this enables learners to carry out collaborative activities anywhere and anytime, which is quite suitable for learning in such a digital age like this [32]. Besides, virtual learning environments can also promote enthusiasm for learning as learners are able to access and take part in virtual spaces, which are fabricated with the combination of varied technologies of the virtual world and the physical world.

The overviews of the related theoretical concepts and literature insist that it is highly significant to apply mobile learning technology in education in various contexts. It can be clearly seen that mobile learning technology allows learners to have more engagement in interactive learning in real contexts by means of various learning techniques through communication channels and the online world. It is believed that this can create limitless experiences that will further promote learning through digital technologies in the new normal world.

2 RELATIONSHIPS BETWEEN THE RELATED RELEVANT THEORIES

The analysis in this study was conducted on the basis of the relevant conceptual frameworks, the theories, and the research in order to develop the C-PBL mobile and virtual learning. Thereby, the relationships of this development are as follows:

2.1 Relationships between the problem-based learning theories and the development of the C-PBL mobile and virtual learning

The problem-based learning is a kind of learning-management in which teachers will set up situations or problems for students to think analytically and solve the said problems in a sequential manner. Students are expected to create bodies of knowledge by their own based on the problem-solving processes in different situations or problems while teachers are responsible for facilitating and supporting students only [8]. The problem-based learning consists of six steps, i.e., 1) Define problems: Teachers establish different situations and arouse students to be interested and realize the problems therein. Thereby, the said problems can be set up as to students' interest so that they are eager to know and find out the solutions. 2) Understand problems: Students try to understand the problems they are learning about, and they must be able to explain any things related to the said problems.

3) Study self-directed contents: Students determine what they have to study and carry out their own research based on various methods. 4) Synthesize knowledge: Students exchange and learn the knowledge derived from research with others, analyze and discuss the study results, and then synthesize the knowledge for their own groups. 5) Summarize results: Each group of students summarizes the research results and evaluates the suitability of the information they have studied, which can be done by examining the ideas within their group. 6) Present and evaluate results: Students organize the acquired information into bodies of knowledge and present them in a systematic manner.

In this study, it can be clearly seen that the problem-based learning processes have a relation with the development of the C-PBL mobile and virtual learning. This is because the problem-based learning makes the learning process developed herein have an explicit structure with clear elements, and it can support the learning formats that are appropriate to the current situations. The roles of teachers are limited to designing activities, creating classroom atmospheres, giving advice and guidance, and encouraging students to think analytically. Meanwhile, students are required to have the characteristics of curiosity and enthusiasm in seeking information, and they must have full engagement during the learning process in order that they can enhance their analytical thinking skills and curiosity.

2.2 Relationships between the cooperative learning theories and the development of the C-PBL mobile and virtual learning

Cooperative learning is a style of instruction management in which students who possess different abilities are allowed to work together in small groups. The learning of this style emphasizes the teamwork process and gives students opportunities to work together in order to achieve the outcomes of the groups [16]. Teachers are responsible for giving advice and assistance and guiding additional resources. Referring to the benefits of cooperative learning, it is believed that this learning style helps students achieve better learning results, improve social skills, and have more confidence when presenting or discussing in their groups [33], [34], all of which will make them well-prepared for the future challenges.

In this research, the authors studied the processes of cooperative learning that are believed to enhance learning efficiency, arouse motivation, improve attitudes towards learning, and help students achieve their goals while having more fun in learning. This is all to synthesize the elements and guidelines for the development of C-PBL mobile and virtual learning, which is composed of five steps [16], i.e., 1) join the group, in which students are divided into small groups, and teachers explain the teaching methods, students' roles, and information sources for use in learning; 2) propose lesson issues, in which students are allowed to do instruction activities and taught about the contents defined in learning plans; 3) study in teams, in which teachers assign tasks to students based on the contents of learning plans and define the scopes of work and the roles and responsibilities of each person in the group; 4) test, in which students are allowed to test their knowledge derived from learning activities during each learning process; and 5) evaluate group success, in which teachers and students jointly summarize and evaluate the bodies of knowledge to see whether the learning goals are achieved or not.

2.3 Relationships between the mobile learning theories and the development of the C-PBL mobile and virtual learning

At present, mobile technologies are considered an effective way to develop students' skills, e.g., positive thinking, collaboration, communication, etc. Besides, mobile technologies are also deemed as important innovations that have contributed to the development of several e-learning research areas. Due to the requirements of the 21st century, it is necessary to develop certain skills in order to correspond to the increasing demands in higher education, and this has led to a shift from traditional teaching methods to mobile learning [28]. Furthermore, mobile technologies have also become an important part of modern life, especially for adolescents, as these technologies have revolutionized the ways they communicate, learn, and interact with the world [35]. Smartphones, tablets, and other mobile devices provide unprecedented access to information sources and social connectivity because the real-time interactivity and engagement features in these devices enable users to create customized social experiences and have more engagement [36]. In the meantime, these technologies also serve as valuable tools for building social networks, accessing support systems, and developing digital literacy skills, all of which are quite essential for living in the modern world [29].

This research is intended to study the learning approaches and the significance of interactive mobile learning technology and then synthesize them to find out elements and guidelines that can be used to further design the instruction processes and the facilitation of instruction activities through virtual smart classrooms. The objectives thereof are to increase engagement and access to real-time usage with real situations and provide learning experiences via smartphones and desktop platforms developed for use in this study.

2.4 Relationships between the AI-powered theories and the development of the C-PBL mobile and virtual learning

The COVID-19 pandemic has geared up the application of AI technologies in learning. Thanks to AI-powered platforms, educators are now able to deliver content in virtual environments more efficiently, and at the same time, they can track students' engagement and performance [30], which can help them improve resilience and adaptability in the event of unexpected challenges. The transition mentioned above places an emphasis on the integration of AI into educational frameworks [37]. The use of AI in higher education is becoming more and more prevalent, and a number of institutions have been using these tools to enhance the services of academic guidance, including support for their students, and to improve learning experiences and learning outcomes. For example, students can ask for help at any time from an AI chatbot that can not only answer questions about academic resources but also provide useful suggestions for their further study [38]. AI technologies are believed to increase their accessibility with more engaging learning environments, which is particularly beneficial as these can promote adaptive learning and inclusive educational environments [39]. Additionally, AI-driven collaboration can increase learners' engagement as it promotes collaboration through real-time interactions, allowing learners to work hand in hand more smoothly with more interaction.

This study is aimed at studying the characteristics of AI-powered mobile learning and AI-driven learning environments and then synthesizing them to find out the guidelines for instruction management and facilitation of instruction activities that can promote real-time interactions in virtual environments.

2.5 Relationships between the virtual smart classroom theories and the development of the C-PBL mobile and virtual learning

The virtual smart classroom relies on the application of technologies related to artificial intelligence and virtual reality with an intention to follow up on the progress of students in real time, especially when letting them do learning activities. For instance, it will be more convenient to analyze the results of knowledge tests of both individual students and their groups if they are allowed to do the tests in the form of online games. Furthermore, the virtual smart classroom also makes use of artificial intelligence in order to enable teachers and students to interact with one another. The education management by means of the virtual smart classroom [9], [11] requires the following six specifications: 1) flexible cloud-based learning environments, 2) comprehensive technology tools for work and communication, 3) learning systems with enhanced interaction and engagement, 4) automated education management systems, 5) teaching methods focusing on the creation of innovations, and 6) support for learners of all levels in terms of learning. Nevertheless, there are still some limitations in the instruction management through the virtual smart classroom. For example, the problems related to access to technologies may arise due to insufficient internet connection; the systems may crash, causing immediate suspension of learning activities; or students may get stressed from the use of such technologies because they are not familiar with the virtual smart classroom environments [40], [41].

In this study, the authors studied the essential specifications of the virtual smart classroom, which can provide opportunities for students to learn and receive learning experiences via virtual reality and artificial intelligence technologies, and then synthesized and applied them as guidelines to design the instruction processes and facilitate the learning activities in the virtual smart classroom with an attempt to promote students' analytical thinking and curiosity through the C-PBL mobile and virtual learning developed in this study.

2.6 Relationships between the theories of analytical thinking and the development of the C-PBL mobile and virtual learning

Analytical thinking is the process of thinking and considering the things around us. Thereby, the elements of the said things are classified and distinguished logically in order to find their importance, relationships, and connections, and then apply them in the new situations or make predictions so as to find out the facts of specific accounts [20]. Analytical thinking can be divided into three categories, i.e., analysis of elements, analysis of relationships, and analysis of organizational principles. Analytical thinking can be measured and evaluated on the basis of the learning behaviors of students. This can be done by considering the importance of information or content about different things, leading to the analysis of relationships resulting from the selection of importance, followed by the analysis of organizational principles in order to discover the connection of information [19], [42].

In this study, the authors studied the relationships of elements in analytical thinking that are related to the aforementioned relevant theories and then used them as the output of the C-PBL mobile and virtual learning.

2.7 Relationships between the theories of curiosity and the development of the C-PBL mobile and virtual learning

Curiosity is regarded as a strong desire to have knowledge, study lots of information, or seek new challenges and experiences with an intention to extend one's knowledge, which can be done by learning from others and from the outside world. The indicators of curiosity in learning can be categorized into four aspects, i.e., 1) engagement and interest, 2) behaviors related to research, 3) degree of efforts to search, and 4) emotional responses. Once applied in the instruction management, curiosity can help promote better learning and develop thinking skills in such a way that students can improve their problem-solving abilities, increase their engagement in the classroom [22], [43], and have pleasant interactions with others during the activities. In this research, the authors studied the output of curiosity indicators after learning with the C-PBL learning via virtual smart classroom in order to see how much it matched with the evaluation criteria in the four aspects of curiosity indicators, which had been synthesized by the researchers. Then the said output was used as feedback information in order to improve the efficiency of the C-PBL mobile and virtual learning in the future.

3 RESEARCH OBJECTIVES AND HYPOTHESES

This research is mainly related to the study of perspectives towards the development of C-PBL mobile and virtual learning. Whereby, the research participants were willing to do the questionnaire in the evaluation form, and they were all protected with the policies of confidentiality and anonymity. This is to examine to what extent the C-PBL virtual learning can fulfill the users' needs and whether it is suitable for being put to practical use. The objectives of this study are as follows:

OB1: To synthesize the C-PBL mobile and virtual learning process.
OB2: To design the C-PBL mobile and virtual learning model.
OB3: To develop the C-PBL mobile and virtual learning system.
OB4: To evaluate the results after using the C-PBL mobile and virtual learning system.

In this study, the authors employed the pre-experimental research method with a single pre- and post-test group [44], and the research hypotheses are as below:

H_1: The suitability of the C-PBL mobile and virtual learning model is at a high level.
H_2: The quality of the C-PBL mobile and virtual learning system is at a high level.
H_3: The learning achievement of the students after learning with the C-PBL mobile and virtual learning system is higher with a statistical significance level of 0.01.
H_4: The outcomes of satisfaction of the students after learning with the C-PBL mobile and virtual learning system are at a high level.

4 RESEARCH METHODOLOGY

The development concepts of C-PBL mobile and virtual learning are based on the systems approach [45], which consists of four main elements, i.e., input factor, learning process, output, and feedback. These four main elements have been applied in the design and development of this instruction system.

4.1 Participants

The participants in this research include: 1) nine experts specialized in the instruction system design from different vocational institutions and higher education institutions, all of whom were derived by means of purposive sampling, and 2) 30 vocational certificate students (dual vocational education) at Nakornluang Polytechnic College, who are studying in Year 1 and Year 2 in Semester 2 of Academic Year 2024. Derived by means of cluster sampling. The participants gave their consent to take part in this study, and they were well protected under the policies of confidentiality and anonymity.

This study observes the strict ethical guidelines in accordance with international standard research principles, including the principles of the Declaration of Helsinki, The Belmont Report, CIOMS Guidelines, and the International Conference on Harmonization in Good Clinical Practice (ICH-GCP). In addition, this study is exempt from review by the University Ethics Committee because it involves minimal risk to participants. The study just tested common behaviors in a short period of time, and the data collected herein could not be used to identify any volunteers. The details in the interview and assessment forms are presented in the Thai language with the details about (1) the purposes and procedures of the study, (2) the benefits and risks that may occur, (3) confidentiality measures, (4) voluntary participation, and (5) the rights of withdrawal from study participation at any time without consequences. The researchers also strictly follow the policies of confidentiality and protection of the participants' information.

4.2 Research instruments and data collection

The data instruments used in this research include (1) the C-PBL mobile and virtual learning model, (2) the C-PBL mobile and virtual learning system, (3) the evaluation form on the suitability of the C-PBL mobile and virtual learning model, (4) the evaluation form on the quality of the C-PBL mobile and virtual learning system, (5) the measurement form on the learning achievement before and after learning with this classroom, containing 20 questions (multiple-choice), and (6) the evaluation form on the satisfaction of the C-PBL mobile and virtual learning system. The statistics used in data analysis are mean, standard deviation, and t-test dependent.

The authors employed the evaluation form, which had been proved for validity and for index of item objective congruence (IOC) by experts, to collect data from the research participants. All the participants gave their consent to join this study after learning about the detailed information of this research, and they were assured that the information they had given would not be disclosed and could not be used to identify their identities. This is to find out to what extent the C-PBL mobile and virtual learning can satisfy the users' needs and whether it is suitable for being put in practical use.

4.3 Method

The design of the C-PBL mobile and virtual learning is based mainly on the concepts of the systems approach, which are widely applied in the design and development of instruction systems [46]. The authors divided the research methodology into four stages as below:

Stage 1: Synthesize the C-PBL mobile and virtual learning process. In this stage, the authors studied the relevant documents and research in order to obtain the main elements needed in the design of the C-PBL mobile and virtual learning process to enhance analytical thinking and curiosity.

Stage 2: Design the C-PBL mobile and virtual learning model. The authors used the results gained from the synthesis in stage 1 to design the C-PBL mobile and virtual learning model with an intention to enhance analytical thinking and curiosity. The design herein is based primarily on the principles of instruction system design (ADDIE model) [37], and the learning model developed in this study would be assessed in terms of its suitability by the experts.

Stage 3: Develop the C-PBL mobile and virtual learning system. In this part, the authors had developed the said learning system on the basis of the principles of the ADDIE model and then requested the nine experts to evaluate its quality.

Stage 4: Study the results after using the C-PBL mobile and virtual learning system. This stage is related to the study of results derived from the assessment of the quality of the C-PBL mobile and virtual learning system, which was conducted by the experts. In addition, the C-PBL mobile and virtual learning system will be tested for practical use with a sample group of vocational certificate students (dual vocational education) at Nakornluang Polytechnic College, who are studying in Year 1 and Year 2 in Semester 2 of Academic Year 2024. Whereby, the criteria for evaluation and the interpretation of results [47] are as below:

- 4.50–5.00 points means the suitability is at a very high level
- 3.50–4.49 points means the suitability is at a high level
- 2.50–3.49 points means the suitability is at a moderate level
- 1.50–2.49 points means the suitability is at a low level
- 0.00–1.49 points means the suitability is at a very low level

5 RESULTS AND DISCUSSION

The results of the design and development of the C-PBL mobile and virtual learning to enhance analytical thinking and curiosity can be summarized as below:

5.1 Results of the synthesis of the C-PBL mobile and virtual learning system

The authors studied the related documents and the research so as to obtain the elements needed in the design of the C-PBL mobile and virtual learning model to enhance analytical thinking and curiosity. The working process in this case is illustrated as below.

Table 1. Synthesis of problem-based learning process

PBL Process	[7]	[8]	[12]	[48]	[49]	[50]	This Work
Define problems	✓	✓	✓	✓	✓		✓
Analyze problems	✓		✓			✓	
Understand problems	✓	✓	✓				✓
Study self-directed contents	✓	✓	✓			✓	✓
Create learning points			✓			✓	
Learning management					✓		
Synthesize knowledge	✓	✓				✓	✓
Summarize results	✓	✓				✓	✓
Design a solution				✓			
Develop and present inventions				✓	✓		
Present and evaluate results	✓	✓	✓	✓		✓	✓
Analyze and evaluate problem-solving process					✓		
Provide individual or group investigative advice				✓	✓		

Table 1 illustrates the synthesis of the PBL process. After doing synthesis on the relevant documents and researches [7], [8], [12], [48]–[50], the authors acquired the guidelines to establish the PBL process in this study, which includes six steps, i.e., define problems, understand problems, study self-directed contents, synthesize knowledge, summarize results, and present and evaluate results.

Table 2. Synthesis of cooperative learning process

Cooperative Learning Process	[16]	[34]	[51]	[52]	This Work
Organize the learning environment		✓	✓		
Define the goals		✓			
Join the group	✓	✓		✓	✓
Preparation				✓	
Set the small groups			✓		
Propose lesson issues	✓	✓			✓
Group by ability			✓		
Study in teams	✓			✓	✓
Doing activities		✓			
Test	✓				✓
Check and test		✓			
Evaluate group success	✓	✓			✓
Summarize and evaluate the group work				✓	
Summarize the main points			✓		
Create a problem-solving sequence			✓		
Check the validate			✓		

Table 2 represents the synthesis of the cooperative learning process. The authors had synthesized the related documents and researches [16], [34], [51], [52] and received the guidelines for the learning process of this kind, which can be divided into five steps, i.e., join the group, propose lesson issues, study in teams, test, and evaluate group success.

Table 3. Synthesis of analytical thinking

Elements	[20]	[42]	[53]	[54]	This Work
Analysis of elements	✓	✓	✓		✓
Analysis of relationships	✓	✓	✓		✓
Analysis of organizational principles	✓	✓	✓		✓
Define goals/problems				✓	
Define the assumptions				✓	
Summary of information				✓	
Evaluation				✓	

Table 3 shows the synthesis of the elements in analytical thinking. After the synthesis of the documents and researches concerning this issue [20], [42], [53], [54], the authors found out the three elements in analytical thinking, including analysis of elements, analysis of relationships, and analysis of organizational principles.

Table 4. Synthesis of indicators of curiosity in learning

Indicators	[21]	[22]	[24]	[43]	[55]	This Work
Engagement and interest	✓		✓		✓	✓
Intrinsic motivation	✓	✓			✓	
Behaviors related to research	✓	✓	✓			✓
Asking questions		✓			✓	
Degree of efforts to search			✓	✓		✓
Emotional responses	✓		✓		✓	✓
Inquire for information/problem				✓		
Explore the details	✓	✓		✓		
Eagerness to learn				✓	✓	
Search data		✓		✓		
Knowledge linkage		✓				

Table 4 explains the synthesis of indicators of curiosity in learning. The authors had studied the relevant documents and researches [21], [22], [24], [43], [55] and gained the guidelines for use in this study. The indicators of curiosity in learning obtained from the synthesis above can be categorized into four aspects, i.e., 1) engagement and interest, 2) behaviors related to research, 3) degree of efforts to search, and 4) emotional responses.

5.2 Results of the design of the C-PBL mobile and virtual learning model

The C-PBL mobile and virtual learning model is a research tool designated for problem-based instruction management combined with cooperative learning. This instruction format focuses on the integration of education technologies with learning management so as to promote students' analytical thinking and curiosity by means of cooperative learning, which can help them achieve the group outcomes. Besides, this style of learning is said to enable students to think analytically and examine problems in a systematic manner. The C-PBL mobile and virtual learning model is illustrated in Figure 1.

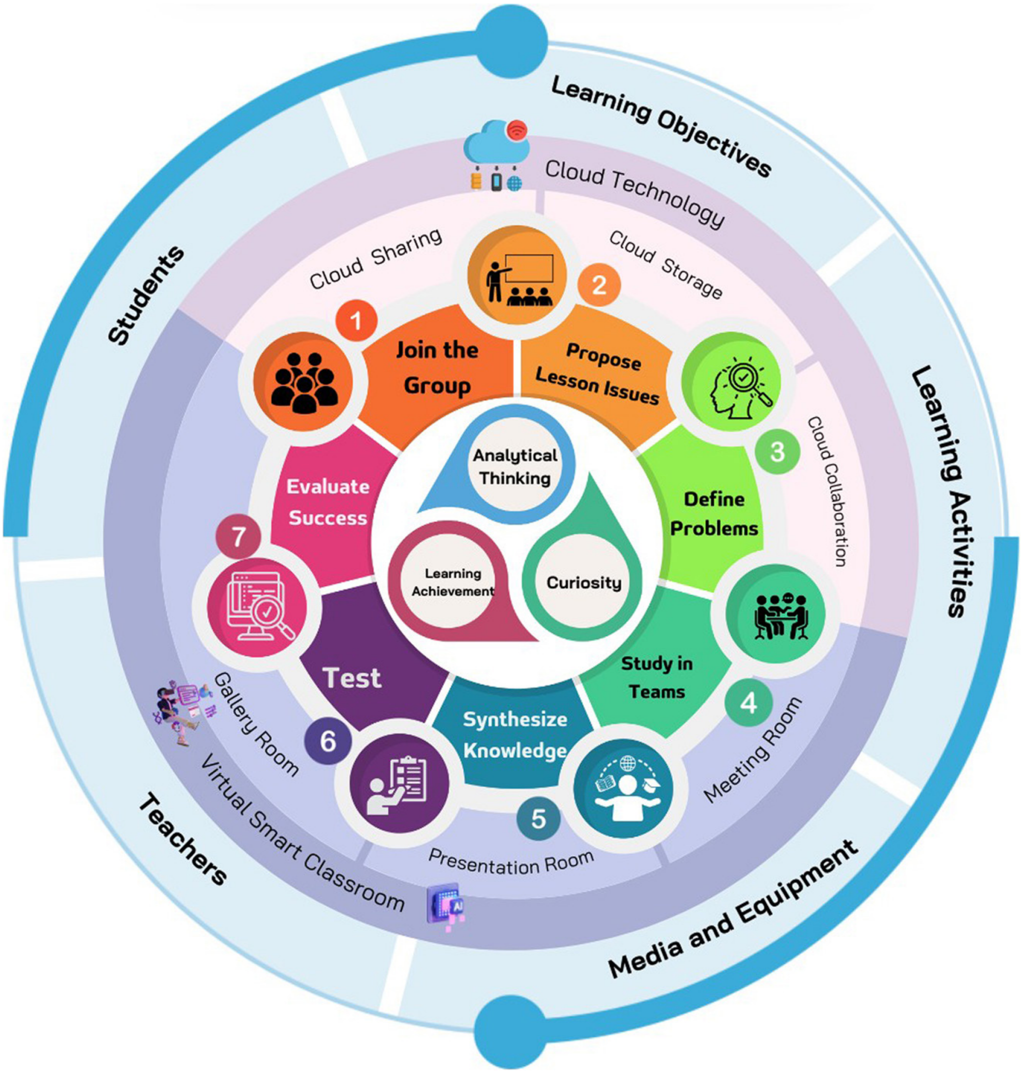


Fig. 1. The C-PBL mobile and virtual learning model

Figure 1 illustrates the C-PBL mobile and virtual learning model, which is composed of the following elements:

1. **Input factor:** This element refers to the factors needed for the design and development of the C-PBL mobile and virtual learning model, including learning objectives, students, teachers, learning activities, and media and equipment.
2. **C-PBL mobile and virtual learning process:** This element is the learning process that was initiated by integrating the concepts of PBL with those of the

cooperative learning. In addition, the authors also employed cloud technology and the virtual smart classroom to enhance the efficiency of this cooperative PBL process with an expectation that it can help students develop analytical thinking and increase curiosity in learning, both of which are regarded as the main learning characteristics necessary for education 4.0. The cooperative PBL process via virtual smart classroom also consists of the three main components as below:

i) **The cooperative PBL process,** which consists of seven steps, i.e., join the group, propose lesson issues, define problems, study in teams, synthesize knowledge, test, and evaluate success.
ii) **Virtual smart classroom,** which is a tool used to promote learning and doing activities. The virtual smart classroom is fabricated based on the concepts of artificial intelligence technology combined with virtual reality technology. The authors employed the virtual smart classroom in step 4 to step 7 in order to monitor the students' progress in real time. This technology is also used to assist in doing the tests in the format of online games, which can help analyze the results of knowledge tests of both students and their groups. The virtual smart classroom consists of two elements, including (1) artificial intelligence technology and (2) the metaverse.
iii) **Cloud technology,** which is used to assist in doing the activities in the cooperative PBL process. This technology is applied particularly in step 1 to step 3 in order to assure that the management of instruction activities can proceed as planned.

3. Output, which is the results after learning with the cooperative problem-based virtual learning process. The output herein includes (a) learning achievement, (b) analytical thinking, which is divided into three categories, i.e., i) analysis of elements, ii) analysis of relationships, and iii) analysis of organizational principles, and (c) curiosity, which refers to the strong desire to learn and study new information or seek new challenges and experiences from others and from the outside world in order to broaden the scope of knowledge. The indicators of curiosity in learning can be categorized into four aspects, i.e., 1) engagement and interest, 2) behaviors related to research, 3) degree of efforts to search, and 4) emotional responses.
4. Feedback, which refers to the use of the results obtained from evaluation on the output (learning achievement, analytical thinking, and curiosity) to improve the cooperative problem-based learning process.

The results of the evaluation on the suitability of the C-PBL mobile and virtual learning model to enhance analytical thinking and curiosity can be summarized as seen in Table 5.

Table 5. The suitability of the C-PBL mobile and virtual learning model (overall)

Items for Evaluation	Mean	SD	Interpretation
1. Suitability of principles and concepts used to design the C-PBL mobile and virtual learning model	4.89	0.33	Very high
2. Suitability of the elements in this model			
2.1 Input factor	4.89	0.33	Very high
2.2 Cooperative problem-based virtual learning process	4.67	0.50	Very high
2.3 Output	4.89	0.33	Very high
2.4 Feedback	4.89	0.33	Very high
3. Suitability of the sequencing of coherent relationships of the elements	4.89	0.33	Very high

(Continued)

Table 5. The suitability of the C-PBL mobile and virtual learning model (overall) *(Continued)*

Items for Evaluation	Mean	SD	Interpretation
4. Suitability and understandability of the order of the elements	4.89	0.33	Very high
5. Completeness and comprehensiveness of the overall elements	5.00	0.00	Very high
Average scores	4.88	0.31	Very high

Referring to the results in Table 5, it is evident that the overall suitability of the C-PBL mobile and virtual learning model (overall elements) is at a very high level (mean = 4.88, SD = 0.31). It can be concluded that the C-PBL mobile and virtual learning model contains all necessary elements, and it can be applied to further develop other C-PBL mobile and virtual learning systems that can be put to practical use in the future.

Table 6. The suitability of the C-PBL mobile and virtual learning model

Items for Evaluation		Mean	SD	Interpretation
Input factor				
1. Learning objectives		4.89	0.33	Very high
2. Students		4.56	1.01	Very high
3. Teachers		4.89	0.33	Very high
4. Learning activities		4.89	0.33	Very high
5. Media and equipment		4.89	0.33	Very high
C-PBL mobile and virtual learning process				
Cooperative problem-based learning process	**1.** Join the group	4.78	0.44	Very high
	2. Propose lesson issues	4.89	0.33	Very high
	3. Define problems	4.67	0.50	Very high
	4. Study in teams	4.89	0.33	Very high
	5. Synthesize knowledge	4.78	0.44	Very high
	6. Test	5.00	0.00	Very high
	7. Evaluate success	4.89	0.33	Very high
Virtual smart classroom	**1.** Artificial intelligence technology	5.00	0.00	Very high
	2. Metaverse	4.78	0.44	Very high
Cloud technology		5.00	0.00	Very high
Output				
1. Learning achievement		4.89	0.33	Very high
2. Analytical thinking		4.67	0.50	Very high
3. Curiosity		4.78	0.44	Very high
Feedback				
1. Evaluation on the learning achievement		5.00	0.00	Very high
2. Evaluation on the analytical thinking		4.67	0.50	Very high
3. Evaluation on the curiosity		5.00	0.00	Very high
Average scores		4.85	0.33	Very high

Referring to Table 6, it is found that the overall suitability of the C-PBL mobile and virtual learning model (individual elements) is at a very high level (mean = 4.85, SD = 0.33). This insists that the C-PBL mobile and virtual learning model is composed of all essential elements, and it can be employed as a guideline to design other learning tools that can be applied in practical use to enhance analytical thinking and curiosity in learning. Both analytical thinking and curiosity are regarded as the essential characteristics for learners in the digital age because these characteristics enable learners to perform self-learning through varied technologies quite well. The results are also in line with the research of Suvandy et al. [56], who applied the systems approach as a guideline to design and develop the MICRO-META model, which is a research tool designated for learner-centered instruction management, in which small units of learning activities are carried out by means of micro-steps under digital learning environments.

5.3 Results of the development of the C-PBL mobile and virtual learning system

The C-PBL mobile and virtual learning system is an online learning tool developed with the combination of virtual technology and artificial intelligence technology. The virtual smart classroom in this study can promote group learning through the virtual world, in which the students can also create their own avatars and perform active learning therein. In addition, within this virtual smart classroom, the students are able to present their works or express their opinions to the classmates anywhere and anytime via virtual technologies that are compatible with the displays on smart devices and smartphones. It is believed that the instruction management in this modernized style can also add more fun to the class. Additionally, the virtual smart classroom enables the students to track their own progress in every activity or review the contents assigned by the teachers. In the case of group work where the students in small groups have to work together, the virtual smart classroom can facilitate them when doing analysis on their assignments, while the teachers can monitor the operation, the submission of assignments, or even the group activities of the students in an instant manner.

The C-PBL mobile and virtual learning system is an online learning tool that can be put to practical use as it is compatible with a variety of interactive screens of smartphones, tablets, and desktop platforms. With the aid of mobile technology, learners are able to participate in learning, study content and conduct interactive activities in virtual environments, which are fabricated with the Spatial.io platform coupled with the ClickUp application, the tools used to produce and organize the works with high quality and attractiveness. The researchers have developed this platform with the structure and components that are consistent with the learning contents and users' needs. The platform also has the real-time feedback system that focuses on learners' engagement with an attempt to provide them with new experiences that can lead to self-learning. Not only that, this real-time feedback system enables both instructors and learners to interact with each other in an instant manner. The C-PBL mobile and virtual learning system is illustrated in Figure 2.

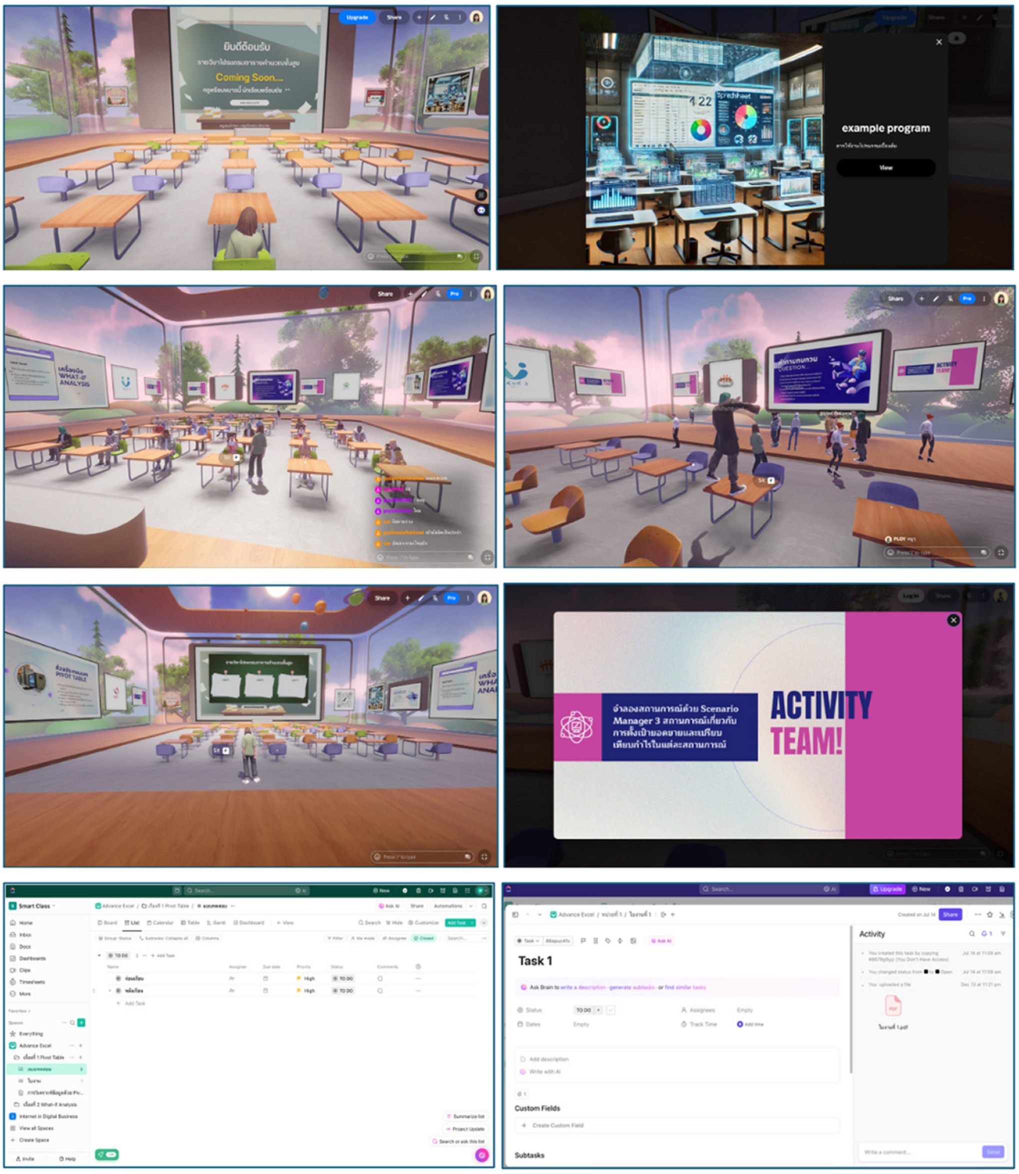


Fig. 2. The C-PBL mobile and virtual learning system

Table 7. The quality of the C-PBL mobile and virtual learning system

Items for Evaluation	Mean	SD	Interpretation
Function requirement			
1. Ability to run the system	4.56	0.53	Very high
2. Ability to add information	4.22	0.67	High
3. Ability to update information	4.56	0.53	Very high
4. Ability to present information	4.89	0.33	Very high
Overall function requirement	4.56	0.51	Very high
Functions			
1. Accuracy of system functionality	4.89	0.33	Very high
2. Accuracy in classification of information	4.44	0.73	Very high

(Continued)

Table 7. The quality of the C-PBL mobile and virtual learning system *(Continued)*

Items for Evaluation	Mean	SD	Interpretation
3. Accuracy in addition of information	4.78	0.44	Very high
4. Accuracy in update of information	4.78	0.44	Very high
5. Accuracy in presentation of information	4.67	0.50	Very high
Overall functions	4.71	0.49	Very high
Usability			
1. Ease of running the system	4.67	0.50	Very high
2. Suitability of design in virtual smart classroom	4.56	0.53	Very high
3. Clarity of presentation of the contents	4.56	0.53	Very high
4. Convenience of access to the system	4.56	0.53	Very high
5. Attractiveness of the system	4.78	0.44	Very high
Overall usability	4.62	0.50	Very high
Performance			
1. Speed of data display after connection	4.56	0.53	Very high
2. Speed of saving and updating information	4.67	0.50	Very high
3. Speed of presentation of information	4.56	0.53	Very high
4. Speed of overall system operation	4.67	0.50	Very high
Overall performance	4.61	0.51	Very high
Overall, 4 aspects	4.63	0.50	Very high

Table 7 shows the results of the evaluation of the quality of the C-PBL mobile and virtual learning system; thereby the said evaluation was conducted by the seven experts specialized in the field of instruction system design from various vocational institutions and higher education institutions. It is found that the overall quality (four aspects) of the C-PBL mobile and virtual learning system is at a very high level (mean = 4.63, SD = 0.50). Once considering the values of standard deviation, there is only a small dispersion of values. The values in the mean are nearly similar to each other, which means the research results have only little deviation. This insists that the students have quite the same opinions towards the quality and abilities of the C-PBL virtual learning system after putting it in practical use. Furthermore, it is expected that the application of this learning system will help promote the students' analytical thinking and curiosity in learning as well.

In reference to the discussion with the participants in the research by means of in-depth interviews, the authors found that the C-PBL mobile and virtual learning system is capable of presenting the information via the virtual classroom, in which the students can join activities, talk, and assign tasks to the group members before doing them. Besides, this learning system assists the students in reviewing their knowledge before taking the tests, which can increase their interest in following the contents in a continuous manner. In addition, the students are found to be satisfied with the ability to interact with the system in real time via smartphone devices, which allows them to access the system anywhere and anytime because the learning system herein can be run on a variety of operating systems. All of the aforementioned are in accordance with the research of Aqeel Alzoubi [57], who mentioned that not only does the introduction of multimedia and virtual environments minimize the misunderstandings and discrepancies when providing mathematical information, but it can also significantly promote students' learning efficiency.

5.4 The outcomes of the C-PBL mobile and virtual learning system

The main target of this research is to study the participants' learning outcomes derived from the C-PBL mobile and virtual learning system. Thereby, the participants in this research, derived by means of cluster sampling, are 30 vocational certificate students (dual vocational education) at Nakornluang Polytechnic College, who are studying in Year 1 and Year 2 in Semester 2 of Academic Year 2024. These participants were asked to use the C-PBL virtual learning system in order to find out whether the C-PBL virtual learning system has enough quality and efficiency to promote vocational students' learning achievement. The study results can be summarized as below:

A. Comparison of learning achievement before and after learning from the C-PBL mobile and virtual learning system

Table 8. Comparison of learning achievement before and after learning (N = 30)

Test	Full Score	Mean	SD	t-Value
Pre-test	20	7.67	2.93	26.70**
Post-test	20	17.43	1.50	

Note: ** Significant at the level of 0.01 (α = 0.01, df = 29).

According to the results of the comparison of learning achievement before and after learning in Table 8, it is obvious that the learning achievement score of the students who learned with the C-PBL mobile and virtual learning system is higher. Once considering the mean of the said score, it is found that the mean score after learning (mean = 17.43, SD = 1.50) is higher than before learning (mean = 7.67, SD = 2.93). This shows that learning with the C-PBL mobile and virtual learning system helps enhance the students' learning achievement with a statistical significance level of 0.01. Therefore, it can be concluded that the virtual smart classroom using cooperative PBL can promote students to achieve higher learning achievement, which corresponds to hypothesis 3 (H_3).

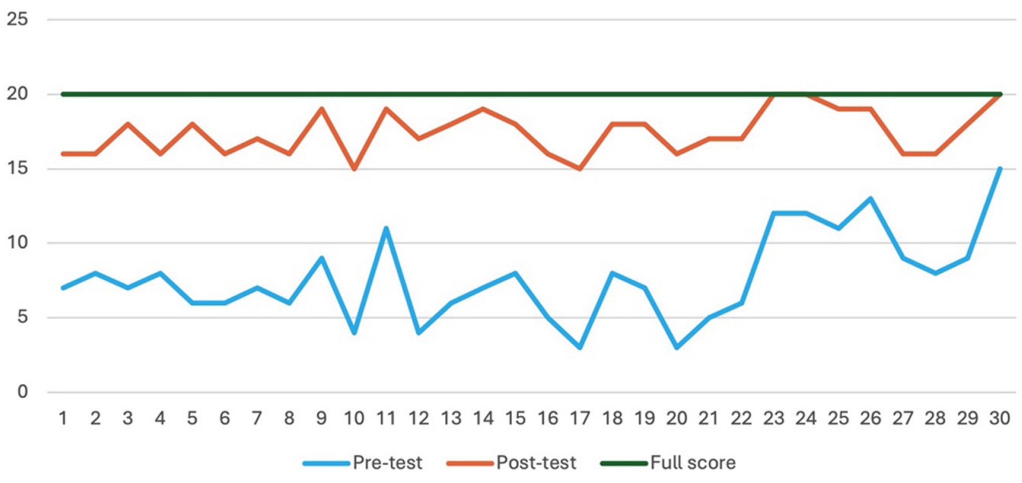


Fig. 3. The learning achievement before and after learning of each learner

In Figure 3, the outcomes of learning achievement before and after learning obviously reflect the effectiveness of learning of each learner. Once considering the full score of 30, it is found that the individual learners' learning achievement score after learning is significantly higher than before learning. This implies that learning with the C-PBL mobile and virtual learning system can improve the learning achievement of these learners.

The findings of this study underscore the importance of evidence-based development of approaches by making use of the potential of mobile technologies and the real-world environments in order to provide more engaging and effective learning experiences that can increase learner engagement and improve their learning outcomes through AI-powered mechanisms, which can provide learners with real-time assistance and mobile-supported adaptive learning. The study is in line with the research of Alasmari [30], who stated that the application of AI in mobile learning can create interactive learning environments that comply with individual learners' learning needs, and this obviously highlights the positive influence of AI technology. Nonetheless, there are still some challenges in terms of AI's potential for mobile learning, including the issues concerning the digital divide, insufficient infrastructure constraints, and resistance from certain instructors. Furthermore, the issues related to data privacy and cultural relevance of AI-powered learning systems need to be cautiously addressed.

B. The satisfaction of the students after learning with the C-PBL mobile and virtual learning system

The evaluation of the satisfaction was carried out with the evaluation form containing 16 questions with a 5-level rating scale for each question. Whereby, the said form had already been proved for validity and for index of item objective congruence (IOC) by experts. The items for evaluation are classified into four aspects, i.e., design, contents, virtual smart classroom, and design of learning activities, in accordance with the components of the C-PBL mobile and virtual learning system.

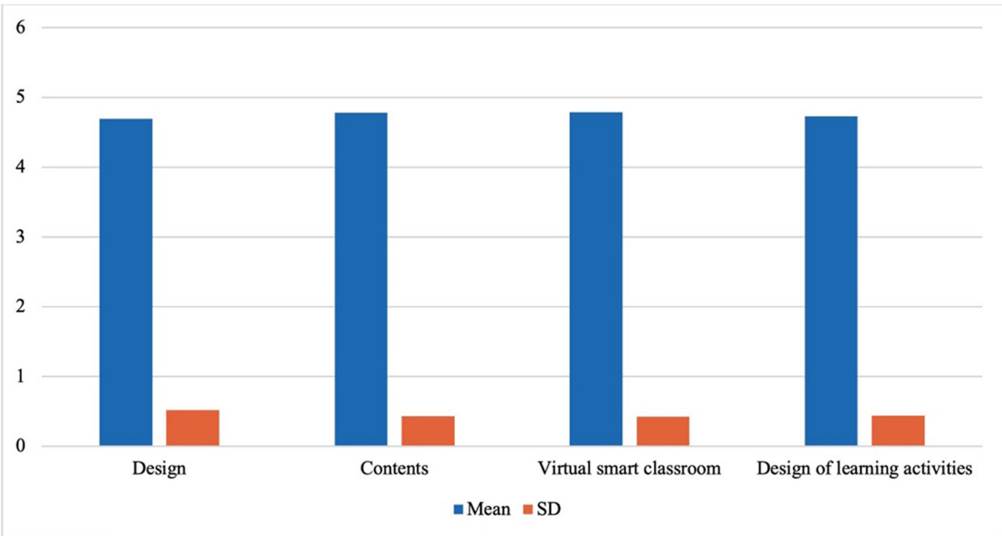
Table 9. The satisfaction after learning with the C-PBL mobile and virtual learning system

Items for Evaluation	Mean	SD	Interpretation
Design			
1. Suitability of the design of learning media components.	4.63	0.49	Very high
2. Suitability of the design of interactive learning media.	4.63	0.56	Very high
3. Convenience when using the learning support tools.	4.77	0.43	Very high
4. Suitability of colors and font sizes.	4.67	0.55	Very high
5. Continuity when using the system.	4.77	0.43	Very high
Overall satisfaction towards design	4.69	0.52	Very high
Contents			
6. The contents are easy to understand.	4.70	0.53	Very high
7. The elements of the contents are complete and comprehensive.	4.80	0.41	Very high
8. The contents are accurate and up to date.	4.83	0.38	Very high
9. The contents are interesting.	4.80	0.41	Very high
Overall satisfaction towards contents	4.78	0.43	Very high

(Continued)

Table 9. The satisfaction after learning with the C-PBL mobile and virtual learning system *(Continued)*

Items for Evaluation	Mean	SD	Interpretation
Virtual smart classroom			
10. Suitability of the design of virtual smart classroom.	4.77	0.43	Very high
11. Convenience of access to virtual smart classroom.	4.80	0.41	Very high
12. The attractiveness that can promote the attendance in virtual smart classroom.	4.80	0.41	Very high
Overall satisfaction towards virtual smart classroom	4.79	0.42	Very high
Design of learning activities			
13. Suitability of the design of learning activities to promote learners' analytical thinking.	4.73	0.45	Very high
14. Suitability of the design of learning activities to promote learners' curiosity.	4.60	0.50	Very high
15. Opportunities from learning activities to demonstrate learners' knowledge.	4.80	0.41	Very high
16. Availability of the real-time feedback system in learning activities that can improve learners appropriately.	4.80	0.41	Very high
Overall satisfaction towards design of learning activities	4.73	0.44	Very high
Overall satisfaction towards 4 aspects	4.74	0.45	Very high



	Design	Contents	Virtual smart classroom	Design of learning activities
Mean	4.69	4.78	4.79	4.73
SD	0.52	0.43	0.42	0.44

Fig. 4. Results of satisfaction with the C-PBL mobile and virtual learning system

In reference to the results of the evaluation on the satisfaction after learning with the C-PBL mobile and virtual learning system in Table 9 and Figure 4, it can be clearly seen that the overall mean of all 16 items for evaluation is at a very high level (mean = 4.74, SD = 0.45). Once considering the four aspects separately, it is found that the mean of design (mean = 4.69, SD = 0.52), contents (mean = 4.78, SD = 0.43), virtual smart classroom (mean = 4.79, SD = 0.42), and design of learning activities (mean = 4.73, SD = 0.44) is at a very high level as well. This is corresponding to the research hypothesis 4 (H_4).

According to the discussion with focus groups of 3–5 learners, it is found that the C-PBL mobile and virtual learning system can encourage learners to conduct hands-on self-learning by means of interactive mobile learning. In addition, there is the real-time feedback system that allows learners to receive information quickly and meanwhile follow the contents continuously, which can lead to more effective learning. This is in line with the research of Sisamud et al. [58], who stated that the application of virtual environments and digital tools to support self-learning enables Chinese Mahayana novices to quickly perceive new bodies of knowledge and adapt their learning quite conveniently to their needs, leading to the effective development of knowledge and innovator skills (questioning, observation, interaction, testing, and cognitive linkage). Accordingly, in such a digital age like today, these novices are able to disseminate Buddhism to the public with the aid of technologies and platforms in the virtual world, creating immersive learning like in the real world, or the new normal world at present. Furthermore, this is also consistent with the research of Annuar et al. [59], who studied the results of the research on "Enhancing Early Childhood Cognitive Development via Mobile Game-Based Learning Applications: Insights and Practical Experiences." It is found that the creation of more engaging and interactive learning environments in game-based learning can motivate young learners to learn and promote their exploration skills, problem-solving skills, and creativity through hands-on learning and self-directed learning.

6 RESEARCH CONCLUSION AND LIMITATIONS

This study focuses mainly on the examination of perspectives towards the development of C-PBL mobile and virtual learning with an aim to find out to what extent it can fulfill the users' needs and whether it is suitable for being put in practical use. This study can also encourage the students to do self-learning and enhance their analytical thinking and curiosity in learning, which can further promote lifelong learning as well. Thanks to the application of virtual technologies integrated with artificial intelligence technology, it is possible to fabricate "the virtual smart classroom" that can promote group learning in the instruction management through virtual environments and avatars. It is said that this style of learning can respond well to the learning situations in today's world.

6.1 Research conclusion

The C-PBL mobile and virtual learning system is an online learning tool that enables students to follow up on their own progress in every single activity or review the contents assigned by their teachers. This learning tool also facilitates the students' analytical thinking processes, and at the meantime, the teachers are able to monitor the students' work, submission of assignments, and group activities in real time. With this learning system, the students are allowed to conduct active learning, present their works, and express their opinions to other classmates via virtual technologies that are compatible with the displays on smart devices and smartphones anywhere and anytime. Above all, the C-PBL mobile and virtual learning system can add more fun to the instruction management by making use of digital innovations and technologies under the New Normal virtual environments.

It can be clearly seen that this study can stimulate the students to think analytically and systematically, consider different elements in a logical manner in order to find out the relationships and connections of things, and eventually manage to effectively apply the acquired knowledge in new situations. Once coupled with the cooperative PBL process, the learning system in this study can also promote students' curiosity in learning and seeking new experiences, which can help further extend their scope of knowledge and escalate their competencies. Moreover, this can also promote lifelong learning and improve the quality of social services, especially those related to education. Most importantly, it is believed that the exchange of knowledge and interaction through virtual technologies allow Thai people to access varied sources of information with no limitations, and at the same time, this can enhance their knowledge and skills and also add more fun to both teaching and learning.

6.2 Research limitations and future work

This study is intended to present the guidelines to develop the C-PBL mobile and virtual learning system via mobile learning technology and virtual environments that can satisfy the needs of interactive learning and enhance learners' engagement and flexibility through AI-powered mechanisms. However, there are still some noticeable limitations in this study. First of all, this research is just a specific group study, and the usability of the system is quite limited. Thus, in order to confirm the suitability and clarity of study results, future research should be conducted with more diverse participants, and the survey should be done with a larger population. The findings in this study, therefore, are considered just the findings from a pilot study and can be used only as a guideline for future development. Moving on to the other limitation, the contexts of technologies employed in this study are limited to education only. Thus, future studies may place an emphasis on the more various technologies along with the skills that have effects on the use of both educational technologies and other relevant technologies. The other limitation is that the research methodology was an experiment with a single pre-test/post-test group. This method limits the usability of the system, and it is not sufficient to identify the causal relationship. Therefore, in order to confirm the results and the appropriateness of the research more clearly, a comparative study between the C-PBL mobile and virtual learning and the traditional PBL should be conducted with more solid research methods, such as a control group or a quasi-experimental design. In addition, future research can emphasize the study of the scalability of virtual smart classrooms for large-scale educational adoption, comparative studies with traditional PBL, and longitudinal effects on student retention.

In conclusion, this study still has a significant role to promote and support analytical thinking and curiosity in learning. This is because students are able to learn and practice in an immersive virtual environment freely, which encourages them to carry out active learning through media and information technology. Consequently, it is obvious that the C-PBL mobile and virtual learning system can support students to gain self-learning experiences, resulting in the learning society that promotes learning skills highly needed in the digital age.

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