Teaching an Educational Innovation and Digital Technology Course Using Project-Based Learning in an Online Learning Environment

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***Abstract*—This paper presents the teaching of an educational innovation and digital technology course using project-based learning in an online learning environment. The objective of this research was to examine the efficiency of teaching using project-based learning in an educational innovation and digital technology course. A total of 470 students in a graduate diploma program in teaching at the Faculty of Industrial Education, Rajamangala University of Technology, Phra Nakhon, Bangkok, Thailand, participated in this study. A mixed methods design was used to collect data from the students. Data from the students' projects, questionnaires, and grades were analysed. The results indicate that project-based learning is an effective teaching method in an online learning environment.**

***Keywords*—educational technology, online learning, project-based learning, teaching an educational innovation and digital technology course**

I. Introduction

This introductory section presents the historical context of Information and Communication Technology (ICT) adoption in Thai education. The introduction maps the advancement of ICT from its early stages to the present to highlight the obstacles encountered in online teaching.

The first two computers were introduced to Thailand in 1964 [1]. In 1971, Ruamkhamhaeng University (RU) was established as a pioneering institution for distance education in Thailand. In 1996, RU delivered instructional broadcasts to classrooms via radio and television [2]. RU later incorporated web boards, email, and CDs as teaching media to support distance education in conjunction with traditional classroom instruction. This university offers blended learning and awards official degrees.

In 1978, Sukhothai Thammathirt Open University was established to provide distance education through print-based packages delivered by mail. Subsequently, technology was incorporated into higher education instruction. During the Asian economic crisis in 1997, Thailand continued to adopt ICT, which was targeted as a key component of educational reform under the National Education Act of 1999. Between 2002–2003, 13 universities employed e-learning for web-based instruction. However, 75 Thai universities utilized their websites solely for news dissemination [1]. In 2006, Suanpang and Petocz [3] conducted a comparative study of classroom and online teaching. Later, in 2008, Rueangprathum *et al*. [4] surveyed the adoption of e-learning in teaching and reported that e-learning was utilized by 20 universities in the central region, 4 universities in the northeast, 3 in the north, and 1 in the southern region of Thailand.

In 2013, Sukhothai Thammathirat Open University began offering instruction through e-learning [5]. In 2015, a professional community called the "KrooThai ICT model" was established with the aim of creating a knowledge-sharing network [6]. In 2017, the concept of Massive Open Online Courses (MOOCs) was introduced to disseminate education to people of all ages [7]. Concurrently, the Thai government recognized the benefits of online education. The government established the Thai Massive Open Online Course (Thai MOOC) platform under the Thai Cyber University project in 2017. The Thai MOOC offered online degree programs [8–10]. The project has continued, but the acceptance of online degree programs through Thai MOOCs remains limited. The MOOC platform has since shifted its focus from degree programs to short courses focused on teaching fundamental knowledge.

Before the COVID-19 pandemic, the predominant mode of teaching students in Thailand from kindergarten through universities was classroom-based instruction. Owing to the absence of official statistics on the number of online classes conducted in Thailand during that period, observations must be drawn from research trends. In 2006, O'Sullivan [11] focused on developing teaching methods for primary school classrooms. In 2013, Åkesson and Vallin [12] studied classroom teaching at the secondary level in southern Thailand. In 2020, Chaiyasat [13] examined the impact of practical teaching conducted in classrooms. Chaiyasat [13] noted that university administrators and stakeholders were still focused on enhancing facilities and teaching tools for teaching in the classroom environment. Moreover, university instructors had integrated Learning Management Systems (LMSs) into their teaching alongside traditional classroom instruction [14].

Since the global outbreak of COVID-19, online learning has become a common teaching platform. With face-to-face instruction prohibited to limit the spread of the virus, online learning was introduced as an emergency option [15]. Recently, although health protocols have been loosened by the government, some university professors continue to prefer online teaching, for example, at universities in Malaysia, Singapore, and Thailand [16]. Kaur *et al*. [16] reported that university professors preferred online learning because online learning supports personalized learning. Students were able to study independently and utilize the methods and materials they favoured. However, problems such as gender, cultural interactions, untimely feedback, a

lack of social indications, and reduced social interaction are all elements that make online learning environments complex [17].

Recently, researchers have attempted to examine novel methods to avoid problems in online learning. Students have proposed favourable online learning strategies [18]. These strategies fall into two main categories: engagement and interaction. Examples of engaging students include checking their understanding, providing content and case studies, and offering meaningful digital tools. Examples of enhancing teacher–student interaction methods include improving teacher–student and student–student connections and fostering positive classroom culture. Kim [19] proposed problem-based learning and Project-Based Learning (PjBL) as methods to assist students in staying engaged and connected in their learning.

Online learning has become increasingly prevalent since the onset of the COVID-19 pandemic. In response to global health protocols, governments have required students to minimize face-to-face interactions. The pandemic prompted universities worldwide to undergo digital transformation processes [20]. Online teaching and learning were in place from early 2020 to early 2022, lasting for two years as a result of COVID-19 [21, 22]. The impact of the COVID-19 pandemic at universities has shifted pedagogy. The teaching environment has shifted from the physical classroom to online classes. Technological tools have been utilized to transition from conventional classroom settings to virtual education [23].

The introduction section presented a brief overview of the teaching environment in Thailand. The next section addresses the necessity of improving the quality of education to enable learners to pursue careers that lead to higher incomes. The development of educational quality is discussed as a means to cultivate essential skills in students, such as problem solving, collaborative teamwork, and communicative proficiency. Additionally, PjBL is introduced as an approach that can be utilized to develop these skills.

A. Challenges in Applying PjBL in Online Teaching to Enhance Educational Quality

A United Nations report has identified educational quality as a key objective in educational development [24]. The education goals of the United Nations's Sustainable Development Goals (SDGs) report aimed to increase the proportion of primary school students from 51% in 2015 to 67% by 2030. The United Nations estimated that approximately 300 million children and adolescents will continue to lack essential literacy and numeracy skills by 2030. In addition, there are other SDG subgoals, such as improving low levels of ICT skills; extending access to basic school facilities such as electricity, water, sanitation and handwashing facilities; and addressing the lack of qualifications to train teachers. The SDGs emphasize the urgent need to improve educational quality.

The Organisation for Economic Co-operation and Development (OECD) has noted that attaining education beyond the upper secondary level enhances workers' skills, leading to greater knowledge, higher income, improved careers, and overall prosperity [25]. Similarly, the study conducted by Phakdi, et al. reveals that increasing the education budget by one unit is associated with a 0.0126-unit increase in GDP. According to the data, education plays a significant role in boosting the productivity of the population. Rukspollmuang and Fry [26] emphasized that Thailand's future is dependent on both the reform of the education system and the increase of population productivity. In addition, Durongkaveroj [27] noted that inequalities in education can affect the Thai economy. The abovementioned research has shown that increasing the quality of education is an important key to national development. One method to improve the quality of education is to increase the effectiveness of teachers and students, which can be achieved independently of increasing educational expenditure.

Every year, the OECD, an international organization that operates to develop policies for enhanced lives, publishes a report titled "Education at a Glance" [25]. For example, the theme of Education for All 2024 focused on equity in education, whereas the theme of Education at a Glance 2022 focused on the changing environment for tertiary education. In 2023, Education at a Glance emphasized enhancing Vocational Education and Training (VET) systems. The OECD aims to increase the proportion of students engaged in VET programs. It recognizes the growing significance of VET, as it provides learners with a combination of skills essential for transitioning from school to the workforce. The OECD has also indicated that integrated academic and workplace training programs remain insufficient in numerous countries [25].

The concept of VET emphasizes the importance of abilities such as collaborative teamwork, problem solving, and communicative proficiency, which are essential for employability and enhancing both academic and practical competencies. The evidence shows that PjBL can be used effectively in VET teaching [28, 29]. The concept of PjBL may also encourage the objectives of the OECD, which emphasize the significance of problem solving, collaboration and communication abilities.

Recently, educational concepts utilized in VET, such as practical-based learning, student-centred learning, learning through experience, discovery learning, and PjBL, have been widely used. These concepts highlight the importance of capitalizing on human attributes such as inquisitiveness, expertise, and self-management [30]. A study by Bei Qiu found that PjBL was an efficient teaching method in modern vocational education [31]. PjBL is a learner-centred approach that tends to be teacher-driven. PjBL has become more prevalent than the project work approach [32]. The PjBL approach has been strongly recommended for educational implementation by teachers and embraced by higher education institutions [33]. PjBL has gained popularity in the teaching of many subjects, such as English language instruction [32], physics [34], engineering [35] and [36].

In addition, researchers have reported that encouraging learners to engage in creative thinking positively impacts their academic outcomes as well as their creative capacities [37]. A previous study revealed that PjBL was one of the teaching methods that encouraged students to think more critically and creatively compared to traditional teaching methods such as the project work approach [32].

Although previous research has demonstrated the success of PjBL in classroom teaching [38-40], studies have shown

that PjBL fails to be effectively implemented in online teaching [41, 42]. Students struggle to share a common vision of the project among participants and often experience uncertainty and a lack of clarity regarding the next steps. Compared with conventional instructional methods, the PjBL approach requires more time [43]. This poses a challenge for implementing PjBL in online courses, particularly in subjects that require the creation of new projects. In addition, there is a need for further research conducted in diverse teaching environments that considers factors such as learner behaviour, educational background, level of instruction, and subject matter.

Research into the effectiveness of PjBL in online environments increases the benefits for teachers and students via effective teaching. Identifying the factors in different environments that affect success in teaching is a research challenge. The results of this study are intended to advance teachers' knowledge and understanding of online teaching methods.

The next section will discuss the definition of PjBL and its management process to provide readers with a foundational understanding of PjBL.

II. Project-Based Learning (PjBL)

A. Definition of PjBL

The PjBL approach has its roots in the early twentieth century. The term "project" was mentioned by Kilpatrick in 1918 [44]. PjBL emerges from the ideals of progressivism [45]. Progressivism refers to a wide-ranging practical and theoretical framework in education [46]. The evolution of PjBL has been influenced by Dewey's experiential approach to education, Bruner's discovery learning model, Thelen's focus on group investigation, and Kilpatrick's project method [45]. The PjBL approach is grounded in constructivist philosophy [47]. According to constructivist theory, knowledge is constructed by individuals through their interactions with the environment. Constructivism strongly emphasizes student-centred learning. In PjBL, teachers provide students with opportunities to investigate, inquire, and independently construct their own knowledge. Recent developments in the field of education have led to renewed interest in PjBL in online environments from scholars such as Randazzo *et al*. [48] The development of PjBL was motivated by the combined influence of these foundational theories. PjBL fundamentally combines multiple instructional elements and methodologies. Important aspects include rubric development, 21st-century skills, inquiry-based learning, problem-based learning, cooperative learning, and authentic learning.

In the present report, PjBL is defined as a teaching methodology centred on collaborative inquiry, where learners work together to synthesize, apply, and build their understanding while performing complex problem-solving tasks. According to the definitions, collaboration to generate resolutions to solve complicated problems is a key objective of PjBL [49].

Almulla [33] noted that the PjBL approach does not have an exact definition. PjBL is widely recognized by its proponents as a cooperative and research-based pedagogical approach that involves active student engagement and the use of comparative learning strategies [33].

As defined by Nilsook *et al*. [50], PjBL is an instructional method centred on practical learner experiences. It equips students with skills in problem solving, scientific planning, creative thinking, self-evaluation, and effective communication and collaboration.

PjBL is influenced by philosophies and concepts of constructivism, constructionism, and experimentalism. According to constructivism, students are capable of generating knowledge through their own cognitive practices. Constructionism emphasizes that students learn by independently constructing meaningful products [50]. The philosophy of experimentalism, developed by Dewey, centres on the relationship between pedagogical theories and classroom practice [51].

PjBL differs from general projects. General projects refer to assignments that mandate that students or groups complete projects encompassing multiple areas of their academic curriculum. In contrast, PjBL is a learning process that focuses on the learner to accomplish independent learning and cooperative knowledge building. Project-based learning involves assigning students projects that are related to real-world contexts. Learners are encouraged to explore and execute tasks autonomously, with teachers offering supervision and advice on project conceptualization, planning, design, execution, and demonstration [50].

PjBL offers numerous benefits, but there are also drawbacks. One challenge faced by teachers implementing PjBL is that students tend to disregard their guidance and feedback [43]. Several factors can discourage educators in instructor-led instruction and practical laboratory training. including insufficient student engagement, such as insufficient discussion and note documentation, as well as the absence of practical relevance and simulated events [52].

Table 1 summarizes the review of studies on PjBL that were designed and applied in research conducted between 2020–2023.

On the basis of the data in Table 1, Table 2 analyses the PjBL framework to illustrate its current stages. The frameworks are ordered from the minimum to the maximum number of steps.

Table 1. Summarized review of PjBL

Studies / years	Experiment in subject(s)	Level / Location / Number of participants	Objective	Results	Research limitation	Teaching setting
Amin and Shahnaz [53] / 2023	Organizational culture course	University / Indonesia / 45	To determine the impact of PjBL.	Positive. Most students (90%) reported positive experiences with PjBL methods, identifying 17 benefits alongside 6 obstacles encountered in the online	A single experimental group was utilized.	Online

				context.		
Balyk *et al*. [54] / 2021	Computer modelling course	University students majoring in secondary education / Ukraine / 1866	To motivate students' attitudes and create modelling training.	Positive. PjBL sustains and enhances student engagement in computer modelling.	The investigation was limited to one course subject.	Classroom
Brüngel *et al*. [55] / 2020	Machine learning course	Master's program in computer science / Germanay / 35	Enhance interpersonal skills and apply practical problem solving to the development of machine learning miniprojects.	Positive. Enhanced student proficiency in constructing machine learning projects corresponds with lower attrition rates.	The investigation was limited solely to computer science topics.	Classroom
Karahasanović and Culén [56]/ 2023	Human–computer interaction	Bachelor in computer science department / Norway / 13 students and 3 partners	Develop a theoretical framework centred on service-dominant logic.	Positive. PjBL enhances the learning experience while facilitating more efficient management for stakeholders.	The research was confined to one specific subject area.	-Classroom in 2018 -Online in 2020–2022
Linares-Pellicer *et al*. [57] / 2020	Programming and related courses	Undergraduate course / Spain / N/A	Proposed PjBL models.	Two PjBL models were introduced, one focusing on coding, data structures, and procedures, and the other on game software development and digital graphics synthesis.	The research was confined to presenting a model and did not encompass empirical testing with student participants.	N/A
Malik and Zhu [58] / 2022	Introductory theoretical computing classes	Undergraduate course / USA / N = 165	Enhanced student learning.	Positive. Students demonstrated a considerable increase in their scores upon finishing the course.	The generalizability of the findings is constrained due to the study's exclusive focus on a computer science course.	-Groups 1–5: classroom - Group 6 : online
Markula and Aksela [49] / 2022	Biology	K–12 science education / Finland / N = 152	To examine the main characteristics of PjBL.	Positive. The constructed framework offered significant advantages in the design of PjBL.	This research is to achieve an in-depth understanding of particular cases, rather than to produce generalizable result.	Classroom
Nilsook *et al*. [50] / 2021	N/A	Vocational and technical education / Thailand / N/A	Conduct a comprehensive analysis and synthesis of research studies related to PjBL.	Positive. The proposed implementation of PjBL was within the context of vocational education.	The review article did not involve experimental procedures utilizing a sample group.	N/A
Rahayu and Sukardi [59] / 2020	Basic and computer network course	Vocational school / Indonesia / 36	To increase the effectiveness of student learning.	PjBL has been shown to enhance students' academic performance and encourage active engagement in the learning process.	The study involved one experimental group.	Online
Randazzo *et al*. [48] / 2021	Research methods courses in health science	University / United States / 48	To promote higher levels of students' satisfaction and self-confidence in learning.	Positive. PjBL enhanced students' self-confidence and active participation.	The study's outcomes are not broadly applicable because it compares only two instructional modalities: online traditional learning and online PjBL.	-Group 1: traditional learning in online -Group 2: PjBL in online
Wang [60] / 2023	Robotics	Master's degree / China / N = 79	To enhance students' involvement and computational thinking skills within robotics education.	PjBL enhanced students' engagement and computational thinking skills.	The generalizability of the findings is constrained due to the study's exclusive focus on a computer science course.	-Group 1: traditional classroom -Group 2: PjBL in online

Table 2. Analyses of the PjBL framework

Authors	No. of PjBL steps	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Randazzo *et al*. [48]	3	Application	Analysis	Creation of instructional knowledge.					
Karahasanović and Culén [56]	3	Service delivery ecosystem	Service frameworks	Shared value creation					
Malik and Zhu [58]	4	Inquiry	Examination	Review	Improvement				
Rahayu and Sukardi [59]	4	Stages = Identify	Construct	Create, and	Distribute				
Brüngel *et al*. [55]	5	Identifying industrial requirements	Administrative management	Developing software	Producing documentation	Disseminating results			
Nilsook *et al*. [50]	5	Planning	Theme specification	Production and evaluation	Demonstration	Review			
Wang [60]	5	Engaging with content on an online platform	Analysing assignments	Acquiring relevant knowledge	Designing and developing robots	Submitting assignments			
Balyk *et al*. [54]	6	Defining the problem	Outlining project tasks	Collaborative thinking	Construction	Evaluation	Presenting outcome		
Markula and Aksela [49]	6	Formulating research questions	Defining study aims	Applying scientific methods	Fostering collaboration	Employing technological tools	Creating a product		
Amin and Shahnaz [53]	6	Formulation of essential questions	Proceeding to project development	Timetable creation	Student supervision	Evaluation of results	Reflection on the learning experience		
Linares-Pellicer *et al*. [57]	8	Important concept	Essential knowledge	Key inquiry	Student participation and selection	21st-century skills	Deep investigation	Review and reflective analysis	General audience

As shown in the first row of Table 2, Randazzo *et al*. [48] designed a PjBL framework on the basis of Bloom's taxonomy consisting of three steps: application, analysis, and the creation of instructional knowledge. Among the frameworks analysed, Randazzo's PjBL has the fewest steps—for example, Nilsook *et al*. [50]'s framework consists of five steps. Nilsook's framework includes two additional steps: demonstration and review.

As summarized in the second row, Karahasanović and Culén [56] proposed an interesting PjBL framework whose concepts differ from those of the other PjBL frameworks in Table 2. Karahasanović and Culén proposed a "service-dominant logic framework" focused on real-life projects for human–computer interactions. The framework consists of three components: the service delivery ecosystem, service frameworks, and shared value creation. The service delivery ecosystem is defined as a system characterized by relative self-regulation, comprising educational beneficiaries and industrial participants, all of which are linked by a common interest in innovation and the joint creation of value through the development of new technologies and the exchange of services. A service framework is a framework that enables interactions among stakeholders and/or additional elements. Shared value creation refers to the collaborative generation of value through interactive engagement among student team members, between the team and project stakeholders, and with other participants in the broader ecosystem.

Shown in the third row, the framework by Malik and Zhu [58] consists of four steps. One step in this framework is called "improvement." Furthermore, the first step differs from the Randazzo *et al*. [48] framework, which focuses on "application", whereas in the Malik and Zhu framework, the focus of this step is "inquiry".

As summarized in the fourth row, the framework by Rahayu and Sukardi [59] has four steps. Unlike Nilsook's framework, Rahayu's framework does not include a testing step.

The frameworks without a presentation step are those developed by Malik and Zhu [58], Wang [60], Markula and Aksela [49], and Amin and Shahnaz [53]. This omission results in fewer steps than in the frameworks of Brüngel *et al*. [55] and Nilsook *et al*. [50].

As illustrated by the data in row five, Brungel designed his framework to increase student performance in creating projects for industrial sectors. The Cross Industry Standard Process for Data Mining (CRISP-DM) was utilized in the design of the PjBL framework to facilitate student acquaintance with machine learning methods. The Brungel PjBL framework consists of 5 steps: 1. Identification of industrial requirements, 2. Administrative management, 3. Software development, 4. Production of documentation, and 5. Dissemination of results.

Notably, the PjBL frameworks presented in the table all employ the same principle—constructivism—which emphasizes that learners construct knowledge through experimentation, hence the comparable steps among frameworks. However, only the framework of Brüngel *et al*.

[55] differs substantially from the others because it applies the principles of CRISP-DM for machine learning.

Among the frameworks, Linares-Pellicer *et al*. [57]'s framework contains the most detail.

In summary, instructors and researchers can apply the frameworks in the table and adapt them according to their teaching objectives and environmental contexts.

The next section of this study of the implementation of PjBL in teaching innovation and digital technology describes the research questions guiding the use of PjBL in an educational innovation and digital technology course.

III. Research Questions

Teaching objectives in the 21st century require students to succeed in core subjects such as reading, writing and mathematics. Students must also learn other essential skills, such as problem solving, creative thinking, critical thinking, communication, and collaboration [61]. Research on methods to teach students skills according to their ability to acquire subject-specific and other essential skills is a challenging task. Therefore, the following research questions were developed.

1) Is PjBL an effective approach to teaching Thai students in online educational innovation and digital technology courses?
2) What factors determine the effectiveness of PjBL in an online learning environment to improve learning in educational innovation and digital technology courses?
3) What are the obstacles to teaching innovation and digital technology courses using PjBL in an online learning environment for Thai students?

To answer the research questions above, the next section presents relevant literature on the research design, a course description, the backgrounds of research participants, and information on online teaching platforms and Scratch and YouTube tools for teaching innovation and digital technology.

IV. Research Methodology

A. Mixed Methods Research Design

A mixed methods research design is defined as a design that employs both qualitative and quantitative methods for data collection and analysis, implemented either concurrently or in successive stages [62]. Storey *et al*. [63] described the following popular mixed method design variations: exploratory sequential, explanatory sequential, convergent parallel, embedded, and multimethod.

The convergent parallel design involves both qualitative and quantitative methods to produce complementary insights to answer a research question. The convergent parallel mixed methods research design enables researchers to simultaneously collect and analyse both quantitative and qualitative data. Accordingly, this research design helps researchers understand the factors that determine the effectiveness of PjBL in an online learning environment.

Owing to these advantages, this research selected a convergent parallel mixed method research design.

The principles guiding mixed method research designs consist of four key elements: rationale for the methodology, innovative comprehensive insights, rigorous procedures, and ethically conducted research. Fig. 1 shows the convergent parallel design applied from Storey *et al*. [63]. The research goal is to examine the effectiveness of using PjBL in an online learning environment to teach Thai students in educational innovation and digital technology courses. Research questions were developed on the basis of the research goal. Key elements were applied in the research design.

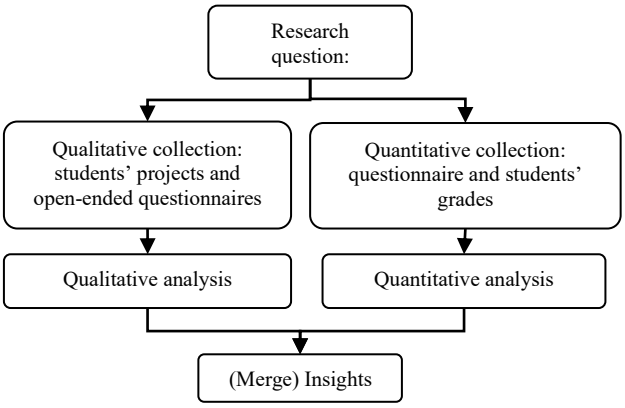

Fig. 1. Convergent parallel design.

With respect to the rationale for the methodology, the inductive (from data to theory) data were collected from two angles in tandem. Qualitative methods were used to assess the quality of the students' projects and open-ended questionnaires. These observations are complemented by the quantitative data collected from students' questionnaires and grades.

To generate innovative comprehensive insights, qualitative and quantitative data were analysed to understand the efficiency, processing, advantages and disadvantages of PjBL. The results-based integration was conducted by comparing and combining qualitative and quantitative data. The researcher expected that the use of a convergent parallel design that conducted both qualitative and quantitative methods in parallel would provide novel insights into the effectiveness of PjBL in an online learning environment.

Questionnaires were used to collect data from 470 students. Questionnaire data, students' grades, and students' projects were collected. The questionnaires were divided into two parts, with details presented in Table 3. The first section used a five-point Likert scale, and these data were analysed using descriptive statistics.

1) The questionnaire was designed by the committee of the Office of Academic Promotion and Registration at RMUTP. This questionnaire serves as the standard instrument for evaluating the quality of teaching at RMUTP during the COVID-19 period with the aim of assessing the teaching performance of all instructors across every course offered at RMUTP. The teaching evaluation results for all courses are compiled and reported as the teaching quality of each faculty in the annual "Student Satisfaction Survey Report" of RMUTP.
2) The researcher utilized this questionnaire in the present study because it addresses the following research objectives: (1) to examine teaching methods in accordance with Nilsook's PjBL management process; (2) to assess the quality of online teaching; and (3) to assess

the teaching standards of RMUTP instructors. The details are presented in Table 3.

Table 3. Student questionnaire

Question No.	Nilsook's PjBL process	assess online teaching	Assess RMUTP instructor
Section One:			
Part 1: Student self-assessment questionnaire			
1. Learners clearly understand the course objectives and content.	Step 1: Planning		
2. Students attend classes punctually and regularly.			√
3. Learners engage in activities and share opinions.	Step 3: Production and evaluation		
4. Learners consistently perform assigned tasks.	Step 3: Production and evaluation		
5. Learners regularly review lessons before class.	Step 1: Planning		
6. Learners study beyond the teacher's instruction.	Step 3: Production and evaluation		
7. Learners dress neatly per university rules.			√
8. Learners obtain knowledge from taking this course.	Step 5: Review		
9. Learners are satisfied overall.			√
Part 2: Student survey on teaching quality			
10. Instructors inform teaching with objectives, activities, and assessment.	Step 1: Planning		
11. Teachers come to teach and finish teaching on time.			√
12. The instructor fully teachers content following the teaching code and ethical standards.	Step 5: Review		
13. Teachers are enthusiastic and responsive to students' questions.	Step 2: Theme specification		
14. The teacher assigns task exams, and analyses the results.	Step 3: Production and evaluation		
15. Instructors provide information and suggest knowledge source for further student learning.	Step 2: Theme specification		
16. Teachers foster and open classroom for idea exchange, questions, and diverse activities.	Step 4: Demonstration		
17. Teachers use innovative materials appropriately with the course content.	Step 5: Review and Step 2: Theme specification		
18. Teachers allow students to seek advice outside of class.	Step 5: Review		√
19. Teachers measure learning outcomes aligned with the teaching content.	Step 3: Production and evaluation		
20. The instructor shares test scores with learners before the final exam.	Step 5: Review		
21. Instructors dress and speak politely to seta good example.			√
Part 3: Student survey on on satisfaction with online PjBL learning			
22. Satisfied with online teaching.		√	
23. Takes full advantage of online channels.		√	
24. Links in lessons are easy to use.		√	
25. Meets the needs of learners.		√	
26. Attend lessons like a regular classroom.		√	
27. Submitting work online is convenient.		√	
28. Teachers offer information or to learners as needed.	Step 2: Theme specification		
29. Convenience of taking classes online.		√	
30. Collect points from tasks or homework.	Step 5: Review		
31. Collect exam points.	Step 5: Review		
Section Two:			
Part 4: Open-ended question (Option)			
32. Please provide additional suggestions for improving teaching			

The second section of the questionnaire consisted of open-ended questions that were analysed by quantitative techniques. The student projects were analysed to reveal the quality of students' project work. The open-ended question was "Please provide additional suggestions for improving teaching." This question, listed as item 32, was optional, and respondents could choose whether to answer it

To ensure rigorous research procedures, this design allowed researchers to integrate and understand the process and results while teaching in PjBL in an online learning environment. The quantitative aspects revealed students' opinions as provided in the questionnaire in numerical terms and students' overall performance in terms of students' grades. The qualitative data demonstrated the output of the students' learning through their projects and triangulated the data from the open-ended questions.

To ensure that the research was ethically conducted research, the researchers sought permission from research

participants by informing students and briefly describing the research procedures. Data from questionnaires were collected via the RMUTP evaluation academic system. The researcher, acting as a teacher in this course, was allowed to obtain the overall results from the questionnaire without permission to access individual questionnaire answers to prevent biased consideration of participants.

B. Participant Backgrounds

This section describes the basic backgrounds of the research participants and provides the basic characteristics of the research sample.

The Graduate Diploma Program in Teaching is a preservice teacher program for those who hold a bachelor's degree in various educational fields, such as engineering, mathematics, physics, or sports science, and want to pursue a career as a teacher. This program takes three semesters to complete. After graduating from the Graduate Diploma Program, students are permitted to take an exam to receive a provisional teaching licence.

The students enrolled in this course volunteered to participate in the experimental group. The participants in this research consisted of 470 students pursuing graduate diplomas in teaching at Rajamangala University of Technology Phra Nakhon (RMUTP), Bangkok, Thailand. The participants, aged 22 to 35, lived or worked in Bangkok and the surrounding metropolitan region, and the distribution of males and females was in Table 4.

Table 4. No. of male and female survey respondents

Semester/Year	Male	Female	Total
1/2021	31	54	85
2/2021	19	63	82
1/2022	20	47	67
2/2022	32	39	71
1/2023	26	59	85
2/2023	27	53	80
Total	155	315	470

C. Online Teaching Platforms

The RMUTP has prepared teaching platforms, such as the Moodle LMS, Google platform, Microsoft software, e-mail, registration and grading system, to help teachers conduct online instruction. This research selected Google Classroom as the main teaching platform. The online class was taught on Saturday and Sunday. The instructor used a synchronized teaching method by lecturing through Google Meet and posting instructional media in Google Classroom. Students can also submit projects through Google Classroom. A line application and mobile phones were utilized as supplementary communication channels after online classes were synchronized [64].

D. Scratch and YouTube as Tools for Teaching

Recently, researchers have developed many software tools that teachers can use for teaching in educational innovation and digital technology courses effectively, such as Scratch [65] and YouTube [66].

According to the literature review, Scratch operates using a set of graphical programming blocks. Scratch is suitable for teaching "digital fluency", which refers to the process of designing, creating, and remixing [67]. Previous studies have noted that programming and computational thinking are needed for 21st-century learners in today's classrooms [68]. Şener and Umutlu [68] used Scratch to teach preservice teachers as novice programmers. They reported that preservice teachers learned structured, contextualized, and visually well-designed programming tasks. Scratch enabled the preservice teachers in that study to produce high-quality programs.

On the basis of Pérez-Marín *et al*. [69]'s research, it is suggested that primary students acquire programming skills through programs such as Scratch. Scratch and other software applications, such as ChatGPT, Doroty, and AutoTutor, were described as parts of PCAs that preservice teachers should learn as basic programming skills for teaching students. Pedagogic Conversational Agents (PCAs) are software applications that interact with students using natural language.

YouTube is widely used as an online teaching medium because of its advantages, such as being the largest and most popular video-sharing service, being freely accessible and offering high-speed streaming. Previous studies have shown the advantages of using YouTube as a tool in teaching.

For instance, Zulkifli *et al*. [70] investigated the influence of YouTube tutorials on the mental computation skills of preservice teachers. The results demonstrated that YouTube tutorials significantly enhanced preservice teachers' competency in mental computation. YouTube can be used for teaching any subject, such as English language learning [71] or medical science [72].

On the basis of the advantages offered by using Scratch and YouTube as tools for teaching, this research experimented with assigning two tasks: assigning students to write programs using Scratch and creating instructional media using YouTube.

In the next section, the concept of the instructional design of the educational innovation and digital technology course is described.

E. Instructional Design

This study designed a course structure on the basis of the project-based instructional management process of Nilsook *et al*. [50]. Nilsook's framework was chosen because it offers a reasonable number of steps, five in total, which is neither too few relative to the frameworks of Randazzo *et al*. [48], Karahasanović and Culén [56], Malik and Zhu [58], and Rahayu and Sukardi [59] nor too many compared with the six steps in Linares-Pellicer *et al*. [57]'s framework. The PjBL management process was divided into five steps, with the roles of teachers and students defined as follows:

1) Planning: The teacher gives advice and suggestions. Students investigate and develop workgroups, generate ideas collaboratively, consider various possibilities, and outline the main problems.
2) Theme specification: The teacher approves the task and gives feedback. Students develop a project proposal and deliver presentations on their chosen topics.
3) Production and evaluation: The teacher follows the track and verifies the procedure. Students construct the project, evaluate its function and solve any problems identified.
4) Demonstration: The teacher listens, makes suggestions, encourages and supports the project. Students demonstrate the finalized project, receive

recommendations, and refine their project.

5) Review: The teacher provides authentic assessment. Students perform self-assessment.

The next section describes the teaching activities in each week.

F. Educational Innovation and Digital Technology Course Content

As discussed in the previous section, the course content was designed and adapted from Nilsook's PjBL organizational framework for vocational and technical education. Prior to developing the course content, the lecturer needs to comprehend the objectives of the curriculum to achieve the intended learning outcome.

The length of each course was 15 weeks or a full semester. In weeks 1–7, students conducted Scratch programming projects. Weeks 8–14 focused on teaching media projects using YouTube. Week 15 is a discussion summarizing the learning results with the students.

Before beginning teaching, the teacher prepares a teaching plan according to the course description.

Week 1 was a preparation week for the students. The teacher instructed the students to help them understand PjBL. The teacher explained the course description, subject goals, learning methods, academic performance evaluations, and evaluation criteria for student projects to the students. Providing orientation information and holding discussions with students were necessary to support learners in understanding the learning objectives. The teacher then assigned students to work on two projects. The first project aimed to create instructional media using the Scratch program. The teacher first introduced the basic Scratch program. Next, the teacher assigned students to create Scratch projects. The teacher assigned 3 students to complete 1 project.

Week 2 was the project topic approval week. The teacher approved the project and provided feedback. The students created a project plan and presented their project topics.

Weeks 3–5 were dedicated to creating and testing projects. The students created the project, tested it, and solved project problems. The teacher provided suggestions and verified procedures.

Week 6 was the presentation week. This week, the students presented their final project, listened to suggestions from the teacher and revised their work. The teacher listened, inquired about obstacles and problems, made suggestions, and encouraged and supported the project.

Week 7 was an evaluation week. The teacher assessed the students' projects, summarized the content of the lesson, and recommended books and related research for further study after the students completed the course.

The second project was to create multimedia materials for teaching through YouTube, which was conducted in weeks 8–14. The teacher set the goals of the project. Weeks 8–14 repeat the 5-step PjBL management process described for weeks 1–7.

V. Questionnaire Results

After the course was completed, RMUTP's administrative staff sent questionnaires to students enrolled in this class to evaluate the teaching. The questionnaires were divided into three parts: the learners assessed themselves with 9 questions, the quality of teachers with 12 questions and student satisfaction with online learning with 10 items. Data collected across different semesters provide insights into respondent perceptions on a 5-point Likert scale.

From a scale of 1 (very dissatisfied) to 5 (very satisfied), Table 5 presents the teaching data for semester 1 of the 2021 academic year, which was the first year of 100% online instruction due to the COVID-19 pandemic. Eighty-six students were enrolled, 85 of whom completed the questionnaire. The results of the student satisfaction survey revealed a mean score of 4.41, with a standard deviation of 0.75. These data exceed the satisfaction level of 4, which indicates that learners were generally satisfied with PjBL in online learning.

Table 5. Results of the student satisfaction questionnaire for Group 1/2021

Semester/years	No. of students enrolled	No. of respondents	Mean	S.D.
1/2021	86	85	4.41	0.75

Table 6 presents the results of the student self-assessment questionnaire for Group 1/2021. The item with the lowest score was item 9, "The learners were satisfied overall," which received a mean score of 4.33 with a standard deviation of 0.73, still exceeding the satisfaction level of 4. Overall, the data indicate that students were satisfied with PjBL in online learning. The highest-rated item was item 2, "Students attend classes on time and consistently," which scored 4.53, with a standard deviation of 0.65, which was also above the satisfaction threshold. These results suggest that students demonstrated interest in and commitment to this course.

Table 6. Results of the student self-assessment questionnaire for Group 1/2021

Question	Mean	S.D.
1. Learners clearly know the objectives and content of the course.	4.36	0.74
2. Students attend classes on time and consistently.	4.53	0.65
3. Learners participate in class activities and express opinions.	4.38	0.77
4. Learners consistently perform assigned tasks.	4.46	0.68
5. Learners regularly review lessons before going to class.	4.39	0.73
6. Learners study and research more than what the teacher teaches.	4.46	0.66
7. Students dress neatly according to university regulations.	4.42	0.79
8. Learners obtain knowledge from taking this course.	4.36	0.74
9. Learners were satisfied overall.	4.33	0.73
Mean	**4.41**	**0.72**

Table 7 presents the results of the student questionnaire assessing teaching quality for Group 1/2021. The lowest-scoring item was item 17, "Teachers use innovative teaching materials appropriately and consistently with the course content", which received a mean score of 4.24 with a standard deviation of 0.93. These data exceed the satisfaction level of 4, which indicates that students recognized that teachers appropriately and consistently used innovative teaching materials aligned with the course content. The highest-scoring item was item 21, "Instructors dress politely and speak politely, being a good example," which scored 4.49, with a standard deviation of 0.67, which was also above

the satisfaction threshold. These findings suggest that instructors maintained appropriate outfits and served as good role models during online teaching.

Table 7. Results of the student questionnaire assessing teaching quality for Group 1/2021

Question	Mean	S.D.
10. Instructors inform teaching with teaching objectives, learning activities, assessment and evaluation.	4.32	0.82
11. Teachers come to teach and finish teaching on time.	4.41	0.73
12. The instructor teaches the content completely in accordance with the teaching code and has moral and ethical insertion.	4.28	0.88
13. Teachers are enthusiastic about teaching and willing to ask students questions.	4.44	0.75
14. The teacher gives assignments and examinations and analyses the work assigned.	4.34	0.82
15. Instructors provide information and suggest sources to find knowledge for student to learn more.	4.41	0.71
16. Teachers create a classroom atmosphere where ideas are exchanged. Teachers are open to asking questions and have a variety of activities.	4.36	080
17. Teachers use innovative teaching materials appropriately and consistently with the course content.	4.24	0.93
18. Teachers give students the opportunity to ask for advice outside of class.	4.34	0.81
19. Teachers measure learning outcomes that are consistent with the content according to the teaching process.	4.29	0.91
20. The instructor announces the test scores to the learners before the end-of-semester examination.	4.26	0.91
21. Instructors dress politely and speak politely, setting a good example.	4.49	0.67
Mean	**4.35**	**0.82**

Table 8 presents the results of the student questionnaire on satisfaction with PjBL in online learning for Group 1/2021. The lowest-scoring item was item 23, "Students take full advantage of online channels", which received a mean score of 4.35 with a standard deviation of 0.75. These data exceed the satisfaction level of 4, which indicates that the students felt that they benefited fully from learning via PjBL in the online environment. The highest-scoring item was item 29, "Convenience of taking classes online", which scored 4.52, with a standard deviation of 0.70, which was also above the satisfaction threshold. These findings suggest that learners experienced significant convenience through online learning.

Table 8. Results of the student questionnaire on satisfaction with learning via PjBL in online learning for Group 1/2021

Question	Mean	SD.
22. Satisfied with online teaching.	4.36	0.75
23. Takes full advantage of online channels.	4.35	0.75
24. Links in lessons are easy to use.	4.40	0.71
25. Meets the needs of the learners.	4.38	0.77
26. Attend or follow lessons as in a regular classroom.	4.40	0.79
27. Submitting work through online channels is convenient.	4.46	0.68
28. Teachers provide information or appropriate assistance as needed to learners.	4.41	0.76
29. Convenience of taking classes online	4.52	0.70
30. Collect points from tasks exercises or homework.	4.42	0.78
31. Collect points from exams.	4.44	0.81
mean	**4.41**	**0.75**

The summary statistics are presented in Table 9. The data indicate a positive response across all semesters. The full questionnaire can be downloaded at [73].

Table 9 shows that the mean scores range from 4.41–4.77. The overall mean score of 4.57, with a standard deviation of 0.62, indicates a stable and generally positive perception.

Table 9. Questionnaire to survey students' satisfaction

Semester/years	No. of respondents	Mean	S.D.
1/2021	85	4.41	0.75
2/2021	82	4.77	0.45
1/2022	67	4.63	0.57
2/2022	71	4.52	0.60
1/2023	85	4.61	0.61
2/2023	80	4.51	0.72
Total	470	4.57	0.62

Table 10 and Fig. 2 shows the distribution of grades after the courses were completed across different semesters from 2021–2023. The vast majority of students received grades of A (n = 139) or B+ (n = 324). This result suggests that overall academic performance was high.

Table 10. Students' grades after course completion

Semester/years	Grade A	Grade B+	Grade B	Grade C+	Total
1/2021	39	41	6	0	86
2/2021	9	67	6	0	82
1/2022	66	1	0	2	69
2/2022	0	72	0	0	72
1/2023	7	70	1	0	88
2/2023	18	63	1	0	82
Total	139	324	14	2	479

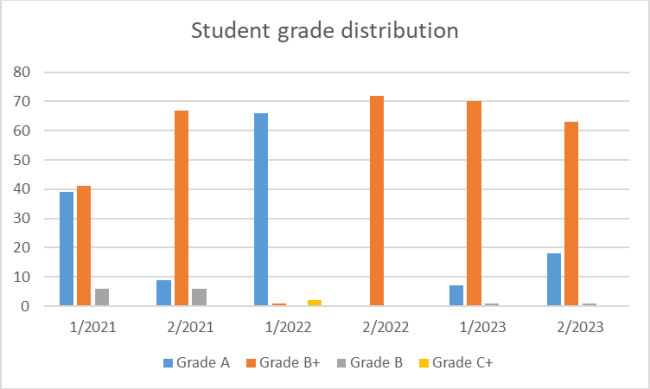

Fig. 2. Student grade distributions.

VI. Open-Ended Question Results

Data from the open-ended questions were analysed in the following six steps: collecting data, preparing data for analysis, reading through the data, coding the data, and coding the text for descriptive purposes [74]. Since the dataset contained fewer than 500 pages, the researcher conducted the analysis manually.

In semester 1 of the 2021 academic year, students expressed their positive opinions about the course as follows: 1. assignments can be applied to teaching; 2. teachers understand students and make it easy to communicate with others. A student recommended that the instructor adjust the content to be up-to-date and consistent with current events.

In semester 2 of the 2021 academic year, the students expressed their opinions about the course as follows: 1. I like the teacher's teaching process. Not difficult, easy to understand, not stressful; 2. The teachers are entertaining, and the content is very practical to work with. 3. Learners can use innovative and new technology in the classroom. Appropriate content and use of time to teach effectively; 4. Teachers have methods of teaching by adjusting teaching

methods to suit the situation of students during COVID.

In semester 1 of 2022, eight students expressed their opinions on the course as follows: 1. The teacher can explain the content well, provide full knowledge and recommend books that the teacher has read to the students; 2. Teachers teach well; 3. The teacher teaches according to the content that the students are interested in. There is humour inserted. It makes the learning environment not too stressful; 4. The instructors are skilled and dedicated to providing good experiences; 5. The teacher was very attentive in tutoring the exam; 6. Teachers bring new knowledge that students do not know or have never known before coming to lectures and introduce new things to students. The teacher teaches very well;

The teacher teaches very well. There is tutoring for exams to be integrated into the content studied and recommended research sources for knowledge to anyone interested in studying further. Makes the students receive more complete information and knowledge; 8. Teachers teach well and involve students while teaching. And give good advice when you don't understand.

In semester 2 of 2022, students did not write additional information in the open-ended questionnaire section.

In Semester 2 of 2023, four students expressed their opinions on the course as follows: 1. Thank you to the teachers for providing knowledge, concepts, and various methods that can be applied in teaching and can be used in everyday life as well; 2. Teachers understand students. The techniques that the instructor teaches can be applied to current work. It's very useful; 3. The teacher has a lot of teaching content and has gained a lot of knowledge. It's straight to the point; 4. Teachers give examples to show the overall picture of using innovation in teaching.

Based on the analysis of the results from the open-ended question, the following themes can be summarized:

1) Learners understand the content and do not experience excessive stress.
2) Learners are able to apply new knowledge in teaching their students.
3) Learners show interest in the subject matter.
4) Learners develop modern skills that can be applied in their work.

Due to the COVID-19 pandemic, instructors were required to shift from traditional classroom teaching to 100% online instruction. PjBL was adopted to reduce lecture time and prevent student fatigue from prolonged online lectures. According to the open-ended questionnaire responses, the students adapted well to online learning and demonstrated enthusiasm in researching information to create the assigned teaching materials, as shown in the results above.

The next section presents the results from students' projects.

VII. Results from Students' Projects

A. Create Instructional Videos on YouTube

During weeks 1 to 7, students created instructional videos on YouTube using various media production software such as CapCut, OBS Studio, and Windows Game Bar. Examples of student work include a video teaching the past simple tense for secondary school students (https://www.youtube.com/watch?v=AE3Pv5xN3Yc) and a video demonstrating motorcycle valve maintenance (https://www.youtube.com/watch?v=bvk9omJQ_qk&t=1s).

B. Create Instructional Materials Using the Scratch Program

During weeks 8 to 14, students developed instructional materials using the Scratch program. Examples include a multiplication table game (https://scratch.mit.edu/projects/721356920) and a waste-sorting game designed for lower primary school students (https//:scratch.mit.edu/projects/719994165).

The PjBL teaching method fosters learners' creativity by encouraging them to integrate their undergraduate knowledge with computer programs to develop instructional materials for various subjects. When using computer software to create teaching media, students are required to research and explore how to operate the programs, which promotes self-directed learning.

The next section discusses the results obtained to answer the research question.

VIII. Discussion

This research employed a mixed-methods research design. Quantitative data from the questionnaire indicated that learners were satisfied with the instruction, with a mean score of 4.57 and a standard deviation of 0.62. The majority of students, 324 out of 479, achieved a grade of B+. These data were merged with qualitative data obtained from open-ended questions, and the advantages of the PjBL method were identified and summarized into themes. These themes suggested that learners benefited from and understood the course content. Qualitative evidence supporting the research findings included students' work on YouTube and games developed using Scratch.

This section presents the following discussion to answer the research questions.

1) Is PjBL in online learning environments an effective approach to teaching Thai students in educational innovation and digital technology courses?

To answer this question, the researcher analysed the students' projects, student satisfaction and student grades and summarized the findings.

The students' projects, presented in Section VII, demonstrated their ability to design and build instructional media using YouTube and Scratch to achieve the course objectives. Through their creation of instructional materials with Scratch, students had the opportunity to apply theoretical knowledge in instructional media and programming. Additionally, peer interaction facilitated the exchange of ideas. The diversity of teaching media produced by the students was outstanding, reflecting their varied backgrounds in fields such as mathematics, science, languages, physics, chemistry, liberal arts, and home economics.

Student satisfaction, as measured by the questionnaire in Table 1, had a mean score of 4.55 across all semesters. The data indicated a positive response. The standard deviations revealed relatively stable variability with minor variations. This positive response suggested consistent learner satisfaction.

The students' grades, detailed in Table 2, predominantly fell within the B+ range. The B+ range indicated a high level of achievement. These findings suggest that PjBL in online environments is an effective approach for teaching innovation and digital technology courses to Thai students. The PjBL method allows students to apply prior knowledge from their bachelor's degree to create instructional media. PjBL promotes essential skills in critical thinking and resolution, cooperation, and interaction. These capabilities are key determinants for employment and enhanced competitiveness in both academic and practical contexts, as emphasized by the OECD [25].

2) What factors determine the effectiveness of PjBL to improve learning in online educational innovation and digital technology courses?

The questionnaire, presented in Section VII, was divided into three sections focusing on self-assessment, teacher quality, and student satisfaction. The results of the questionnaire revealed that the effectiveness of PjBL in an online environment focused on three key factors. First, students' self-rated diligence and enthusiasm significantly influenced project quality. The students were able to design and create instructional media aligned with their interests. Second, the quality of teachers directly impacted the learning process, as they followed instructional design plans and clearly understood PjBL concepts and course objectives. Finally, the management process, guided by Nilsook's PjBL framework, facilitated high levels of satisfaction with online teaching and can serve as a model for other courses.

3) What are the obstacles to teaching innovation and digital technology courses using PjBL in an online learning environment for Thai students?

The analysis presented in Section VI revealed several obstacles in the online teaching environment. First, some students were uncertain about the scope of their assigned projects. Second, the lack of face-to-face interaction presented a challenge, as students lacked the social aspect of learning. Third, online teaching was found to be more suitable for students with solid self-directed learning skills. This finding aligns with previous research by Takács and Pogatsnik [75], which highlighted the isolation experienced by students in online environments and their difficulties in managing time independently. Consequently, while online teaching offers flexibility, it may not be ideal for undergraduate programs that require close teacher guidance and regular interaction.

Fig. 3 presents an overview diagram of the research project. The first step involves the course under investigation: educational innovation and digital technology. This course is well suited for teaching using PjBL in online learning for the following reasons:

1) This course is taught at the postgraduate level, where the philosophy of teaching requires learners to build knowledge independently on the basis of their undergraduate foundation. This approach aligns with the principles of constructivism, constructionism, and experimentalism, which form the theoretical basis for PjBL in online learning [50].
2) The course focuses on new technologies that are constantly evolving, which necessitates training students to acquire new knowledge autonomously. Upon completion, students can apply these principles of self-directed learning to their professional work.
3) This course is not suitable for lecture-based teaching alone, as traditional lectures are teacher-centred and have limitations: (a) The knowledge delivered is restricted to what the instructor provides, which may be outdated, and (b) learners do not develop the ability to seek new knowledge independently.

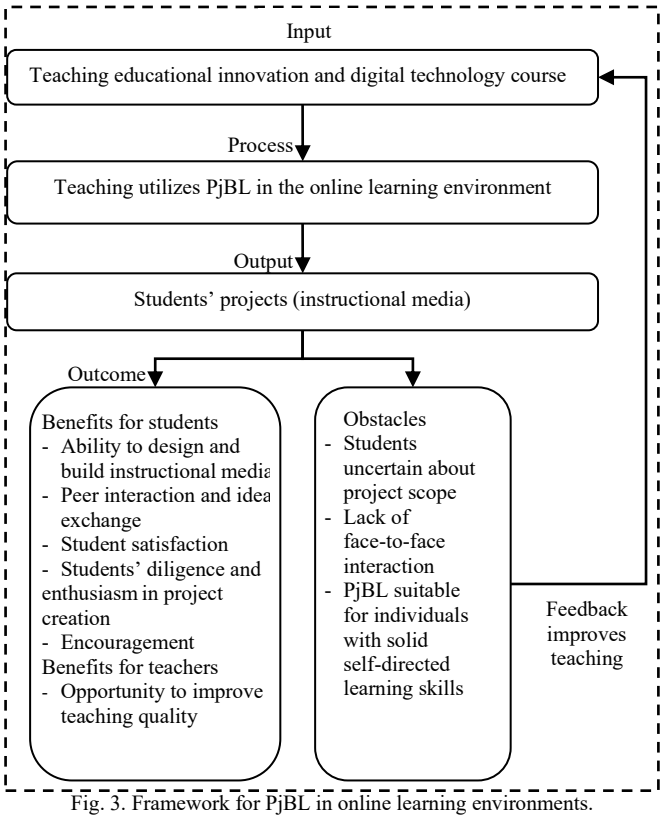

Fig. 3. Framework for PjBL in online learning environments.

In the research experiment, the students integrated technology with various undergraduate knowledge domains to create teaching materials for different subjects, such as mechanical engineering, English language teaching, and craft arts.

The second step illustrates the application of Nilsook *et al*. [50]'s PjBL, which consists of five stages. In accordance with Nilsook's research, this approach involves analysing and presenting a new framework on the basis of the PjBL framework. However, Nilsook's research has not yet been experimentally applied in teaching. This research implemented Nilsook's framework in practice, as evidenced by the following:

1) Results from the open-ended questionnaire showing student satisfaction
2) Good student grades overall
3) Student work in producing diverse teaching media, as demonstrated in the diagram of step three.

The final section summarizes the outcomes of the experiment in three categories: 1) benefits received by the students, 2) benefits received by the instructors, and 3) challenges encountered during teaching. Regarding the first outcome, the experiment demonstrated the following:

1) The PjBL method provides students with the opportunity to design and create teaching materials by applying their prior undergraduate knowledge and exploring new

technologies to develop their projects.
2) Students are engaged in exchanging ideas, which promotes social skills that are essential for the 21st-century workforce.
3) Learners expressed satisfaction with this teaching method, indicating increased engagement and interest in the course.
4) This approach encouraged students to be diligent and committed to their projects, fostering skills aligned with the course objectives.
5) PjBL in online learning effectively supports student learning.

External variables beyond the researcher's control that positively influenced the online teaching experiment were as follows:

1) The environment of the sample group, with most learners residing near Bangkok, facilitated easy internet access. Consequently, issues regarding internet stability and speed occurred less frequently for these students compared to students living in rural areas.
2) The economic status of the students, who live near the capital city and are presumed to have better financial means than those in more remote locations. This likely resulted in the sample group having access to computers and mobile devices, thereby eliminating equipment-related barriers to online learning.
3) The COVID-19 pandemic, which compelled the sample group to engage in online learning, may have increased their acceptance of this mode of instruction.

Regarding project-based learning (PjBL), external factors that affected the experiment included the learners' discipline and self-directed learning ability. The sample group ranged in age from 22 to 35 years and had completed bachelor's degrees. The participants' age and educational level may have contributed to their discipline and capacity for self-learning, resulting in effective PjBL outcomes. Applying the PjBL method to younger groups or those with education levels below a bachelor's degree may be less successful due to potentially lower discipline and self-learning abilities.

IX. Conclusions

This study revealed that PjBL in online environments is an effective approach for teaching innovation and digital technology courses to Thai students. Additionally, the factors that determined the effectiveness of PjBL in an online learning environment in this study contribute to educational research by highlighting the importance of student engagement and teacher preparedness in online PjBL environments. In particular, the information on obstacles reported in the study contribute to educational research by highlighting the need for strategies that lessen these challenges in online learning environments.

Conflict of Interest

The author declares no conflicts of interest.

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