Review Article

Online project-based learning for teacher education during the COVID-19 pandemic: A systematic review

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ARTICLE INFO	ABSTRACT
	Online project-based learning (PjBL) is an increasingly popular teaching approach in higher education, especially in teacher education. Implementing online PjBL differs across subjects, bringing many benefits while posing challenges for educators and pre-service teachers. This systematic review aims to investigate the implementation, effectiveness and challenges of adopting PjBL in teacher education during the COVID-19 pandemic. The review provided a thorough overview of research on PjBL in teacher education during the COVID-19 pandemic, which was carried out using the systematic review methodology and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Several relevant articles from five different databases (Google Scholar, Mendeley, ScienceDirect, Scopus, and Taylor & Francis Online) were collected using the keywords "project-based learning" and "teacher education" along with their synonyms. A final list of 26 included articles to be reviewed in this study is produced after the titles and abstracts screening and full texts evaluation using inclusion and exclusion criteria. This systematic review reveals that PjBL has been applied in teaching various subjects in teacher education with different types of projects and assessment methods. More importantly, integrating PjBL in teaching has been proven to positively impact the development of pre-service teachers' knowledge, professional skills and learning attitudes. In addition, applying PjBL poses certain challenges for educators due to the requirements on teachers' and students' knowledge and skills as well as equipment and technology facilities. On the other hand, the COVID-19 pandemic, if viewed positively, contributes to boosting educators' motivation and facilitating the implementation of online PjBL. The study findings can be used as a reference for future PjBL research and contribute to the literature on PjBL in the context of teacher education. **Keywords:** COVID-19 pandemic, online project-based learning, teacher education, systematic review

INTRODUCTION

The outstanding development of science and technology and the demand for online learning during the COVID-19 pandemic has fundamentally changed society's requirements for teachers' professional knowledge and skills. Therefore, higher education–with a decisive role in training responsible citizenship (Hernández-Barco et al., 2021)–has adopted modern teaching approaches that can connect the learning of teachers-students with real-life problems and their future work (Al-Busaidi & Al-Seyabi, 2021; Martinez, 2022; Poonpon, 2021; Tsybulsky & Muchnik-Rozanov, 2023). A particular example of a promising approach that improves student learning in higher education is the project-based learning (PjBL) approach (Guo et al., 2020). As a

student-centered, inquiry-based instructional approach allows learners to participate in the knowledge formation process by how discovering and providing solutions to real-world problems (Chanpet et al., 2018; Hunter-Doniger, 2018), this is an expected instructional strategy that can promote digital citizenship competencies of student-teachers (Prasetiyo et al., 2023).

PjBL originates from Piaget's and Dewey's constructivist theory, takes students' real-life experiences as the center for learning activities (Hawari & Noor, 2020), and uses projects as a media of learning (Hujjatusnaini et al., 2022). PjBL often poses a realistic situation at the beginning of a unit (Lee & Galindo, 2021; Miller et al., 2021), and then students explore, assess, interpret, and synthesize information to collect and integrate new knowledge and skills based on experience (Chung & Li, 2021; Hujjatusnaini et al., 2022; Martinez, 2022; Miller et al., 2021), and proceed to create the product, such as a report or an artifact or a performance (Sefton et al., 2020). In general, from the study of Alromaih et al. (2022), Martinez (2022), and Nava and Park (2021), it can be said that PjBL consists of the following main stages:

(1) choosing the project–usually starting from a problem discussed by the teacher,

(2) project planning–through the guidance of the teacher, students plan the implementation of the project and consider the necessary conditions,

(3) implementation of the project/authenticity–students apply their knowledge and experience to implement the proposed plan,

(4) project evaluation and reflection–this process is carried out by both the teacher and the student, taking place continuously during the project implementation and after the project is completed, and

(5) public product.

Therefore, PjBL requires students' abilities to set goals, plan, strategic project implementation, creativity, and collaboration (Sefton et al., 2020).

With the above characteristics, many studies have shown that PjBL improves the teaching effectiveness of educators and develops learners' knowledge, skills and attitudes. According to Al-Busaidi and Al-Seyabi (2021), Chanpet et al. (2018), Habibi et al. (2022), Manoban (2021), and Syawaludin et al. (2022), PjBL helps learners understand knowledge more deeply, thereby improving learning outcomes. In addition, the project implementation process with steps such as self-inquiry, self-planning, and investigation helps learners practice independent study skills (Al-Busaidi & Al-Seyabi, 2021; Goldstein, 2016; Manoban, 2021; Prasetiyo et al., 2023; Randazzo et al., 2021) and skills in conducting scientific research (Al-Busaidi & Al-Seyabi, 2021; Alromaih et al., 2022; Charania et al., 2020; Chung & Li, 2021; Rusmini et al., 2021). Furthermore, many studies have shown the positive impact of PjBL on the development of cognitive abilities of learners (Diego-Mantecon et al., 2021), such as higher-order thinking (Baran et al., 2021) like creativity (Baran et al., 2021; Wijaya. et al., 2021), critical thinking (Anggito et al., 2021; Baran et al., 2021; Habibi et al., 2022; Paristiowati et al., 2022), and problem-solving skills (Baran et al., 2021; Paristiowati et al., 2022). Besides, essential soft skills of 21st-century citizens (Martinez, 2022; Morrison et al., 2020; Prasetiyo et al., 2023; Puspitasari, 2020) such as technical skills (Charania et al., 2020), collaboration skills (Aksela & Haatainen, 2019; Alromaih et al., 2022; Baran et al., 2021; Goldstein, 2016; Manoban, 2021; Paristiowati et al., 2022), communication skills (Baran et al., 2021), time-management skills (Kamali Arslantas & Kocaoz, 2021), and students' skills in using digital technology (Al Mulhim, 2022; Baran et al., 2021; Prasetiyo et al., 2023) were also verified with progress after learning with PjBL. Besides, learning with PjBL promotes learning motivation (Aksela & Haatainen, 2019; Goldstein, 2016; Manoban, 2021), engagement (Umar & Ko, 2022), positive learning attitude (An, 2020; Brown & Jain, 2020; Diego-Mantecon et al., 2021; Goldstein, 2016; Paristiowati et al., 2022; Tsybulsky & Muchnik-Rozanov, 2021; Van Loi & Hang, 2021) and belief in energy self-efficacy (Ilyas & Saeed, 2021; Randazzo et al., 2021) and the importance of hands-on and constructivist teaching methods of learners (An, 2020; Brown & Jain, 2020). Additionally, the integration of PjBL with other educational approaches has also yielded many meaningful results, including STEAM (Diego-Mantecon et al., 2021), STEM (Morrison et al., 2020), and blended learning (Yustina et al., 2020).

Besides the benefits gained from PjBL, educators and learners face many challenges to ensure effective teaching and learning processes. According to Lee and Galindo (2021), transforming a learning environment that supports PjBL requires changing curricula and instruction and teachers' teaching thinking (Miller et al.,

2021) and is equipped with strong professional and pedagogical knowledge. At the same time, several other factors need to be considered, such as instructional materials and resources, pedagogical strategies, and assessment practices (Goldstein, 2016; Lee & Galindo, 2021). According to Aksela and Haatainen (2019) and Habibi et al. (2022), teacher performance focusing on improving teaching quality can improve students' learning motivation and higher-order thinking abilities. For students, the main challenges are related to skills in using information technology to access information resources and implement projects (Aksela & Haatainen, 2019; Al Mulhim, 2022; Alromaih et al., 2022; Chung & Li, 2021), and authentic challenges such as the abilities to execute the research steps (Al-Busaidi & Al-Seyabi, 2021), focus on project participation (Alromaih et al., 2022), and the time management skills (Aksela & Haatainen, 2019; Kamali Arslantas & Kocaoz, 2021; Nava & Park, 2021). During the COVID-19 period, on the other hand, both teachers and students are under great pressure, and limited technology skills, inconvenient online communication, project time constraints, and inexperienced management skills have delayed their work (Poonpon, 2021; Prasetiyo et al., 2023), are also significant difficulties for the implementation of PjBL. In addition, implementing teaching strategies such as PjBL also requires investing financial resources, references, tools, and devices for educational institutions, teachers and students (Alromaih et al., 2022).

One of the goals of teacher education is to develop teachers' professional competencies, including content knowledge, pedagogical knowledge and skills, development of cognitive competence, and positive attitudes and beliefs (Buchholtz et al., 2018). Higher education has a decisive role in training responsible citizens. Sustainable practices and policies should be developed to promote green attitudes at university and higher education institutions and to favor the acquisition of sustainable management models to generate sustainable ways of thinking by learners (Gutiérrez et al., 2006; as cited in Hernández-Barco et al., 2021). According to Prasetiyo et al. (2023), PjBL is an instructional strategy to foster digital citizenship competencies in student-teachers. Research by the authors Tsybulsky and Muchnik-Rozanov (2021) and Tsybulsky and Oz (2019) also shows that learning with PjBL affects pre-service teachers' beliefs and positive attitudes about the ability to use PjBL in future teaching. But when it comes to educational technology courses for pre-service teachers, this adaptation becomes even more challenging (Umutlu, 2022). The study of Umutlu (2022) offers implications for design of online teacher education courses promoting pre-service teachers' technological pedagogical content knowledge with TPACK framework. TPACK framework, suggesting that teachers learn to integrate technology effectively by combining their content area and pedagogical knowledge, is appropriate to be used in design of courses for pre-service teachers' learning to form teachers' knowledge required to create meaningful learning experiences in technology-integrated classes (Yadav et al., 2017).

During the COVID-19 pandemic, the application of PjBL in teacher education has been integrated with online PjBL (Al Mulhim, 2022). Online PjBL is a complete teaching technique in which students work together to study and solve an issue in an organized and supportive online environment via online instruction (Awuor et al., 2022; Habibi et al., 2022). Many studies have shown that social networking platforms such as Instagram, Twitter, and Facebook (Chung & Li, 2021) and online learning platforms such as Google Classroom, WhatsApp, YouTube, and Zoom (Anggito et al., 2021; Paristiowati et al., 2022) are effective for the online PjBL implementation in teaching during the COVID-19 pandemic. Accordingly, Prasetiyo et al. (2023) believe online PBL can promote digital citizenship competencies among teachers and students. Through a PjBL, student-teachers are motivated to seek out and validate information citizens, thereby developing into informed and active (Prasetiyo et al., 2023). The need to investigate and improve the quality of the application of PjBL has prompted a variety of studies conducted across different subjects of teacher education to examine the implementation of PjBL, its effectiveness, and the various challenges that PjBL poses to educators, pre-service teachers and institutions. Therefore, there is a demand for review studies to be carried out to survey the overview of relevant studies and to provide educators and researchers with references on how to effectively implement PjBL, different results and challenges when adopting this approach to the teaching process. Some review studies on PjBL have been conducted by authors such as Guo et al. (2020) and Rahmawati et al. (2020), which mainly describe how technology integrated with PjBL and student outcomes.

In this systematic review, we include articles that discuss the use of PjBL in teacher education during the COVID-19 pandemic. To address the research questions, the review aims to identify, analyze, and discuss how PjBL is applied in teacher education, including how well it affects student-teacher outcomes and the various challenges stakeholders face.
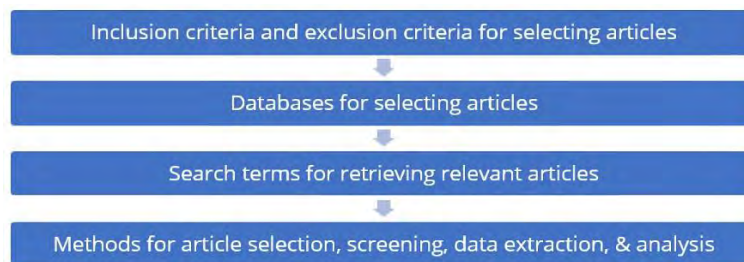
Figure 1. Protocols for article selection (Source: Authors)

Purpose of the Study and Research Questions

This systematic review aims to determine the implementation, effectiveness, and challenges of applying PjBL in teacher education. Based on the aims of this study, the following research questions were defined to clarify the focus of this review:

RQ1. What are the demographic characteristics of the included articles (such as publication year, geographic distribution, subjects, types of projects, and technological support)?

RQ2. Which instruments are used to evaluate the effectiveness of PjBL?

RQ3. What are the main pre-service teachers' outcomes of PjBL in teacher education?

RQ4. What are the advantages and challenges of using online PjBL in teacher education during the COVID-19 pandemic?

METHOD

Design

The systematic review methodology was used to conduct the review. Dempster (2011; cited in Hanley & Cutts, 2013) defines a systematic review as a thorough review of the literature that differs from a conventional literature review in that it is carried out methodically (or systematically) by a pre-specified protocol to minimize bias and synthesize the retrieved information. A systematic review is also useful in summarizing the current evidence within a specific domain and can improve the accuracy of conclusions by showing whether findings across multiple studies are consistent and generalizable (Juhl & Lund, 2018). A systematic literature review has been conducted per the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines to provide a comprehensive picture of the existing research on PjBL teacher education (Moher et al., 2010). This design was similarly used in the research of Chuang and Jamiat (2023). The aim is to investigate selected articles to answer the research questions. After finalizing the research questions of the review, a search protocol was identified. This protocol was necessary to minimize any possibility of research bias (Kitchenham & Charters, 2007; as cited in Alammary, 2019). **Figure 1** represents the research protocols.

Search Methods

Databases were searched in February 2023 to identify articles investigating PjBL in teacher education. Various electronic databases, including Google Scholar, Mendeley, Scopus, ScienceDirect, and Taylor & Francis Online were chosen due to their online accessibility and the wide range of education-related research offered. Nevertheless, to narrow the scope of this study and to minimize the number of the selected studies with poorer quality, only those articles listed in the Scopus index were chosen after being checked through the Scopus resource system. To search for relevant articles, the Boolean search filtering together with the following search strings were used: (pre-service teacher) AND (project-based learning), (prospective teacher) AND (project-based learning), (teacher education) AND (project-based learning), (pre-service teacher) AND (PjBL), (prospective teacher) AND (PjBL), (teacher education) AND (PjBL). The syntax of these search strings may be modified to be appropriate for each database.

On the other hand, to avoid bias in finding relevant articles, the authors of this study independently searched for articles on these databases based on the above search strings and included and excluded articles

based on screening full texts with inclusion and exclusion criteria. In addition, considering the methodological value of the included articles was a crucial step in the review process. Criteria for assessing the quality of all important aspects of research methodology included theoretical background, study design, data collection, data analysis, interpretation, and conclusions. They first worked independently to assess whether each criterion was well described and then discussed the results until they reached an agreement. After discussions, articles with the entire authors' consensus were selected.

Search Limits

The searches were limited to English and peer-reviewed articles published from 2020 to 2023. Additionally, the searches were not limited by researchers' latest publications, which means that different articles by the same researchers could be included if they met the search criteria.

Inclusion Criteria

The articles were considered for inclusion based on the study's objectives if they satisfied the following three criteria:

(1) related to the context of teacher education,

(2) related to the adoption of PjBL in teaching pre-service teachers, and

(3) describe an experimental educational intervention or a survey on implementation, effectiveness, and challenges of PjBL in teaching pre-service teachers.

Exclusion Criteria

Articles were excluded if

(1) the paper was not an original article,

(2) the research design was neither an experimental study nor a survey study,

(3) the teaching approach was not PjBL, or

(4) the results were not related to the implementation, effectiveness, and challenges of PjBL in teaching pre-service teachers, or

(5) the context was not teacher education.

Search Outcomes

The search for articles yielded 212 related articles. The End-Note reference management software created a database of these articles, including their titles, abstracts, and full texts. After identifying duplicate articles and screening article titles and abstracts, 147 articles were excluded. Full-text review and assessment of eligibility were conducted to select the included articles. A number of 39 articles that did not meet the inclusion criteria were excluded. The process retained 26 relevant articles for investigation in this systematic review. The process of selecting articles, as recommended by PRISMA, is described in **Figure 2**.

Data Extraction and Analysis

According to the themes that emerged from the research questions, the extracted data were analyzed descriptively and qualitatively using a narrative format. These themes included demographic characteristics (publication year and geographic distribution, subject matter domains, types of projects, and technological support), instruments used to evaluate the effectiveness of PjBL, student outcomes, benefits and challenges of using online PjBL in teacher education during the COVID-19 pandemic.

RESULTS

Demographic Characteristics

Publication year

The distribution of publication year of included articles is shown in **Figure 3**. It can be seen that, out of a total of 26 included articles, there are the most published articles in 2021 (13 articles, accounting for 50%) and
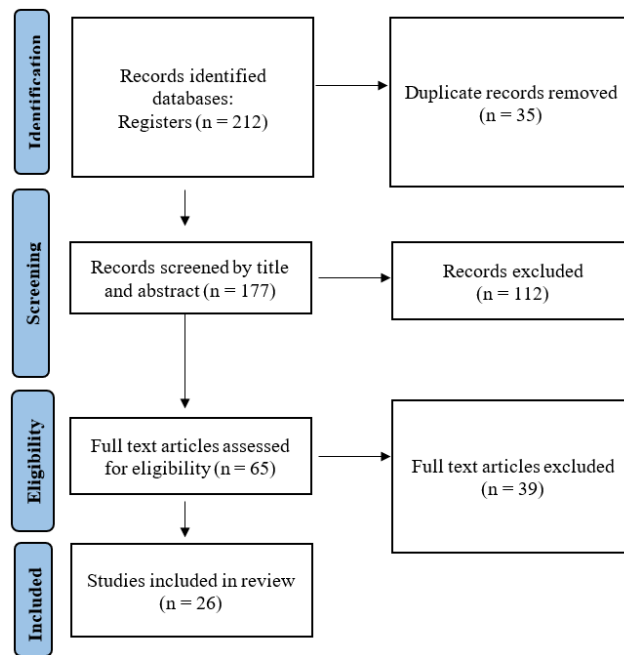
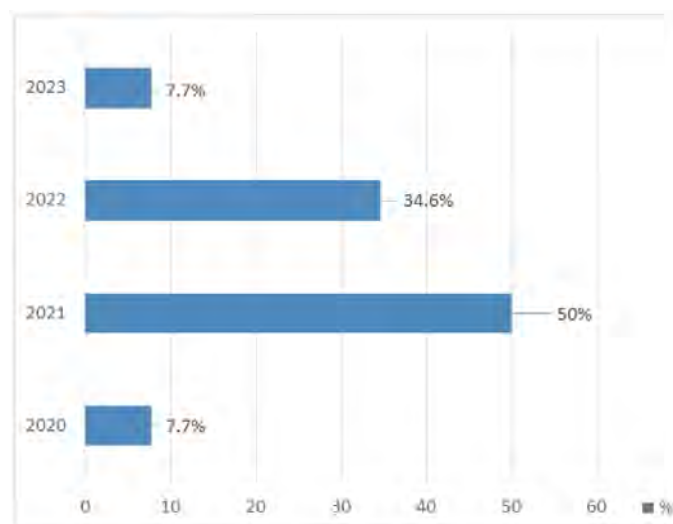**Figure 2.** Review process based on Moher et al. (2010)

Figure 3. Publication year distribution of the included articles (Source: Authors)

2022 (nine articles, 34.6%). Only two articles (accounting for 7.7%) were published in 2020, and two articles (accounting for 7.7%) were published in 2023 (as of February). It can be seen that the number of studies conducted in 2020 is very low compared to 2021 and 2022; this may be the impact of the disruption of educational activities in countries during the period when the COVID-19 pandemic took place most explosively. However, after a certain adaptation period and to meet the learning needs during the COVID-19 pandemic, online PjBL studies have been accelerated in the years 2021-2023 (Paristiowati et al., 2022; Poonpon, 2021; Prasetiyo et al., 2023; Rusmini et al., 2021; Schina et al., 2021; Tsybulsky & Muchnik-Rozanov, 2023; Yustina et al., 2020).

Geographic distribution

Figure 4 shows the geographic distribution of the included articles. According to Andersen et al. (2022), surveying the geographical origin of studies is important because the context of intervention determines the extent to which these studies can be compared with other cases and the future, and learning design interventions may vary across cultures. Most studies were conducted in Indonesia (eight articles) and the USA
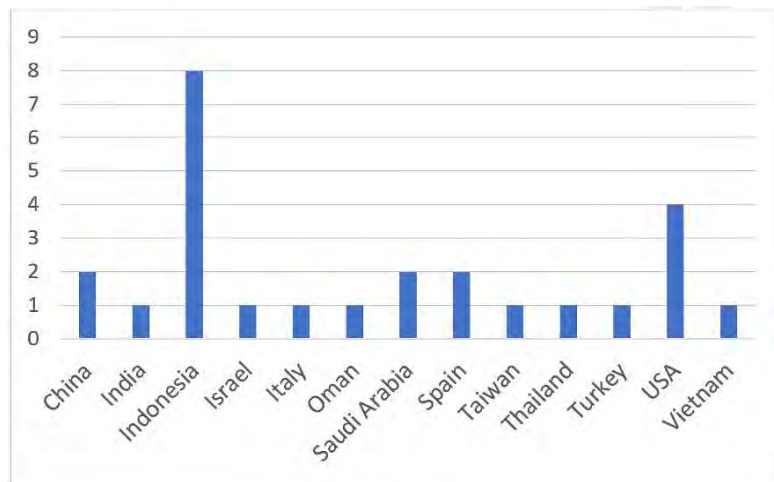
Figure 4. Geographic distribution of the included articles (Source: Authors)

Table 1. Subject distribution of the included articles

No.	Subject	Selected articles	Number of articles	Percentage
1	Arts education	Chung and Li (2021)	1	3.85%
2	Biology education	Hujjatusnaini et al. (2022) & Yustina et al. (2020)	2	7.70%
3	Chemistry education	Domenici (2022), Paristiowati et al. (2022), & Rusmini et al. (2021)	3	11.54%
4	Curriculum & instruction	Martinez (2022)	1	3.85%
5	English language education	Al-Busaidi and Al-Seyabi (2021), Habibi et al. (2022), Poonpon (2021), & Van Loi and Hang (2021)	4	15.38%
6	Elementary education	Syawaludin et al. (2022)	1	3.85%
7	Instructional technology education	Kamali Arslantas and Kocaoz (2021)	1	3.85%
8	Mathematics education	Kholid et al. (2022), Lee and Galindo (2021), Nava and Park (2021), & Wijaya et al. (2021)	4	15.38%
9	Preschool education	Alromaih et al. (2022), Brown and Jain (2020), Elfeky et al. (2022), & Schina et al. (2021)	4	15.38%
10	Science education	Hernández-Barco et al. (2021), Nava and Park (2021), & Syawaludin et al. (2022)	3	11.54%
11	Technology education	Lin et al. (2021)	1	3.85%
12	Not mentioned	Prasetiyo et al. (2023) & Tsybulsky & Muchnik-Rozanov (2023)	2	7.70%

(four articles). The remaining included articles are made in countries including China=2, Saudi Arabia=2, Spain=2, India=1, Israel=1, Italy=1, Oman=1, Taiwan=1, Thailand=1, Turkey=1, and Vietnam=1.

It can be seen that there are a significant number of studies on the implementation of PjBL in teacher education conducted in Asian countries in recent years, especially in Indonesia. Accordingly, PjBL is a learning strategy researchers interested in Asia-related countries might find interesting to study. Especially in countries that suffered the COVID-19 pandemic, PjBL has the potential to increase pre-service teacher learning activities and motivation as well as lecturer teaching practice when utilizing online learning.

Subject distribution

PjBL can be applied in many areas of teacher education (**Table 1**). Some researchers reported investigating the application of PjBL in more than one subject, and each subject was included in these data. Pre-school education, English language education and mathematics education are the majors with the highest number of studies out of the 26 articles, with four articles for each subject (15.38%). In addition, many studies have also been carried out in the fields of training teachers for natural subjects such as science education (three articles, accounting for 11.54%), chemistry education (3 articles, accounting for 11.54%) and biology education (two articles, accounting for 7.70%).

Table 2. Research designs of the included articles

No.	Research designs	Selected articles	Number of articles	Percentage
1	Experimental study	Alromaih et al. (2022), Brown and Jain (2020), Elfeky et al. (2022), Hujjatusnaini et al. (2022), Huo et al. (2021), Kholid et al. (2022), Lin et al. (2021), Nava and Park (2021), Poonpon (2021), Schina et al. (2021), Syawaludin et al. (2022), Van Loi and Hang (2021), & Yustina et al. (2020)	13	50.00%
2	Case study	Chung and Li (2021), Domenici (2022), Paristiowati et al. (2022), Prasetiyo et al. (2023), Rusmini et al. (2021), Tsybulsky and Muchnik-Rozanov (2023), & Wijaya et al. (2021)	7	26.92%
3	Survey	Al-Busaidi and Al-Seyabi (2021) & Habibi et al. (2022), Martinez (2022)	3	11.54%
4	Interview	Alromaih et al. (2022) & Kamali Arslantas and Kocaoz (2021)	2	7.69%
5	Phenomenological study	Lee and Galindo (2021)	1	3.85%

Table 3. Research methods of the included articles

No.	Research methods	Selected articles	Number of articles	Percentage
1	Mixed	Alromaih et al. (2022), Brown and Jain (2020), Elfeky et al. (2022), Habibi et al. (2022), Hujjatusnaini et al. (2022), Huo et al. (2021), Kamali Arslantas and Kocaoz (2021), Lin et al. (2021), Martinez (2022), Rusmini et al. (2021), Schina et al. (2021), & Van Loi and Hang (2021)	12	46.15%
2	Qualitative research	Al-Busaidi and Al-Seyabi (2021), Chung and Li (2021), Domenici (2022), Hernández-Barco et al. (2021), Lee and Galindo (2021), Nava and Park (2021), Paristiowati et al. (2022), Poonpon (2021), Prasetiyo et al. (2023), Tsybulsky and Muchnik-Rozanov (2023), Wijaya et al. (2021), & Yustina et al. (2020)	12	46.15%
3	Quantitative research	Kholid et al. (2022) & Syawaludin et al. (2022)	2	7.70%

In addition, PjBL is also used in teaching disciplines such as arts education, technology education, elementary education, instructional technology education, and curriculum and instruction (one article for each subject).

Methods

Research designs

Many studies have been conducted with diverse research designs to investigate the effectiveness, advantages and challenges of using PjBL in teacher education (**Table 2**). Experimental study (13 articles, accounting for 50%) and a case study (seven articles, accounting for 26.92%) are two research designs used in most included articles. Accordingly, researchers perform an intervention on specific research subjects (with or without a control group) and test the effect of the effect to conclude. Besides, a survey (three articles), interview (two articles) and phenomenological study (one article) were also used to clarify the above aspects of PjBL.

Research methods

Various research methods have been employed to verify the findings produced by the above research designs, as shown in **Table 3**, where mixed and qualitative research methods account for a significant portion (46.15%, respectively). Studies that performed only quantitative analysis accounted for only 7.70% of the total included articles

Sample

The studies reported in included articles have been conducted on pre-service teachers who are studying for bachelor and master degrees in teacher education at universities and who have taken courses taught with PjBL prior to or participating in the study's intervention. Sample size has a large difference between studies

Table 4. Instruments used in the included articles

No.	Instruments	Selected articles	Number of articles	Percentage
1	Survey	Al-Busaidi and Al-Seyabi (2021), Alromaih et al. (2022), Brown and Jain (2020), Domenici (2022), Habibi et al. (2022), Hernández-Barco et al. (2021), Hujjatusnaini et al. (2022), Huo et al. (2021), , Martinez (2022), Paristiowati et al. (2022), Rusmini et al. (2021), & Schina et al. (2021)	12	46.15%
2	Interview	Alromaih et al. (2022), Chung and Li (2021), Kamali Arslantas and Kocaoz (2021), Lee and Galindo (2021), Lin et al. (2021), Martinez (2022), Paristiowati et al. (2022), Poonpon (2021), Prasetiyo et al. (2023), & Van Loi and Hang (2021)	10	38.46%
3	Written reflections/ reflective journals	Domenici (2022, Lee and Galindo (2021), Nava and Park (2021), Poonpon (2021), Paristiowati et al. (2022), Prasetiyo et al. (2023), Schina et al. (2021), & Tsybulsky and Muchnik-Rozanov (2023),	8	30.77%
4	Assessment scales	Elfeky et al. (2022), Kamali Arslantas and Kocaoz (2021), Kholid et al. (2022), Rusmini et al. (2021), Syawaludin et al. (2022), & Yustina et al. (2020)	6	23.08%
5	Tests	Kholid et al. (2022), Syawaludin et al. (2022), Van Loi and Hang (2021), & Yustina et al. (2020),	4	15.38%
6	Observations	Paristiowati et al. (2022), Prasetiyo et al. (2023), & Rusmini et al. (2021)	3	11.54%
7	Flow-map	Lin et al. (2021)	1	3.85%
8	Portfolios	Paristiowati et al. (2022)	1	3.85%
9	Self-reported questionnaire	Brown and Jain (2020)	1	3.85%

with different research designs. There are 12 studies with a number of participants less than 50 and 14 studies with more than 50 participants. The smallest sample size among the above studies is four participants in a case study by Chung and Li (2021), and a survey study by Habibi et al. (2022) has the largest sample size with 350 participants.

Duration

Duration of interventions is one of the most commonly described parameters of learning design (Andersen et al., 2022). Duration of the study conducting the intervention or the time of pre-service teachers learning with the PjBL approach of the included articles varied quite widely, ranging from two weeks (Chung & Li, 2021) to a year (Kamali Arslantas & Kocaoz, 2021; Lee & Galindo, 2021), takes place in the years from 2019 to 2022. In which most of the included articles, this process takes place in about one-two semesters (no less than 16 weeks), including Al-Busaidi and Al-Seyabi (2021), Alromaih et al. (2022), Brown and Jain (2020), Elfeky et al. (2022), Habibi et al. (2022), Hernández-Barco et al. (2021), Huo et al. (2021), Lin et al. (2021), Martinez (2022), Poonpon (2021), Schina et al. (2021), Tsybulsky and Muchnik-Rozanov (2023), Van Loi and Hang (2021), and Yustina et al. (2020). The remaining studies had durations ranging from two to 15 weeks. Most studies were conducted between 2019 and 2022 when the COVID-19 pandemic strained many world regions. Specifically, several studies have described process of conducting interventions with the application of PjBL in teaching during the COVID-19 pandemic (Paristiowati et al., 2022; Poonpon, 2021; Prasetiyo et al., 2023; Rusmini et al., 2021; Schina et al., 2021; Tsybulsky and Muchnik-Rozanov, 2023; Yustina et al., 2020).

Instruments

In order to assess pre-service teacher outcomes and investigate the advantages and disadvantages of using PjBL in teaching pre-service teachers, researchers have used various instruments (**Table 4**). The highest percentage used were surveyed (online and offline survey, 12 articles, accounting for 46.15%), interviews (face-to-face and virtual interviews, ten articles, accounting for 38.46%), and written reflections or reflective journals (eight articles, accounting for 30.77%), to survey the effectiveness, learning experiences, attitudes, and challenges for pre-service teachers in PjBL. In addition, tests (pre/post-test and post-test, accounting for 15.38%), classroom observations, flow-maps, portfolios, and self-reported questionnaires were also used in the studies. In addition, to evaluate the effectiveness of PjBL on the development of specific skills of

Table 5. Projects used in the included articles

No.	Type of projects	Selected articles
1	Instructional design/lesson plan design	Alromaih et al. (2022): Designing instructional units for teaching at kindergarten level; Nava and Park (2021): Designing PBL lesson plans; Poonpon (2021): Designing online lessons for rural school students; & Schina et al. (2021): Composing lesson plans that cover socioeconomic concerns & habitat preservation
2	Curriculum design	Martinez (2022): Crafting an integrated curriculum aligned with industry-based technical knowledge & principles
3	Final reflection	Nava and Park (2021): Reflecting on, analyzing, & interpreting their meaningful experiences; Tsybulsky and Muchnik-Rozanov (2023): Reflecting on, analyzing, & interpreting their meaningful experiences; & Brown and Jain (2020): Reporting on early childhood methodologies & pedagogy used in a field experience in conducting projects with young children
4	Worksheet writing project	Syawaludin et al. (2022): Searching information through the Internet, writing down results of analysis, & compiling reports
5	Laboratory experimentation	Hujjatusnaini et al. (2022): Experimenting on the mucosal immune system–probiotic supplementation in producing s-IgA in serum Balb/c mice as an immune system & Rusmini et al. (2021): Extracting substances
6	Learning material design	Huo et al. (2021): Developing the virtual reality educational software; Kamali Arslantas and Kocaoz (2021): Developing animations for teaching daily life skills to students with intellectual disability; Kholid et al. (2022): Presenting various perspectives of analytic geometry in GeoGebra software; Schina et al. (2021): Composing lesson plans that cover socioeconomic concerns & habitat preservation; & Wijaya et al. (2021): Designing attractive & interactive mathematics learning materials
7	Final product design & construction/ artifacts	Chung and Li (2021): Creating virtual reality art gallery exhibition; Elfeky et al. (2022): Designing & constructing art project; Hernández-Barco et al. (2021): Designing & constructing a rocket using recycled materials; Huo et al. (2021): Creating 3D scenes with Unity 3D; Lin et al. (2021): Making a mousetrap car that could travel more than 10 meters on a 1-meter-wide track; & Paristiowati et al. (2022): Developing projects using agro-industry products that integrate with sustainable agro-industry business ideas
8	Practicum report	Rusmini et al. (2021): Preparing a video presentation of their project (including titles, problem formulations, experimental objectives, theoretical studies, hypotheses, manipulation, response & control variables, tools and materials, working steps, observational data tables, & conclusion) & Schina et al. (2021): Preparing a video presentation of their project (learning objectives of their lesson plan, teaching procedure, activity description, & instructional materials developed for given lesson plan)
9	Others	Al-Busaidi and Al-Seyabi (2021), Habibi et al. (2022), Lee and Galindo (2021), Yustina et al. (2020), Domenici (2022), Van Loi and Hang (2021), & Prasetiyo et al. (2023)

participants, the research teams also used assessment scales (six articles, accounting for 23.08%), specifically the art skills scale (Elfeky et al., 2022), creativity scale (Elfeky et al., 2022; Yustina et al., 2020), assessment scale of science process skills (Rusmini et al., 2021, Syawaludin et al., 2022), geometry scale analytic scale (Kholid et al., 2022), and mentorship effectiveness scale (Kamali Arslantas and Kocaoz, 2021).

Types of Projects Commonly Used in the Included Articles

The included articles' statistics show eight main types of projects done during pre-service teacher learning with the PjBL approach (**Table 5**).

Some researchers reported using more than one type of project, and each type was included in these data. In particular, due to teacher education's goal of equipping students with pedagogical skills, including lesson preparation skills, the number of projects related to instructional design/lesson plan design, learning material design and curriculum design accounts for a high percentage of the total included articles (four articles, five articles, and one article, respectively). These teaching designs were conducted with different kinds of students (kindergarten, rural school students, students with intellectual disabilities, etc.), subjects (mathematics, science, English, life skills, etc.), off-line or online environments and combined different technological elements (software, animations).

On the other hand, the most used ratio is final product design and construction/or artifacts related to the creation of art products and the construction of technology-real products (six articles). Besides, projects such as worksheet writing projects (one article) and laboratory experimentation (two articles) are also used to facilitate students in improving their professional knowledge. In addition, to evaluate the entire learning process of pre-service teachers, projects that require students to perform final reflection (two articles) and

practicum reports (two articles) are also used. **Table 5** details the characteristics and requirements of the above projects.

Common Technological Tools Used in the Included Articles

The technology elements incorporated when applying PjBL in the included articles can be divided into two groups: those used for delivering lectures and technology elements used when implementing the project. Technology elements used to deliver lectures include online learning platforms such as Collaborate ultra experience LTI virtual classroom (Elfeky et al., 2022), Google Classroom (Paristiowati et al., 2022; Yustina et al., 2020), WhatsApp (Paristiowati et al., 2022), YouTube (Paristiowati et al., 2022), and Zoom (Paristiowati et al., 2022; Syawaludin et al., 2022). Technology elements used when pre-service teachers work on the project include 3D visual virtual reality (Chung & Li, 2021; Huo et al., 2021), GeoGebra software (Kholid et al., 2022), Hawgent dynamic mathematics software (Wijaya et al., 2021), and educational robotics tools (Schina et al., 2021). In general, the above platforms can be operated on various devices, allowing students to study anywhere and anytime, following the needs of independent learning in the current era. COVID-19 epidemic (Huo et al., 2021). On the other hand, using technology when implementing the project gives teachers opportunities for "hands-on" work and handles teachers' needs (Hew & Brush, 2007; as cited in Schina et al., 2021).

Pre-Service Teacher Outcomes of Learning With Online Project-Based Learning

Included articles examined the effectiveness of PjBL for improving pre-service teachers' knowledge, skills and attitude through learning and project implementation (**Table 6**).

Table 6. Pre-service teacher outcomes

No.	Outcomes	Selected articles	Number of articles	Percentage
Knowledge				
1	Increasing learning outcomes	Habibi et al. (2022)	1	3.85%
2	Increasing understanding & constructing specific knowledge	Brown and Jain (2020), Kamali Arslantas and Kocaoz (2021), & Kholid et al. (2022)	3	11.54%
Skills				
3	Academic	Al-Busaidi and Al-Seyabi (2021), Alromaih et al. (2022), Hou et al. (2021), Kamali Arslantas and Kocaoz (2021), & Van Loi and Hang (2021)	5	19.23%
4	Cognitive & skill aspects of instructional design	Al-Busaidi and Al-Seyabi (2021), Alromaih et al. (2022), Kamali Arslantas and Kocaoz (2021), & Lin et al. (2021)	3	11.54%
5	Pedagogical growth	Kamali Arslantas and Kocaoz (2021)	1	3.85%
6	Analytical abilities/science process	Lin et al. (2021), Rusmini et al. (2021), & Syawaludin et al. (2022),	3	11.54%
7	Digital	Hou et al. (2021) & Prasetiyo et al. (2023)	2	7.70%
8	Higher-order thinking	Hujjatusnaini et al. (2022), Lin et al. (2021), & Paristiowati et al. (2022)	3	11.54%
9	Problem-solving	Poonpon (2021) & Wijaya et al. (2021)	2	7.70%
10	Creative thinking	Elfeky et al. (2022), Poonpon (2021), Wijaya et al. (2021), & Yustina et al. (2020)	4	15.38%
11	Analogical/metaphorical thinking	Elfeky et al. (2022)	1	3.85%
12	Collaboration/teamwork	Alromaih et al. (2022), Domenici (2022), Paristiowati et al. (2022), Poonpon (2021), & Van Loi and Hang (2021)	5	19.23%
13	Communication	Alromaih et al. (2022), Domenici (2022), Paristiowati et al. (2022), & Wijaya et al. (2021)	4	15.38%
14	Self-directed learning	Prasetiyo et al. (2023)	1	3.85%
15	Time-management skills	Kamali Arslantas and Kocaoz (2021)	1	3.85%
16	Self-efficacy	Brown and Jain (2020), Martinez (2022), & Schina et al. (2021)	3	11.54%
17	Self-agency	Tsybulsky and Muchnik-Rozanov (2023)	1	3.85%
Attitude				
18	Self-confidence	Alromaih et al. (2022), Brown and Jain (2020), Tsybulsky and Muchnik-Rozanov (2023), & Wijaya et al. (2021)	4	15.38%

No.	Outcomes	Selected articles	Number of articles	Percentage
19	Self-awareness	Paristiowati et al. (2022) & Tsybulsky and Muchnik-Rozanov (2023)	2	7.70%
20	Positive attitude	Hernández-Barco et al. (2021), Kamali Arslantas and Kocaoz (2021), Schina et al. (2021), & Van Loi and Hang (2021)	4	15.38%
21	Motivation & autonomy	Brown and Jain (2020), Lin et al. (2021), Prasetiyo et al. (2023), Tsybulsky and Muchnik-Rozanov (2023), & Van Loi and Hang (2021),	5	19.23%
22	Connecting pre-service teachers to their college study & future job	Al-Busaidi and Al-Seyabi (2021), Martinez (2022), Poonpon (2021), & Tsybulsky and Muchnik-Rozanov (2023)	4	15.38%

Regarding knowledge, four articles show the positive impact of PjBL in increasing pre-service teacher learning outcomes and understanding and specific knowledge. For the skills aspect, the analysis results reveal that pre-service teachers develop academic skills (five articles), teaching-related skills such as cognitive and skill aspects of instructional design (three articles) and pedagogical skills (one article), scientific research skills (three articles) and digital skills (one article). Besides, through the use of competency assessment scales, many studies have shown the effectiveness of PjBL in the development of cognitive skills of teachers-students such as higher-order thinking skills (three articles), problem-solving skills (two articles), creative thinking skills (four articles), and analogical/metaphorical thinking skills (one article).

In addition, participants in the articles included have progressed due to the nature of group project activities and the impact of independent learning and research (especially during the COVID-19 pandemic). These benefits are a set of essential soft skills of citizens of the 21st-century (Martinez, 2022; Prasetiyo et al., 2023), such as collaboration and teamwork skills (five articles), communication skills (four articles), self-directed learning skills (one article), time-management skills (one article), self-efficacy skills (three articles), self-agency skills (one article). In terms of attitude, applying PjBL in teaching has changed the students' learning environment from a traditional approach to a student-centered and practical one (Hunter-Doniger, 2018) and has positively impacted students' learning attitudes. Studies show that through learning with PjBL, pre-service teachers become more self-confident (one article), gain self-awareness (two articles), have a positive attitude (four articles), motivation and autonomy (five articles). Also, PjBL can connect pre-service teachers to their college studies and future job (four articles).

Advantages and Challenges of Adopting Online Project-Based Learning During the COVID-19 Pandemic

PjBL has many advantages for the teaching process and the growth of students' knowledge, skills, and attitudes, but it also presents many challenges for teachers to use it effectively. **Table 7** shows the human factors and equipment challenges for the PjBL implementation. Regarding the human factors, for both learners and teachers, issues of technology and multimedia skills, content and pedagogical knowledge, project management skills, time management skills, science process skills, and pressure affect the quality of their work on PjBL and projects. In particular, the skills and knowledge requirements when implementing a PjBL environment pose a challenge regarding teacher training. In addition to the human factors, the availability and accessibility of information resources and computer equipment, digital inequalities across regions, online communication platforms, and the need to exchange and share in the community about PjBL implementation. The limitation in skill training time for learners and project implementation time is also considered difficult for teachers in PjBL implementation and affects students' ability to complete projects.

Despite the challenges brought on by concerns about social isolation and health safety in the context of the COVID-19 pandemic, educators have seized many opportunities in the online PBL environment. (Schina et al., 2021). Schina et al. (2021) argue that the COVID-19 pandemic allows universities to change and rethink teachers' online education and digital technology content. According to Rusmini et al. (2021), learning during the pandemic, when students perform academic tasks independently, has boosted students' competencies, especially scientific inquiry and research skills, increased motivation and positive learning attitude. The growth of pre-service teachers' creative abilities is also facilitated by the integration of blended learning and PjBL

Table 7. Challenges of implementing online project-based learning

No.	Challenges	Selected articles
1	Technology & multimedia skills	Poonpon (2021)
2	Project management skills	Poonpon (2021)
3	Time management skills	Kamali Arslantas and Kocaoz (2021) & Nava and Park (2021)
4	Science process skills	Al-Busaidi and Al-Seyabi (2021) & Alromaih et al. (2022)
5	Content & pedagogical knowledge	Al-Busaidi and Al-Seyabi (2021) & Lee and Galindo (2021)
6	Teacher's training	Chung and Li (2021)
7	Information resources	Alromaih et al. (2022) & Chung and Li (2021)
8	Computer equipment	Chung and Li (2021)
9	Digital inequalities	Prasetiyo et al. (2023)
10	Online communication	Poonpon (2021)
11	Community	Lee and Galindo (2021)
12	Project time limitations	Al-Busaidi and Al-Seyabi (2021)
13	Longer training time	Alromaih et al. (2022)
14	Pressure	Prasetiyo et al. (2023)

(Yustina et al., 2020). In terms of facilities, taking advantage of the online learning facilities that schools have prepared to respond to the COVID-19 pandemic, such as internet network device facilities, teachers and students can use them to facilitate teaching and learning with PjBL (Yustina et al., 2020).

DISCUSSION

In this systematic review, the following research questions were asked:

RQ1. What are the demographic characteristics of the included articles (such as publication year, geographic distribution, subjects, types of projects, and technological support)?

RQ2. Which instruments are used to evaluate the effectiveness of PjBL?

RQ3. What are the main pre-service teachers' outcomes of PjBL in teacher education?

RQ4. What are the advantages and challenges of using online PjBL in teacher education during the COVID-19 pandemic?

A systematic literature review has been conducted per PRISMA guidelines to answer research questions.

The first research question examines the demographic characteristics of 26 included articles, such as the publication year and geographic distribution of the article, and the subjects, types of projects and technical support mentioned in those studies. The analysis results show that from 2020 to February 2023, studies on applying PjBL in teacher education were published the most in 2021 and 2022, and online PBL was also noticed. During this time, most universities have adapted to the modifications in student learning requirements and the instructional environment brought on by the COVID-19 pandemic, encouraging research to develop novel and higher-quality instructional strategies. In addition, this research question also clarifies the geographic distribution of studies on the application of PjBL in teacher education. With the interest of educators in many parts of the world, the studies included in the articles have been carried out in a total of 13 different countries, including Indonesia, the USA, China, Saudi Arabia, Spain, India, Israel, Italy, Oman, Taiwan, Thailand, Turkey, and Vietnam.

Regarding the different subjects of teacher education that PjBL has been integrating into teaching, the statistical results show that PjBL can be applied in different subjects such as curriculum and instruction, instructional technology, preschool, elementary, English language, mathematics, science, chemistry, biology, arts, and technology education. Educators can organize students to work on different projects for different subjects. From the analysis results, eight main types of projects were used, including projects that equip students with pedagogical knowledge and skills such as instructional design/lesson plan design, learning material design and curriculum design, product creation projects such as final product design and construction/or artifacts, practice projects such as worksheet writing project and laboratory experimentation, and self-assessment projects such as final reflection and practice report. With the above project implementations and educational practices during the COVID-19 pandemic, technological elements have been applied in the PjBL learning environment with two main functions, including delivering lectures and

implementing projects. Technology elements to deliver lectures include online learning platforms such as Collaborate ultra experience LTI virtual classroom, Google Classroom, WhatsApp, YouTube, and Zoom. Technological elements used when pre-service teachers work on the project include 3D visual virtual reality, GeoGebra software, Hawgent dynamic mathematics software and educational robotics tools. The above platforms can be operated on various devices, allowing students to study anywhere and anytime, in line with the need for independent learning during the COVID-19 pandemic (Huo et al., 2021).

The second research question examines the tools the selected studies used to assess the effectiveness of PjBL. Statistical results show that a variety of research designs and research methods with different sample sizes, durations and instruments were used. Commonly used research designs include experimental studies, case studies, phenomenological studies, surveys, and interviews. Besides, research methodologies like qualitative, quantitative, and mixed methods have provided a wealth of evidence on how to organize PjBL, its efficacy, and the challenges it presents. Experimental and case studies are the two most used research designs, showing the effectiveness, feasibility and reliability of these two research designs for studies on the effectiveness of PjBL. In addition, various tools were also used in the research, including surveys, interviews, written reflections or reflective journals, observations, flow-maps, portfolios, and self-reported questionnaires, to survey students' learning experiences and attitudes, the effectiveness and challenges that PjBL brings. On the other hand, to assess the development of specific skills and competence components of students, studies have designed tests and competency scales as assessment tools, including the art skills scale, creativity scale, assessment scale of science process skills, geometry analytic scale, and mentorship effectiveness scale. A review study by Gou et al. (2020) on methods to assess student learning outcomes when studying in a PjBL environment at the university level also synthesizes similar results. However, with the result that a variety of methods can be used to examine the effectiveness of PjBL in teacher education, a question is posed to researchers to investigate the use of different methods in examining different aspects of PjBL implementation. Although this issue was not addressed in the present discussion due to the scope of this study, it can serve as a recommendation for future research.

A third research question was raised to examine pre-service teacher outcomes when learning subjects with the PjBL approach. The analysis shows that pre-service teachers have improved knowledge, skills and attitude. Regarding knowledge, four articles show the positive impact of PjBL in increasing pre-service teachers' understanding and improving specific knowledge, thus improving their learning outcomes. Regarding skills, pre-service teachers develop academic skills, teaching-related skills such as cognitive and skill aspects of instructional design and pedagogical skills, scientific research, and digital skills. Besides, through the use of capacity assessment scales, many studies have shown the effectiveness of PjBL in the development of cognitive skills of teachers-students such as higher-order thinking skills, problem-solving skills, creative thinking skills, and analogical/metaphorical thinking skills and essential soft skills of 21st-century citizens (Martinez, 2022; Prasetiyo et al., 2023) such as collaboration and teamwork skills, communication skills, self-directed learning skills, time-management skills, self-efficacy skills, self-agency skills. Studies show that through studying with PjBL, pre-service teachers become self-confident, have self-awareness, a positive attitude, motivation and autonomy, and can connect pre-service teachers to their college study and future job. The structure of group project activities and the results of independent study and research, particularly during the COVID-19 pandemic, may be to blame for this. In line with that, the study of Rusmini et al. (2021) stated that learning during this pandemic, where students do more assignments independently, encouraged more effective mastery of the material and helped the students to stimulate informative and professional interest and develop creative activities and initiatives, which could consequently increase motivation and learning achievement, increase the students' involvement, and increase their learning behavior.

With the fourth research question, this systematic review analyzed the included articles to determine the advantages and challenges of applying PjBL in teaching teacher education during the COVID-19 pandemic. In general, the effectiveness of the PjBL implementation process depends on two factors, including the human factors and the equipment factors. Regarding the human factors, PjBL requires learners and teachers to have technology and multimedia skills, strong content and pedagogical knowledge, project management, time management, and science process skills. In particular, the skills and knowledge requirements when adopting a PjBL environment pose a challenge regarding teacher training. In addition to human requirements, availability and accessibility of information resources and computer equipment, digital inequalities across

regions, online communication platforms, and need to exchange and share in community about PjBL organizations, also such as problem of limitation in skill training time for learners and project implementation time poses difficulties for teachers in PjBL organizations and affects students' abilities to implement projects.

However, in the time of COVID-19, many opportunities have been exploited by educators in the online PjBL environment. Accordingly, the COVID-19 pandemic allows universities to improve and rethink the content of teachers' online education and the digital technology taught (Schina et al., 2021). Moreover, learning during the pandemic, when students perform academic tasks independently, has boosted students' competencies, especially scientific inquiry and research skills, enhanced motivation and positive learning attitude (Rusmini et al., 2021). Research by Donitsa-Schmidta and Ramot (2021) also reached similar conclusions. PjBL and blended learning together, meanwhile, have a positive impact on the growth of student-teachers' creative abilities (Yustina et al., 2020). This result indicates that PjBL can be investigated in the relationship with other innovative methodologies such as blended learning (Yustina et al., 2020), STEM (Baran et al., 2021; Lin et al., 2021), and challenge-based learning (Portuguez Castro & Gómez Zermeño, 2020), etc. In terms of facilities, taking advantage of the online learning facilities that schools have prepared to respond to the COVID-19 pandemic, such as the existence of internet network device facilities, teachers and students can use them to facilitate teaching and learning with PjBL (Yustina et al., 2020). The effectiveness of PjBL in enhancing pre-service teacher outcomes and the advantages of implementing PjBL in an online learning context can boost lecturers' motivation to use the PjBL approach in teaching practice (Yustina et al., 2020).

From above conclusions about advantages and challenges of PjBL, the study recommends equipping teachers with knowledge and skills about PjBL organization (Brown & Jain, 2020; Morrison et al., 2020), technological knowledge, and its application to remote online classes as the new normal in the future (Andersen et al., 2021; Flores, 2020; Lin et al., 2021; Poonpon, 2021). Additionally, even though pre-service teachers took PjBL-specific courses, they would have benefited from being in a school that used PjBL. As a result, pre-service teachers must have the chance to engage in field experiences consistent with what they have learned in teacher preparation programs (Lee & Galindo, 2021), as this will help for overcoming difficulties in implementing student projects, careful guidance and provision of project-specific models should be considered. Educators should guide students to work collaboratively, avoid conflicts and share resources to improve the efficiency of PjBL (Al-Busaidi & Al-Seyabi, 2021). In addition, to overcome the challenges of equipping facilities in the PjBL application, administrative support must be provided at the district level and in the classroom (Lee & Galindo, 2021). With the results concluded, this study can be used as a reference for status of studies on using PjBL in teacher education during the COVID-19 pandemic. The review studies by Rahmawati et al. (2020) and Guo et al. (2020) have similar results. Teacher training programs can benefit from course design and the findings of included articles. Researchers can benefit from the results of the challenges of applying PjBL in universities to conduct research to overcome them (Al-Busaidi & Al-Seyabi, 2021).

CONCLUSIONS

This systematic review investigates the implementation, effectiveness and challenges of applying PjBL in teacher education during the COVID-19 pandemic. The study has compiled a few broad conclusions about the research on using PjBL during the COVID-19 pandemic through analysis of the 26 included articles. Accordingly, most of the research was carried out from 2021-2022 in various countries on different continents and in subjects under teacher education. The studies have varied research designs and methods, with sample sizes ranging from four to 350 participants depending on research designs, ranging from two weeks to one year. Types of projects used mainly in research include instructional design, lesson plan and learning material design and curriculum design, final product design and construction/or artifacts, worksheet writing project and laboratory experimentation, and final reflection and practice report. In addition, the technological factors used in the studies include those used to deliver lectures, such as online learning platforms (Collaborate ultra experience LTI virtual classroom, Google Classroom, WhatsApp, YouTube, and Zoom) and technology elements used in project implementation, such as 3D visual virtual reality, GeoGebra software, Hawgent dynamic mathematics software, and educational robotics tools. With such ways of organizing PjBL, studies show that PjBL positively impacts the development of subject and pedagogical knowledge, cognitive skills, pedagogical skills and necessary skills in learning in the 21st-century, and positive learning attitudes of pre-

service teachers. At the same time, studies also show that to apply PjBL effectively, educators and learners face challenges in terms of knowledge and skills required in PjBL implementation and project implementation, as well as equipment facilities challenges and limited time. In addition, the study has certain limitations. The limitation in the selection of databases may have limited the number of articles included the variety of results and the ability to generalize the trends of the conclusions made. On the other hand, although the study selected articles published in 2020-2023 to survey the situation of the online PjBL implementation in teacher education during the COVID-19 pandemic, some selected studies have no mention of the online elements in the description of PjBL implementation. Consequently, the results on the technology factor used in online PjBL are relatively brief.

The results can be used as fundamental guidelines for future PjBL research, giving academics and industry professionals a summary of the study on using PjBL in teacher education. Practices who plan to apply PjBL in teaching can use the study results as a reference to improve their teaching design by choosing types of projects, technological supports and teaching strategies, which have the potential to enhance student outcomes and PjBL implementation and help overcome challenges of applying PjBL. Researchers who aim to investigate the role of PjBL in teacher education can benefit from the analysis of methodologies used in the included studies to design their research. From the study results and limitations, some new research directions in the future on PjBL are proposed, as follows: carrying out a systematic review on the application of PjBL and online PjBL in specific subjects of teacher education, conducting systematic review studies focusing on the influence of PjBL on specific types of learners' competencies or studying the student's project and product implementation process, implementing systematic review with more diverse article research databases, and improved measurement instruments and data analyses.

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