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The critical thinking-oriented adaptations of problem-based learning models: a systematic review

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Critical thinking is a significant twenty-first century skill that is prioritized by higher education. Problem-based learning is becoming widely accepted as an effective way to enhance critical thinking. However, as the results of studies that use PBL to develop CT have had mixed success, PBL models need to be modified to guarantee positive outcomes. This study is a systematic review that analyzed how studies have adapted Problem-Based Learning (PBL) to become more Critical Thinking (CT)-oriented, evaluated the effectiveness of these adaptations, and determined why certain adaptations were successful. The review was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) by searching the scientific databases Scopus and Web of Science. Twenty journal articles were chosen based on their adherence to the inclusion criteria established by PICo (Population, Phenomenon of Interest, and Context). In these studies, PBL adaptations were categorized into five classifications, with activities centered on CT development being the most prevalent approach. Researchers utilized a variety of analytical methodologies to assess the effectiveness of these adaptations and derive significant insights and formulate valid conclusions. An analysis of all selected studies revealed positive outcomes, indicating that incorporating CT elements into PBL was effective in enhancing students' CT. These findings were categorized into nine factors that contribute to the successful adaptation of PBL to be CT-oriented.

KEYWORDS

higher education, problem-based learning, critical thinking, educational intervention, systematic review, pedagogical adaption

1. Introduction

The twenty-first century is an era of innovation, requiring individuals to possess skills for academic excellence, success in the workplace, and the capability to cope with life. Examples of such transferable skills include communication, collaboration, creativity, problem-solving, and critical thinking (CT) (Hidayati et al., 2022). Of these, CT is frequently cited as the most crucial (National Association of Colleges Employers, 2016) for individuals to adapt to this quickly changing society (Alper, 2010). Universities view the development of students' CT skills as one of their most significant educational objectives (Facione, 2011; Erikson and Erikson, 2019) and must therefore continually refine their teaching techniques (Bezanilla et al., 2019) and establish a learning environment that improves students' CT capabilities (Evendi et al., 2022). In this way, universities can foster twenty-first-century talents with extraordinary academic performance and excellent professional skills (Hidayati et al., 2022).

Problem-based learning is gaining popularity as a method for enhancing critical thinking. However, PBL models must be adapted to ensure beneficial outcomes, as the results of studies employing PBL to enhance CT have not always been positive. Thus, it is essential to determine which aspects contribute to the success of a PBL-adapted model for developing CT and explore the reason for the success. This paper offers a systematic review of how studies have altered PBL to become more focused on critical thinking, the evaluation of those modifications, and the factors that contribute to enhanced critical thinking.

1.1. Critical thinking

While the importance of CT has been widely acknowledged, scholars from different research fields have conceptualized and defined it differently. For instance, philosophy scholars view CT as the ability to challenge an assumption, evaluate the argument and relevant information, and draw correct conclusions (Fisher, 2011); psychology scholars view CT as a broad range of thinking skills, including problem solving, decision making, and hypothesis testing (Halpern, 2010). The literature generally conceptualizes CT as comprising two equally important elements—skills (CTSs) and dispositions (CTDs). Facione (1990) believes that critical thinkers are unsuccessful if they cannot apply their CT skills effectively.

For this paper, CT is understood as consisting of: (i) making judgments (Chaffee, 1994; Snyder and Snyder, 2008; Papathanasiou et al., 2014; Ennis, 2018); (ii) evaluation (Facione, 1990; Yanchar and Slife, 2004; Fisher, 2011; and (iii) reasoning (Facione, 1990; Ennis, 2011; Elder and Paul, 2012). Characteristics commonly recognized as indispensable for CTD include: (1) open-mindedness (Ennis, 1987; Facione, 1990); (2) fair-mindedness (Facione, 1990; Elder and Paul, 2001); (3) inquisitiveness (Facione, 1990; Elder and Paul, 2001); (4) respect for reason (Ennis, 1987; Lipman, 1991); and (5) propensity to explore alternatives (Elder and Paul, 2001).

CTSs and CTDs are not innate qualities but must be developed through learning and practice. However, conventional teaching approaches: (1) are not conducive to developing students' CT; (2) lack authenticity (Sharma and Elbow, 2000); and (3) are inadequate for developing students' CTSs (Drennan and Rohde, 2002). Education and teaching systems need to be designed to facilitate CT learning (Dekker, 2020) by selecting the most recent effective instructional strategies (Karakoc, 2016).

1.2. Problem-based learning

Problem-based learning (PBL) is a student-centered instructional method that enhances CT (Facione et al., 2000; Choi et al., 2014; Carter et al., 2017), including CTSs (Facione et al., 2000) and CTDs (Dehkordi and Heydarnejad, 2008). PBL occurs among small groups of students who explore problems and find solutions collaboratively (Yuan et al., 2008); it is a continual scientific learning process designed to accustom students to think critically (Nurcahyo and Djono, 2018). PBL begins by challenging students to solve complicated, ill-structured problems (Barrows, 1986) and provides opportunities inside and outside of the classroom to analyze information and consider different viewpoints (Dwyer et al., 2015); students share their thoughts, listen to those of others, reflect on their own ideas, and ultimately obtain a suitable solution to a problem. The required self-directed learning, interpersonal communication, and reasoning foster CT (Orique and McCarthy, 2015).

1.3. Problem-based learning and critical thinking

Liu and Pásztor (2022) meta-analysis of 50 relevant empirical studies with 5,210 participants and 58 effect sizes concluded that PBL was effective for fostering CT. However, Lee et al. (2016) meta-analysis of eight studies concluded that PBL was not effective for enhancing nursing students' CT. These contradictory conclusions suggest that teachers must adapt PBL according to the objectives to be attained (Barrows, 1996). Researchers from different academic fields, such as Kamin et al. (2003), Fujinuma and Wendling (2015), and Evendi et al. (2022) have adapted PBL to improve students' CT.

This study thus sought to: (1) examine how studies have adapted PBL to be more focused on CT development; (2) examine the result of those studies; and (3) explore the reasons for successful modifications. It filled the gap left by the systematic reviews that are focused on the impacts of PBL model instead of adapted CT-oriented PBL models on CT development.

1.4. Research questions

The formulation of the research question for this study was based on the PICo framework, which has been developed specifically for qualitative reviews and identifies the key aspects of Population, Phenomenon of Interest, and Context (JBI, 2011). Utilizing these concepts, the authors incorporated three primary aspects into the review: college students (Population), CT improvement (Phenomenon of Interest), and participation in CT-oriented PBL intervention (Context). The principal research question was thus: How can the PBL model be adapted to enhance students' critical thinking abilities? This broad question was further refined into several specific research questions:

(1) What adaptations can be made to PBL to enhance the CT of college students and what is the rationale for these adaptations?
(2) How are the results of CT-oriented PBL interventions evaluated?
(3) To what extent are these adapted PBL models successful and what factors contribute to their success?

2. Methodology

A protocol encompassing search terms, databases, screening criteria, and analytical methods was established to guide the literature search and generate the initial data set (Yang et al., 2017). The Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) (Page et al., 2021) were employed to identify

pertinent papers concerning PBL adaptations for teaching CTSs and CTDs at the undergraduate level in higher education. Two databases were utilized: Scopus and Web of Science (WOS).

2.1. Search strategy

The key search terms were derived from several sources: previous studies; an online thesaurus; keywords suggested by WOS and Scopus; and the research questions.

Two independent researchers identified research articles published in Scopus or WOS between January 2001 and mid-August 2022 by using a combination of the key search terms with a Boolean operator, phrase searching, and truncation to produce the search string. For WOS, the search string was TS = (PBL or "problem based learning" or "problem-based learning") AND ("critical thinking" or "think critically") AND (university or college or undergraduate or "higher education" or "tertiary education"). For Scopus, the search string was TITLE-ABS-KEY (PBL or "problem based learning" or "problem-based learning") AND ("critical thinking" or "think critically") AND (university or college or undergraduate or "higher education" or "tertiary education").

2.2. Inclusion and exclusion criteria

The inclusion and exclusion criteria were based on PICo (JBI, 2011). Articles were included if they: (1) undertook empirical research; (2) involved undergraduate students; (3) used PBL-adapted models as the main instructional intervention; (4) included research tools to collect CTS and CTD data; (5) explored students' learning experiences; (6) evaluated CTS and/or CTD as the main research outcome; and (7) published in an English peer-reviewed scientific journal.

Studies were excluded if they: (1)were review papers or not empirical papers; (2) did not adapt PBL models for their own research purposes; (3) involved non-undergraduate college students; (4) did not collect CTS and CTD data; (5) did not evaluate CTS and/or CTD as the main research outcome; (6) did not report CTS and/or CTD outcomes; (7) published in languages other than English; and (8) were not published in peer-reviewed journals, e.g., conference proceedings or book chapters.

2.3. Selection of articles

Articles were screened and selected according to PRISMA. Duplicate records and non-research or non-English articles were removed. Two independent reviewers then screened as many articles as possible to not miss any potentially eligible article. Records with a title and/or abstract that suggested the work involved PBL and CT were retained even though they did not fully meet the inclusion criteria for the title and/or abstract. The reviewers then rigorously applied the inclusion and exclusion criteria as they examined the full text of the retained articles. This meant that all eligible articles involved a modified PBL as the pedagogical intervention and evaluated CTS or CTD as the main research outcome. Finally, a database of selected articles was created for data extraction and analysis.

Figure 1 shows the number of records included at the identification, screening, selection and inclusion stages of the review process. The initial database searches uncovered 719 publications. After 70 duplicate records were eliminated, the literature was screened for journal or review articles that were written in English. This reduced the number of records to 499. After evaluating the abstracts of these articles, 292 records were deleted. The entire text of the remaining 207 papers were reviewed; 187 articles that failed to meet the inclusion criteria were excluded, leaving 20 journal articles to be included in this systematic review.

2.4. Data extraction

To extract pertinent information from the 20 studies, Harris et al. (2014) guidelines were employed. These guidelines facilitated the extraction of information such as the author(s), year of publication, types of intervention implemented, types of data collection methods, types of data analysis methods, main findings of the study, and the effectiveness of the interventions in achieving their intended outcomes.

3. Results and discussion

The findings of the study are presented in three distinct sub-sections, each corresponding to a specific research question. The first sub-section details the types of PBL adaptations that were made to improve CT. The second sub-section presents the details of data collection and analysis implemented by each study. The last sub-section discusses the reasons for the observed improvements in student's CT as a result of these interventions.

3.1. The CT-oriented adaptations made to PBL models

An analysis revealed five distinct approaches to adapting Problem-Based Learning (PBL) to enhance Critical Thinking (CT) skills: (1) the implementation of CT-specific tools; (2) the incorporation of CT-focused activities; (3) the utilization of digital technologies; (4) the integration with other pedagogical methods; and (5) the integration with discipline-specific knowledge. As depicted in Table 1, CT-oriented activities ($n = 6$) emerged as the most prevalent strategy for augmenting CT, followed by the utilization of instructional technologies ($n = 5$) and the assimilation of other instructional modes ($n = 4$). Conversely, CT-oriented instruments ($n = 3$) and the combination of PBL with subject-specific knowledge ($n = 2$) were identified as the least frequently employed tactics for adapting PBL to foster CT development.

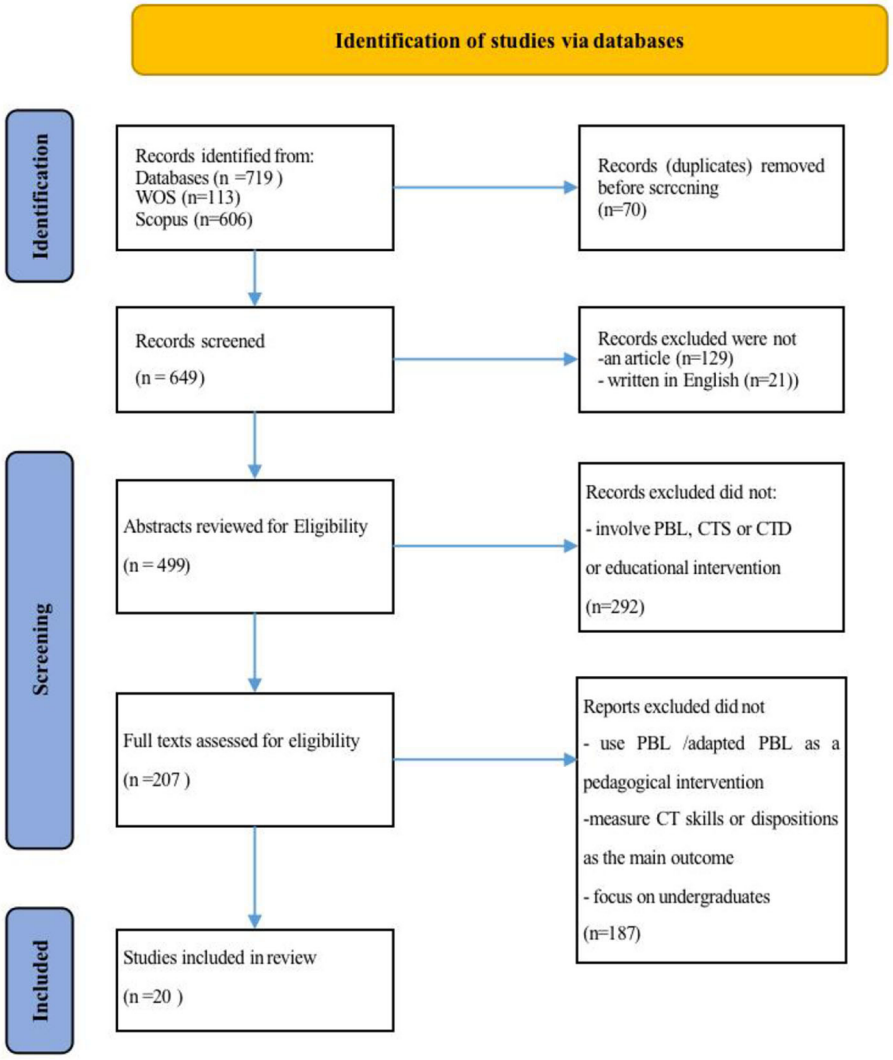

FIGURE 1
The flow diagram of the literature search using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

3.1.1. CT-oriented tools

As is depicted in Table 1, the aforementioned studies employed various adaptations of Problem-Based Learning (PBL) with the objective of enhancing critical thinking (CT). These adaptations encompassed the utilization of CT-oriented guiding questions (Carbogim et al., 2017), concept mapping (Orique and McCarthy, 2015), and a CT assessment rubric (Suryanti and Nurhuda, 2021). In their studies, guiding questions were implemented to stimulate and direct cognitive processes, concept maps served as a visual instrument for representing concerned issues and facilitating the development of solving plans, and the CT assessment rubric was employed to furnish lucid guidelines and expectations that facilitated self-assessment and engendered a more profound engagement with the subject matter. These aforementioned instruments possess the capacity to facilitate the development of students' critical thinking aptitudes by providing a framework for the organization and analysis of information.

3.1.2. CT-oriented activities

The studies examined in this text employed various critical thinking-oriented activities within a problem-based learning (PBL) framework to enhance the development of critical thinking skills. These activities were collaborative in nature, a characteristic inherent to PBL (Yuan et al., 2008), and allowed learners to practice cognitive and/or meta-cognitive skills. With regard to the incorporation of cognitive skills, Hsu (2021), for example, advocates for the integration of collaborative learning with PBL as it requires learners to cooperatively analyze, synthesize, and evaluate ideas to solve complex problems. Additionally, Mumtaz and Latif (2017) and Latif et al. (2018) incorporated debate among learners as it provides an opportunity for deeper analysis and appraisal of issues. The others recognized the significant correlation between meta-cognitive skills and CT improvement. For example, Fujinuma and Wendling (2015) integrated team-based active learning into their PBL model focused on meta-cognitive development to

TABLE 1 The author(s), publication date, and intervention used in studies by approach to PBL adaptation.

Types of adaptation	References	Intervention
CT-oriented tools ($n = 4$)	Carbogim et al. (2017)	Based on Facione's validated guiding questions
	Orique and McCarthy (2015)	Concept mapping integrated with PBL
	Suryanti and Nurhuda (2021)	CT assessment rubric integrated with PBL
CT-oriented activities ($n = 6$)	Fujinuma and Wendling (2015)	Small group PBL activities focused on developing meta-cognitive skills
	Rodríguez et al. (2022)	Peer assessment integrated with PBL to develop a four-stage metacognitive approach
	Mumtaz and Latif (2017)	Debate integrated with PBL
	Latif et al. (2018)	Debate vs. role-playing integrated with PBL
	Rivas et al. (2022)	Actions to incentivize metacognitive work among participant
	Hsu (2021)	Collaborative learning integrated with PBL
Digital technologies ($n = 5$)	Kamin et al. (2003)	Video case simulations presented with PBL
	Evendi et al. (2022)	PBL adapted into electronic form
	Roy and McMahon (2012)	Videos integrated with PBL
	Sendag and Odabasi (2009)	Online PBL and online tutor-centered PBL
	Hidayati et al. (2022)	Digital mind maps integrated with PBL
Integrated with subject knowledge ($n = 2$)	Silviarza et al. (2020)	Problem-solving learning in geography developed
	Silviariza and Handoyo (2021)	Problem-solving learning in geography developed
Integrated with other pedagogical mode ($n = 4$)	Lim (2020)	Simulation teaching method linked with PBL
	Xing et al. (2021)	CPBL (PBL on case) plus SBAR (situation, background, assessment and recommendation)
	Carbogim et al. (2018)	Active learning model for CT included in PBL
	Aein (2018)	Inter-professional learning integrated with PBL

improve critical thinking. Rivas et al. (2022) emphasized individual and interactive meta-cognitive development through reflective activities because effective use of critical thinking skills requires a certain degree of consciousness and regulation of them. Rodríguez et al. (2022) used peer assessment within a PBL framework to develop a four-stage metacognitive approach due to the positive correlation between metacognition and active learning (Biasutti and Frate, 2018), which can help foster higher order thinking skills (Kim et al., 2020). These CT-oriented adaptations suggest that future studies could consider creating active learning environments through collaborative activities to foster cognitive and meta-cognitive skills to enhance critical thinking.

3.1.3. Digital strategies

Included research examined the incorporation of digital technologies into PBL to enhance CT. Sendag and Odabasi (2009) and Evendi et al. (2022) adapted traditional face-to-face PBL to an electronic format known as e-PBL in response to the increasing prevalence of online learning and the demonstrated efficacy of e-PBL in enhancing learning outcomes. Other studies investigated the use of videos in problem-based learning because they can present ill-structured problems in a more vivid manner (Kamin et al., 2003; Roy and McMahon, 2012). Digital mind maps were used in conjunction with PBL by Hidayati et al. (2022) because they can create an engaging learning environment and facilitate deeper learning regardless of the learning styles of the learners.

3.1.4. PBL integrated with other pedagogical models

Researchers attempted to combine other pedagogical mode with PBL to enhance CT development. Lim (2020) integrated problem-based learning (PBL) with simulation-based learning to enable students to tackle problems that mirror real-life scenarios, thereby enhancing their professional skills and critical thinking abilities. Similarly, Xing et al. (2021) employed a clinical case-based PBL approach in conjunction with the "Status-Background-Assessment-Recommendation" (SBAR) teaching model to facilitate communication (Abdellatif et al., 2007). Carbogim et al. (2018) combined PBL with the Active Learning Model for Critical Thinking (ALMCT), which comprises a series of questions designed to promote deeper understanding and exploration of meanings, relationships, and outcomes through inquiry within a clinical context or case. Aein (2018) modified PBL by incorporating inter-professional learning (IPL) to foster teamwork, enhance communication, and overcome inter-professional barriers. These studies share a common focus on the medical field and aim to improve students' professional competencies and critical thinking skills by presenting simulated real-world cases and promoting communication and collaboration among students.

3.1.5. PBL integrated with subject knowledge

Silviarza et al. (2020) and Silviariza and Handoyo (2021) are the sole authors among the studies reviewed to have undertaken research on the integration of problem-based learning (PBL) with the instruction of subject knowledge. They contend that the ability to critically solve problems is of paramount importance in the study of geography (Nagel, 2008). Academics may contemplate the incorporation of problem-based learning (PBL) methodologies within fields of study that necessitate the utilization of critical thinking competencies for problem resolution and knowledge acquisition. Such an approach has the potential to augment not only students' comprehension of the subject matter but also their capacity for critical thinking.

3.2. The evaluation of CT-oriented PBL interventions

The efficacy of Problem-Based Learning (PBL) adaptations in enhancing Critical Thinking (CT) was investigated by examining the results of individual studies. To determine the overall effectiveness of modified PBL models on the development of CT skills or dispositions (CTS or CTD), it is necessary to scrutinize the instruments employed for data collection and the analytical methods utilized. Table 2 provides an overview of the article title, publication year, data collection instrument, and data analysis approach utilized in the study.

3.2.1. Data collection

The instruments employed by the studies included in this analysis can be classified according to their use in collecting either quantitative or qualitative data, as delineated in Table 2. Quantitative instruments comprise questionnaires (e.g., Mumtaz and Latif, 2017; Carbogim et al., 2018; Latif et al., 2018; Lim, 2020; Silviarza et al., 2020; Hsu, 2021; Xing et al., 2021), tests (e.g., Sendag and Odabasi, 2009; Silviariza and Handoyo, 2021; Hidayati et al., 2022; Rivas et al., 2022; Evendi et al., 2022), and assessment rubrics (e.g., Orique and McCarthy, 2015; Suryanti and Nurhuda, 2021; Rodríguez et al., 2022), with questionnaires being the most commonly utilized instrument. On the other hand, several studies have employed qualitative instruments to collect CT-related data, which are less varied than their quantitative counterparts. Qualitative instruments primarily encompass recorded learning activities (e.g., Kamin et al., 2003; Roy and McMahon, 2012; Evendi et al., 2022), interviews (e.g., Carbogim et al., 2017; Aein, 2018; Xing et al., 2021), and open-ended questions (e.g., Fujinuma and Wendling, 2015; Mumtaz and Latif, 2017). Based on an analysis of the tools utilized by the studies involved in this investigation, future research exploring the adaptations of PBL for CT can employ quantitative (e.g., Silviarza et al., 2020), qualitative (e.g., Aein, 2018), or mixed methods (e.g., Carbogim et al., 2017).

As indicated in Table 2, researchers employ one of two approaches in constructing data collection instruments for quantitative data: either directly utilizing tools developed by others or developing their own research instruments. For instance, widely used and well-developed instruments include the Chinese adaptation of the California Critical Thinking Disposition Inventory (CCTDI) and the California Critical Thinking Skills Test (CCTST). Xing et al. (2021) employed the Chinese version of the CCTDI to investigate the impact of modified PBL on learners' CT disposition, while Carbogim et al. (2018) utilized the CCTST to assess students' CT skills. These extensively used tools have been demonstrated to be valid and reliable for data collection and analysis. Alternatively, researchers have endeavored to design their own instruments tailored to their specific study requirements. For example, Silviarza et al. (2020) and Hidayati et al. (2022) developed an essay test and a CTS test, respectively, based on the CT indicators proposed by Ennis (2011). These self-made instruments were subjected to validity and reliability checks prior to being employed for data collection (e.g., Hidayati et al., 2022). Both of the above-discussed approaches, when implemented with established credibility and validity, are effective in collecting the desired data. On the other hand, most studies employing qualitative tools do not test validity and reliability in the same manner as quantitative studies (e.g., Kamin et al., 2003; Roy and McMahon, 2012), but instead utilize triangulation to enhance validity and reliability (e.g., Rodríguez et al., 2022).

3.2.2. Data analysis

As delineated in Table 2, the studies included in this analysis employed distinct analytical methodologies based on their data collection methods. It is only through the application of analytical techniques that are appropriately tailored to the data and research objectives that researchers can derive meaningful insights and draw valid conclusions from their data.

For quantitative data, researchers utilized descriptive analysis to determine the means and proportions of CT-related data. Several studies employed this method, including Mumtaz and Latif (2017), Carbogim et al. (2018), Latif et al. (2018), Suryanti and Nurhuda (2021), and Rivas et al. (2022). In addition to descriptive analysis, other statistical techniques were also frequently employed. Analysis of variance (ANOVA) was used by Sendag and Odabasi (2009) and Fujinuma and Wendling (2015) to compare the means of multiple groups and determine whether there were any statistically significant differences between them. The *t*-test technique to compare the means of experimental and control group was also commonly used, as seen in studies by Carbogim et al. (2018), Latif et al. (2018), Silviarza et al. (2020), and Xing et al. (2021).

In contrast to the quantitative methods described above, content analysis was typically applied to qualitative data. Studies that employed this method include Kamin et al. (2003). In addition to content analysis, narrative summary was also used to present and interpret qualitative data (e.g., Mumtaz and Latif, 2017).

TABLE 2 Evaluation of included educational intervention.

References	Data collection instruments for CT	Data analysis
Kamin et al. (2003)	(1) Transcribed virtual group discussions	(1) A content-analysis coding system was used for the transcripts of 13 of the 24 group discussions.
Orique and McCarthy (2015)	(1) Holistic critical thinking scoring rubric (HCTS) by Facione and Facione (1994)	(1) A repeated measures analysis of variance (ANOVA) was conducted to determine the differences between pre and post HCTS results.
Fujinuma and Wendling (2015)	(1) Essays designed to foster critical analysis (2) Short-answer questions on the semester's written final exam	(1) Module effects on essay assignment marks were tested using a one-way ANOVA with Tukey's HSD test at $p = 0.05$. (2) The final exam results were compared to those of previous semesters.
Rodríguez et al. (2022).	(1) Rubric developed by a panel of experts to evaluate critical thinking skills (2) An hour-long focus group with the aim of analyzing each of the learning activities	(1) The students' critical thinking skills were assessed by two evaluators based on their final responses (2) Two researchers analyzed the results from the focus groups independently using Triangulation, and the results were explored by use of Content Analysis.
Mumtaz and Latif (2017)	(1) Questionnaire with closed-ended statements used to explore students' perceptions of the usefulness of debate sessions for enhancing communication and critical thinking skills. (2) A few open-ended questions on the questionnaire with the aim to explore the pros and cons of the debate sessions for further improvement.	(1) Descriptive statistics were used for analysis. (2) Narrative summary was utilized.
Evendi et al. (2022)	(1) a CTS test in the form of an essay with eight test items accommodating CT indicators. (2) Classroom observation through the use of an observation sheet developed by the researcher. (3) 20–30 min discussion between the observer and lecturer after the learning is finished in each meeting.	(1) Data analysis of the CT skills of each student was carried out descriptively with five scoring levels. (2) The effectiveness of the e-PBL model in improving students' CT skills is measured by increasing their CT scores using n-gain analysis.
Latif et al. (2018)	(1) Questionnaire with closed-ended statements used to explore students' perceptions of the effectiveness of debate and role play sessions in improving critical thinking and communication skills by use of a three-point scale.	(1) Descriptive statistics were used to analyze the quantitative data. (2) A paired *t*-test was used to compare the responses of students for the two learning modalities.
Lim (2020)	(1) A self-reported questionnaire to test CT disposition developed by Yoon (2004).	(1) The differences in critical thinking disposition before and after S-PBL were analyzed by *t*-test. (2) The relationship between self-learning efficacy, critical thinking tendency, and problem-solving ability was examined by using Pearson's correlation coefficient.
Suryanti and Nurhuda (2021)	(1) An assessment rubric, a descriptive schema, developed as referred to Zainul (2001).	(1) Descriptive statistical test; (2) Mann Whitney Test
Silviarza et al. (2020)	(1) Questionnaire based on indicators of critical thinking proposed by Ennis	(1) Independent sample *t*-test
Roy and McMahon (2012)	(1) Tutorials were audio-recorded	(1) The resulting audio files were transcribed verbatim with student identifiers removed. All student utterances were then allocated a code using the scheme described by Kamin et al.
Sendag and Odabasi (2009)	(1) Turkish version of the Watson–Glaser critical thinking skills test.	(1) Two-way mixed design analyses of variance (ANOVA) were conducted to see the effects of online PBL and instructor-led practices on content knowledge and CTS scores.
Xing et al. (2021)	(1) Chinese Version of CCTDI (Peng et al., 2004) (2) Semi-structured interview to further explore the effect of CPBL + SBAR teaching mode	(1) Paired *t*-test was used to compare the critical thinking and problem-solving ability of nursing students before and after the intervention. (2) The interviews were audio-recorded and were transcribed later. Colaizzi's phenomenological analysis was used to analyze the interview data.
Carbogim et al. (2018)	(1) Portuguese version of CCTDI to evaluate CT dispositions. (2) Portuguese version of CCTST was used to evaluate CT skills.	(1) Descriptive analysis was conducted. (2) Paired *t*-test was subsequently used to compare mean scores and CT score changes in the CCTDI and CCTST tests. (3) The Covariance Analysis (ANCOVA) was used to verify the influence of independent variables (gender, age, and group) on CT scores.
Aein (2018)	(1) Focus group interviews with guiding questions.	(1) Data were analyzed according to the six steps of the concurrent thematic analysis method.

(Continued)

TABLE 2 (Continued)

References	Data collection instruments for CT	Data analysis
Rivas et al. (2022)	(1) Critical thinking test-PENCRISAL, a battery of consisting of 35 production problem situations with an open-answer format, composed of five critical thinking factors (Saiz and Rivas, 2008; Rivas and Saiz, 2012). (2) Metacognitive awareness inventory from Schraw and Dennison (1994) in the form of 52 likert scale-type items with five points.	(1) Frequency and percentage tables were presented for qualitative variables, exploratory. (2) Descriptive analysis of quantitative variables was conducted with a goodness of fit test to the normal Gaussian model, habitual descriptive statistics (median, SD, etc.) for numerical variables, and Student's *t*-tests for significance of difference.
Hsu (2021)	(1) Inventory of Critical-thinking disposition, ICTD (Yeh and study of substitute teachers' professional knowledge, 1999). (2) Learning Experience Opinions investment (LEOI) with 35 quantitative and 4 qualitative questions	(1) Mean scores, standard deviation, and paired sample *T*-test were conducted. (2) Responses regarding critical thinking were with sub-categories: too complex to think; lack of thinking habit; unfamiliar to CT skills
Hidayati et al. (2022)	(1) An essay test based on critical thinking indicators suggested by Ennis (2011).	(1) The data obtained were analyzed using ANCOVA at a significance level of 5% and an LSD test.
Silviariza and Handoyo (2021)	(1) Critical thinking skills test in the form of a test question sheet that refers to the indicators of critical thinking skills from Ennis (2011).	(1) An independent sample *t*-test was conducted to analyze the data.
Carbogim et al. (2017)	(1) Semi-structured interviews; (2) An evaluation instrument with self-reflection of the learning experience	(1) Bardin's content analysis technique was applied in three phases: pre-analysis, material exploration and treatment of results, inference and interpretation.

3.3. Examination of the findings from PBL-adapted interventions

3.3.1. Interventional outcomes

The results of individual studies were examined to explore the success of PBL adaptations for improving CT. Table 3 summarizes the CT development outcomes of each intervention. All the studies had positive outcomes with students showing increased CT. This indicates that the planful integration of CT elements into PBL was effective and necessary for enhancing students' CT which cannot be assured with PBL that do not have CT-oriented adaptations (Lee et al., 2016).

3.3.2. Positive findings

Although all of their studies reported positive outcomes in the development of critical thinking (CT), the depth of their research varied. Some studies documented general improvements in CT as a result of instructional interventions, while others reported enhancements in specific CT sub-skills. For instance, Silviarza et al. (2020) discovered that engaging students in debates and encouraging them to confirm information through research promoted critical thinking. Similarly, Aein (2018) found that challenging students to respond to difficulties posed by their peers with concealed features of disorders prompted them to think critically about current and potential health concerns. On the other hand, several researchers confirmed that problem-based learning (PBL) oriented toward CT improved CT sub-skills. Latif et al. (2018), for example, reported that exposing students to challenging real-life situations encouraged them to conduct research based on their arguments, fostering the CT processes of analysis and interpretation. Carbogim et al. (2017) argued that pairing PBL with guided questions enhanced students' abilities to analyze, reason, and generate solutions for safe care action, demonstrating intellectual stimulation for CT.

Although critical thinking (CT) encompasses both critical thinking skills (CTSs) and critical thinking dispositions (CTDs), only three studies have specifically investigated the development of students' CTDs. Carbogim et al. (2018) employed the Portuguese version of the California Critical Thinking Disposition Inventory (CCTDI) to evaluate CTDs and discovered that integrating problem-based learning (PBL) with the Active Learning Model for Critical Thinking (ALMCT) influenced the acquisition of an analytical disposition. Hsu (2021) utilized Yeh and study of substitute teachers' professional knowledge (1999) Inventory of Critical-Thinking Disposition (ICTD) to determine that support for social contacts enhanced students' CT cognitive development. Lim (2020) applied Yoon (2004) self-report questionnaire to assess CTDs and found a correlation between CTDs and problem-solving abilities. These findings indicate that current research primarily concentrates on the development of CTS, suggesting that future studies should not overlook the development of CTD.

3.3.3. Success factors

An analysis of the key CT-related findings from each study, as presented in Table 3, was conducted to explore the reasons for successful adaptation of problem-based learning (PBL). These findings were categorized into nine factors that contribute to the successful adaptation of PBL to be CT-oriented, as delineated in Table 4. These factors comprise self-directed learning, CT-related activities, interaction, problem-solving skills, metacognitive activities, authentic learning, positive atmosphere, self-efficacy, and role of teacher. These factors can serve as the principles upon which CT-oriented PBL models should be based.

As is shown in Table 4, the nine principles are identified. The principle of self-directed learning refers to students accepting responsibility for their own learning and actively participating in the learning process (Kamin et al., 2003). CT-related activities refer to the activities of students applying their learning to enhance CT, such as debating (e.g., Latif et al., 2018). Interaction refers to students: (1) being assigned to small groups and sharing their learning within the group and across groups (Kamin et al., 2003; Fujinuma and Wendling, 2015; Silviarza et al., 2020); (2) sharing

TABLE 3 The main findings of each study.

References	Main findings
Kamin et al. (2003)	(1) Increased individual accountability required by the online discussion lead to greater portion of deep learning related to CT. (2) Videos integrated with PBL can develop critical thinking such as problem description, applicability, and integration.
Orique and McCarthy (2015)	(1) Students actively engaged in learning through collaboration and by sharing their knowledge and research. (2) Students demonstrated increased clinical reasoning and decision-making skills when CM and PBL were applied during nursing care plan development.
Fujinuma and Wendling (2015)	(1) A repeating format of small-group PBL activities and critical-thinking essay assignments can improve student learning outcomes in the short term, as indicated by academic performance.
Rodríguez et al. (2022)	(1) The meta-cognitive process allows for the development of critical thinking skills, since metacognition influences critical thinking.
Mumtaz and Latif (2017)	(1) While preparing for a debate, a student meticulously researches the issue using reason, logic, and analysis to synthesize opinions, leading to the improvement of critical thinking.
Evendi et al. (2022)	(1) Presenting and solving authentic problems is the basis for building their knowledge in PBL to support their deepening of thinking. (2) Regarding the purpose of CT, interactivity can guide students' enthusiasm for learning mathematics and support their CT performance. (3) Inviting students to reflect on the learning process they have gone through helps to build their CT. (4) The learning atmosphere of PBL is more attractive, which guarantees an increase in active learner involvement in learning and thinking skills that lead to CT.
Latif et al. (2018)	(1) Controversial issues depicted in real life help students to do research based on their arguments, emanating a critical thought process, which is built up on analysis and interpretation.
Lim (2020)	(1) Critical thinking tendency pointed toward the relationship between problem solving ability. In S-PBL, in order to improve students' problem-solving skills, instructors should provide examples that are appropriate to the students' level of learning, and students should work with their peers and take the lead in problem solving. (2) Learning self-efficacy after S-PBL had a significant positive correlation with critical thinking tendency and problem-solving ability, and there was a correlation between critical thinking tendency and the degree of problem-solving ability.
Suryanti and Nurhuda (2021)	(1) PBL model by using rubrics is beneficial to improve the students' critical thinking skills, albeit not significantly in the intermediate financial accounting classroom.
Silviarza et al. (2020)	(1) Students were able to identify problems from a spatial perspective, orient problems spatially, formulate problems, collect and compile data and information spatially, analyze data and information spatially together and communicate scientifically about the results of problem-solving in front of other groups by way of presentation using power points in front of the class. (2) The process of arguing confirmation through the information search process enabled students to think critically (Ennis, 2011).
Roy and McMahon (2012)	(1) The use of video-based cases is associated with a meaningful decrease in critical thinking during PBL tutorials compared with text-based cases, as students may easily be distracted by video content.
Sendag and Odabasi (2009)	(1) It was revealed that ill-structured problems used in PBL environments led learners to think deeper, question, discuss and conduct research. (2) In addition, organization of the learning resources and the facilitating role of the instructor increased the difference between the PBL and the instructor-led group in terms of CTS scores.
Xing et al. (2021)	(1) The CPBL + SBAR teaching mode emphasizes the student-centeredness. Students analyze and solve problems in clinical cases by group discussion, literature retrieval, and consultation with teachers. Their interest and enthusiasm in learning and their confidence are enhanced.
Carbogim et al. (2018)	(1) PBL with ALMCT influenced the acquisition of analytical disposition and the students' skill to analyze.
Aein (2018)	(1) Challenging each other in order to solve problems confronted with learners with hidden aspects of the diseases helped them think more critically about actual and potential problems in the women's health.
Rivas et al. (2022)	(1) Interactions in the form of dialogues and reflective debates strengthen critical thinking.
Hsu (2021)	(1) The development of critical thinking can be improved through discussion, clarification of ideas, and evaluation of others' ideas. However, the quality of the interactions among the learners and educators would be a key issue. Moreover, the instructor's role is not to transmit information, but to serve as a facilitator for learning. (2) The assistance of the social interaction, including of plenty teamwork practices, peer evaluation, and pressure to push individuals to work harder and think deeper and broader, did promote their CT cognitive development.
Hidayati et al. (2022)	(3) The students asked many higher-order level questions that could promote their critical thinking. (4) Both PBL and DMM-Integrated PBL contain authentic problems that require students' higher-order thinking to figure out a solution to a problem. (5) The DMM-Integrated PBL students have the same opportunity to explore their ideas and challenge themselves to think critically. During the process, the students are actively engaged in a brainstorming activity, discussion sessions, and reflection because cooperative learning positively affects students' critical thinking skills. (6) The students in both groups are required to study independently. They need to collect information from various sources to figure out which solutions suit the problems. Every student comes to the classroom with different findings and then is required to share the information with other students in a discussion.

(Continued)

TABLE 3 (Continued)

References	Main findings
Silviarza et al. (2020)	(1) Students can identify spatial problems, orient spatial problems, formulate spatial problems, collect and organize spatial data and information, analyze spatial data and information with groups, and communicate it in front of other groups, in this case, group presentations.
Carbogim et al. (2017)	(1) When associated with guiding questions, the PBL stimulated the ability to analyze, reason and produce strategies for safe care action, which demonstrates intellectual stimulation for CT. (2) Higher mental functions are developmental acquisitions mediated by the interaction between individuals.
Roy and McMahon (2012)	(1) The use of text-based cases in CT during PBL can produce positive outcomes while video-based PBL can distract students, leading to a decrease in CT.

TABLE 4 Classification of the main findings from the studies by theme.

References	Theme								
	Self-directed learning	CT-related activities	Interaction	Problem-solving activies	Metacognitive activities	Authentic learning	Positive atmosphere	Self-efficacy	Role of teacher
Carbogim et al. (2017)		+	+						
Orique and McCarthy (2015)	+		+						
Fujinuma and Wendling (2015)		+	+						
Rodríguez et al. (2022)					+				
Mumtaz and Latif (2017)		+							
Latif et al. (2018)						+			
Rivas et al. (2022)			+		+				
Hsu (2021)			+						+
Kamin et al. (2003)	+	+							
Evendi et al. (2022)			+		+	+	+		
Sendag and Odabasi (2009)						+			+
Hidayati et al. (2022)	+	+	+			+			
Silviarza et al. (2020)		+							
Silviariza and Handoyo (2021)		+	+						
Lim (2020)			+	+				+	+
Xing et al. (2021)		+							
Carbogim et al. (2018)		+							
Aein (2018)			+						
Total	3	9	10	1	3	4	1	1	3

Roy and McMahon (2012) and Suryanti and Nurhuda (2021) did not report specific findings that could be classified.

their knowledge with other students (Orique and McCarthy, 2015); (3) peer discussions on how to solve problems (Lim, 2020; Hidayati et al., 2022); (4) challenging each others' views (Aein, 2018); and (5) debating with each other (Rivas et al., 2022). CT propensity in PBL has also been found to be associated with problem-solving abilities and metacognitive skills (Rodríguez et al., 2022). Authentic learning in PBL is key to developing students' CT skills which involve authentic real-world problem that contain diverse, difficult, and ill-structured answers (Hidayati et al., 2022) and utilizing relevant real-world experiences to solve it (Latif et al., 2018). The problems are authentic (Hidayati et al., 2022), relevant to learners' real-world experiences (Latif et al., 2018), and contain diverse, difficult, and ill-structured answers. There was scant scholarly attention given to the learning environment and self-efficacy even though a positive learning environment can assist students to enhance their CT (Evendi et al., 2022). Likewise, self-efficacy has

received scant scholarly attention. After simulated PBL, students' learning self-efficacy was positively linked to CT propensity and problem-solving ability (Lim, 2020). Teachers had a significant impact on PBL students, particularly when they assumed the role of facilitator rather than merely transmitting information (Hsu, 2021), were less the center of attention in the classroom (Sendag and Odabasi, 2009), and provided examples that were appropriate for the students' level of learning.

The principles for PBL adaptations for CT development align with those of original PBL models but are optimized to maximize CT development. For instance, Carter et al. (2017) assert that students should be at the center of learning, Barrows (1986) posits that PBL problems should be ill-structured, and Yuan et al. (2008) contend that students should collaborate to solve problems. These principles are intrinsic to PBL. Consequently, the design of new PBL models to enhance CT should adhere to the fundamental principles or characteristics of PBL.

4. Conclusions

In this study, a systematic review was undertaken of published articles associated with PBL adaptations as educational interventions to improve students' CT skills and dispositions. Using the 20 articles that met the inclusion criteria and the PICo approach, this paper explored the methods used to adapt the PBL model to optimize CT development, examined the effectiveness of those models and explored the reasons why these adaptations were successful with the intent to fulfill the gap of the limited number of systematic reviews on adapting the original PBL model to be a more CT oriented model.

Five distinct categories of the strategies employed to adapt PBL were found: activities centered on CT development, incorporation of digital technologies, integration of alternative pedagogical approaches, utilization of CT-specific instruments, and combination of PBL with discipline-specific knowledge. These adaptations were found to be effective in augmenting students' CT skills and dispositions, although the methodologies employed for data collection and analysis varied across studies. Future research is warranted to investigate the potential of these adaptations in diverse educational contexts.

Nine factors that contribute to the successful adaptation of PBL to be more CT-oriented were identified. They are: self-directed learning, CT-related activities, interaction with peers and teachers, problem-solving skills, metacognitive activities, authentic learning, positive atmosphere, high self-efficacy, and supportive teachers. These principles are congruent with those of traditional PBL models but have been specifically designed to optimize CT development. Future research could explore the relative significance of each of these factors in fostering CT development and examine their interplay. Additionally, researchers could investigate the effective integration of these factors into PBL models across diverse educational contexts and disciplines.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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