



Enhancing students' online collaborative PBL learning performance in the context of coauthoring-based technologies: A case of wiki technologies

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Abstract

Understandability and completeness are essential in modern collaborative digital platforms and their learning systems. These platforms have shaken up the traditional education setting, particularly in leveraging the coauthoring approach in problem-solving and streamlining the learning behavior of cowriting or corevising. Such a learning context has attracted considerable interest from various stakeholders; however, it needs to be explored further as an independent topic. Based on social capital and social identity theories, we explore how online collaborative problem-based learning (PBL) effectiveness, relational quality, and social identity influence students' perceived PBL performance during learning activities. Based on the core elements of online coauthoring processes (i.e., platform, cocreation, and problem-solving), this study employs a holistic view of the coauthor to discuss the effects of understandability and completeness. This study also highlights the mediating impact of trust on students' social identity. Based on the responses of 240 students, the results support the proposed hypotheses using partial least squares analysis. The study's implications suggest guidelines to educators on how to enhance students' perceived PBL performance by using wiki technologies.

Keywords Understandability · Completeness · Trust · Social identity · Online collaborative problem-based learning

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1 Introduction

Previous studies state that an appropriate collaborative digital platform can improve the flexibility, mobility, interactions, and quality of logical reasoning of learning activities that contribute to the enhancement of students' learning performance (Bringula & Atienza, 2022; Mohammadi Zenouzagh et al., 2023). Students can access various viewpoints/opinions and learning resources, which are vital for performing deep learning activities (Stockleben et al., 2017; Resta & Laferrière, 2015). Additionally, it is critical to assist students in understanding complex learning topics and to assess the effectiveness of interdisciplinary collaboration (Bizami et al., 2023; Daoudi, 2022; Tiernan, 2015). A handful of studies have evaluated the effectiveness of learning approaches that are supported by collaborative digital platforms (e.g., Bruguera et al., 2022; Hilliard et al., 2020; Salem, 2019; Zhu & Zhang, 2022). Nevertheless, Barajas and Frossard (2018) note that the potential for fostering creative pedagogies or learning approaches through those platforms remains largely unknown. Therefore, there is a need for further investigation into learners' perceptions regarding the applications of such platforms (Courtney et al., 2022; Zavolokina et al., 2020). Moreover, while there have been calls for more research on investigating how students' learning processes are impacted via the use of various advanced technologies and educational practices (Mavengere & Ruohonen, 2018; vanOostveen et al., 2019), research on the critical factors (i.e., completeness and understandability) that contribute to the effectiveness of using wiki technologies (e.g., coauthoring) in collaborative problem-based learning (PBL) environments for improving students' learning performance are scarce.

In a virtual learning environment, particularly in a collaborative learning platform (e.g., a wiki), learners' perceived effectiveness of the assigned learning tasks can, to some extent, positively contribute to the occurrence of their collaborative learning behaviors (e.g., coauthoring, cowriting, or corevising) (Lizzio & Wilson, 2013; Wang & Hong, 2018). That is because when the learners can jointly appreciate the effectiveness (in terms of completeness and understandability) of the learning tasks (e.g., a PBL-based case study) in a collaborative PBL context in which a wiki-based collaborative learning platform is implemented, they tend to develop a sense of identity and trust in learning partners, and are thus more likely to actively engage in online collaborative learning activities. Nevertheless, students' learning effectiveness may also be influenced by the information content, design of learning procedures, tools used, or interpersonal interactions in such learning processes (Niu et al., 2022; Xu & Li, 2015). Although a handful of studies have investigated relational capital in PBL education, such as those in medicine (Harriel & Parboosingh, 2020) and the tourism industry (Jaaron et al., 2021), there seems to be a need for more studies focusing on the investigation of the collaborative PBL effectiveness. Because learners' perceptions of learning methods and collaborative PBL effectiveness may influence their perceived learning performance (Koranteng et al., 2019; Lin & Wang, 2022). Previous studies have indicated that learners perceived learning effectiveness is likely influenced

by higher-order affective outcomes, such as a sense of belonging, identification, and trust (Lizzio & Wilson, 2013; Mohammadi Zenouzagh et al., 2023). Thus, it is critical to developing a more comprehensive understanding of the factors influencing the effectiveness of collaborative PBL activities in order to know how the effectiveness of such a learning process may be enhanced (Mavengere & Ruohonen, 2018).

Based on the end user's perception, the understandability of the learned information/knowledge enabled by Web 2.0 technologies (e.g., wikis) may be an important antecedent of perceived identification for the end user (Alsaedi et al., 2022). Some studies have stated that understandability is related to critical indicators of learning performance, including reasoning skills (vanOostveen et al., 2019; Zhu & Zhang, 2022), engagement/participation, and motivation (Zhang et al., 2021), and therefore can impact the effectiveness of collaborative learning efforts. On the other hand, information completeness was found to be significantly associated with usability or usefulness (Wu & Zhang, 2014). Completeness may motivate the end users' collaborative willingness when they solve problems in real-world practices.

With new technological developments in the end-user of system field, Web 2.0 applications (e.g., Facebook, Instagram, YouTube, wikis, and blogs) allow user-generated content to share or exchange information, which evolves into new services (Dash et al., 2022; Heo & Lee, 2013) and applications in pedagogical and learning fields. Therefore, investigating students'/learners' perceptions and learning performance in collaborative PBL activities is needed to explore more fully and identify the positive effects of implementing PBL in virtual space (Li et al., 2021). PBL has been applied in many areas, and it is always formed by a small group to solve an ill-structured problem using collaborative learning ability. Scheibenzuber et al. (2021) indicated that effective online communication/interaction and useful feedback, as the critical elements of PBL activities, are important to students. This virtual space (e.g., wikis) helps to share beneficial information, smooth the conflicts between individuals and peers, or exchange opinions/voices within a PBL group for individual and group purposes. This collaborative activity is a codependent, complicated, and relational norm; thus, peers/partners can continuously reconstruct and explore solutions to problems in real-world practices (Choi et al., 2020; vanOostveen et al., 2019; Wang & Lin, 2021).

During the COVID-19 pandemic, most schools were forced to use virtual classes; thus, teacher-student and student-student interactions are critical. Virtual teaching/learning has reattracted many researchers' interest in educational interaction and learning performance (e.g., Koranteng et al., 2019; Wang et al., 2022). In a virtual group, previous studies indicated that the biggest challenge is the completeness of knowledge that drives high levels of collaboration, such as note-taking, cowriting, or coauthoring (Courtney et al., 2022) and usability (Kesh, 1995). Here, completeness is defined as the degree to which wikis provide enough breadth, depth, and scope of information/knowledge (Huang & Fan, 2023). Additionally, understandability also plays a vital role that end users must validate based on their experience or prior knowledge (Hosseini et al., 2018). Understandability can be defined as the degree to which students perceive the quality of reading information/knowledge that is easy to comprehend on a platform

(Gupta et al., 2023; Niu et al., 2022). Therefore, the literature needs more attention than ever to completeness and understandability in Web 2.0 applications.

Based on social capital theory, social identity theory, and the information literature, this study proposed the information effectiveness of wikis for knowledge cocreation in PBL groups. Completeness, understandability, relational quality, and social identity were found to influence individual learning performance within a group/team (e.g., Fujita et al., 2018; Ray et al., 2014; Sharif et al., 2020; Zavolokina et al., 2020). Wang et al. (2022) examined the relationship between social capital and social identity, and continuous participation in social groups and explored coordination in group-level social capital. Burgess et al. (2020) suggested that motivating health professional students to collaborate effectively with other professionals and cultivating their awareness of social capital (e.g., trust, resources, norms) is vital in interprofessional teamwork. O'Brien et al. (2022) argued that PBL has been espoused in the pedagogical approach. Similarly, online collaborative PBL activities enabled by wiki technologies can create a context that facilitates the development of students' social capital and social identity, which can enhance PBL's effectiveness to gain convenient access to professional knowledge.

From the results of prior research, it can be inferred that peers' ability to obtain professional knowledge in answering/solving questions, information that is complete and comprehensible, the willingness to share knowledge, and the motivation to collaborate are most important in a group (Han et al., 2020; Lin & Wang, 2022). Therefore, using the concepts of social capital theory and social identity theory, the purpose of this study is to provide stakeholders (e.g., instructors, readers, students) with evidence or an overview for using wikis to aid in smoothing the operations of PBL activities in professional health care education settings. Therefore, this study's research question (RQ) is as follows.

RQ: How do understandability and completeness influence students' trust and social identity and thus improve their perceived PBL performance in the context of the use of coauthoring-based technologies?

2 Literature review and hypothesis development

Currently, education practices not only use a static format in transferring knowledge or in classroom teaching but also involve using collaborative technological tools to make it convenient for students to express their points of view and perform critical thinking. Such education forms have become mainstream in our society. However, there is still no consensus or full educational practice. Therefore, this study uses an appropriate instructional design and a theory-driven approach to focus on wiki-based PBL teaching and identify the diverse needs of students and learning outcomes.

2.1 Wikis as a collaborative platform in PBL activity

Creating a learning platform to guide students' learning or as a pedagogical tool is widespread in higher education. Such a platform enables students to share individual

cognitions or ideas and use critical and creative information drawn from various communication sources or experiences to support higher-order thinking (Chai et al., 2020; Zhu & Zhang, 2022). For example, with the PBL process, wikis can be considered a collaborative tool in this study. Wikis could be a relatively effortless form of online PBL for students to master when they are integrated with professional knowledge. Additionally, wikis are an open and accessible collaborative platform for students, allowing users to freely access, rearrange, or edit the content shared by others and keep all editing histories of the content (Lin & Wang, 2023). Such a case is likely to promote students' active learning. Several studies have indicated that PBL and collaborative strategies might enhance students' learning outcomes (e.g., Burke et al., 2022; Lin & Wang, 2022). Learners also welcome wikis to foster personalization learning. However, the use of wikis seems to be less commonly discussed in the completeness and understandability of platform effectiveness to enhance authenticity and problem-solving in real-world contexts.

PBL activities generally require considerable resource/knowledge exchange and time to interact with peers and express their opinions, which cannot be resolved in formal classrooms (Hussin et al., 2021). Carriger (2015) stated that the PBL approach could be more effective in promoting knowledge acquisition in collaborative learning. Interaction issues (e.g., completeness or understandability) must be considered in such learning methods. Thus, Web 2.0 tools are appropriate to help students' active participation and contribution through platforms (i.e., wikis, Google DOC, social networking sites, and learning management systems). For example, wikis help to build better relationships with instructors and students, help with communication and engagement, and improve their teaching/learning (Hilliard et al., 2020). Additionally, wikis are stable, universal, free of charge, and free of advertising, which may help students' learning processes. Several studies have presented better student participation and understanding to create more interaction, personal meaning, and practice in PBL activities (Harris et al., 2020; Mavengere & Ruohonen, 2018; Lin & Wang, 2022). Therefore, this study explores students' perceptions of using wikis as collaborative learning platforms to interact in solving real-world problems of learning tasks.

2.2 Social capital theory

Based on the nature and role perspective, social capital theory is a kind of invitational resource that is potentially embedded in the exchange relationships of individual social networks (Nahapiet & Ghoshal, 1998). Social capital theory emphasizes that social networks affect individual actions; similarly, it is one of the paradigms for understanding interpersonal interaction behavior. Individuals cannot exist separately from society; thus, individuals must cooperate and share/exchange their resources with stakeholders (Liu et al., 2019). This theory provides guidance on how to maintain interpersonal relationships; similarly, social capital theory is appropriate for learning networks and offers a basis for trust in a group/team (Han et al., 2020; Koranteng & Wiafe, 2019). For example, Luo et al. (2022) have used this theory to investigate whether social network sites can promote students' engagement in online

learning. In this study, wikis provide an opportunity to measure intangible resources between individuals and groups in network structures. Thus, we focused on relational social capital (i.e., trust and identification). Although social capital theory has been widely discussed in the field of learning behavior, research on coauthoring experience in wiki-based PBL is very limited.

In the context of a social network platform, trust, including individuals' trust in their fellow users and in the platform, itself can be considered to be the key to facilitating collaborative interactions among individuals (Mohammadi & Hashemi Golpayegani, 2021). The former is a subjective expectation regarding members' future behaviors in a group; the latter is a reflection of the users' usage experience that is developed based on the quality of feedback from the platforms, and both types of trust can promote individuals' engagement in collaborative activities performed via the use of the platforms (Chaker & Impedovo, 2021; Koranteng & Wiafe, 2019; Nahapiet & Ghoshal, 1998). Here, trust refers to students having more trust in peers' abilities, leading to taking peers' feedback posted on the wiki platform seriously or relying on each other more often, and they thus will do their best to fulfill their obligations to mitigate uncertainty or perceived risk (Barajas & Frossard, 2018; Mpin-ganjira, 2018; Lin & Wang, 2022). With each successful interactive experience, individuals' beliefs will increase the level of trust and dependence; inversely, the level of trust will decrease when the expectations are not satisfied. Consequently, creating trust ties with peers is based on whether peers have higher interpersonal relationships and are willing to collaborate with others. In other words, the internal properties of a group need to be considered in building interpersonal trust. In an online learning network, interpersonal trust can create strong ties and be constantly reinforced, which is associated with learning resource sharing (McAllister, 1995; Yu et al., 2022a). Here, trust can be regarded as a self-control tool to stop peers' opportunism, which might facilitate peer collaboration and communication in a PBL group. In addition, wikis can contribute to peers' learning through interaction and provide support when they cope with uncertainty or lack of information. Relational trust with peers has been reported as an influential antecedent of social identity (Wang et al., 2022). Individuals with higher trust ties to peers are likelier to engage in social identity and cooperative interactions. As mentioned above, it can be inferred that trust and social identity do not only include the entire social network.

2.3 Social identity theory

The social identity theory proposed by Tajfel (1974) emphasizes the difference in identity between the in-group and out-group, revealing that individual self-concept, self-image, or actions are often influenced by peers or members (Guo & Li, 2016). Specifically, personal identity is a social behavior that is expressed through social relationships, roles, communication, and interaction, which individuals internalize (Conole & Culver, 2009). Presented identity (self-presentation) and relational identity (social exposure) are often used to predict engagement behavior in the Web 2.0 field; Web 2.0 plays a vital role in this mediated process (Bliuc et al., 2011; Guan et al., 2018; Ng et al., 2022).

Social identity is the degree to which an individual experience a sense of wellness or psychological affiliation within a group (Ashforth & Mael, 1989; Turner & Tajfel, 1986). Tajfel (1974) defined social identity as a three-dimensional activity. First, cognitive identity involves the recognizable characteristics that describe them as like members or as dissimilar to others in their groups. Cognitive identity results in a self-categorization process of group membership based on individual self-awareness. Second, affective or emotional identity involves a deep level of affective commitment or emotional attachment. Individual involvement includes the social and physical components of a group and allows a means of personal learning that induces a certain level of affective relationship (Heidari et al., 2020). This identity emphasizes the emotion attached to the members' interaction in the group to which they belong, which is similar to the attachment conception. Finally, evaluative identity involves distinguishing the individual from others, creating positive self-esteem or self-efficacy, and maintaining a sense of continuity to avoid nervous feelings in a group. Therefore, an individual's identity with their group might be determined by their evaluation (Cao et al., 2022; Wang, 2020).

2.4 Hypothesis development

As shown in Fig. 1, research has stated that understandability is a critical qualitative factor underlying users' acceptance of online information on a platform (Liu & Park, 2015). Improving understandability or clarity is correlated with content writing (Confetto & Covucci, 2021). Similarly, an individual with a good understanding of the problem-solving process may help to improve the identification of peers when using wikis as a collaborative tool, particularly in a coauthor context. That is, reasonable problem solutions are based on identifying peers' capabilities in their information and knowledge. Additionally, when a platform (i.e., wikis) is easier to understand, this will determine the breadth of its application, making its content easier to

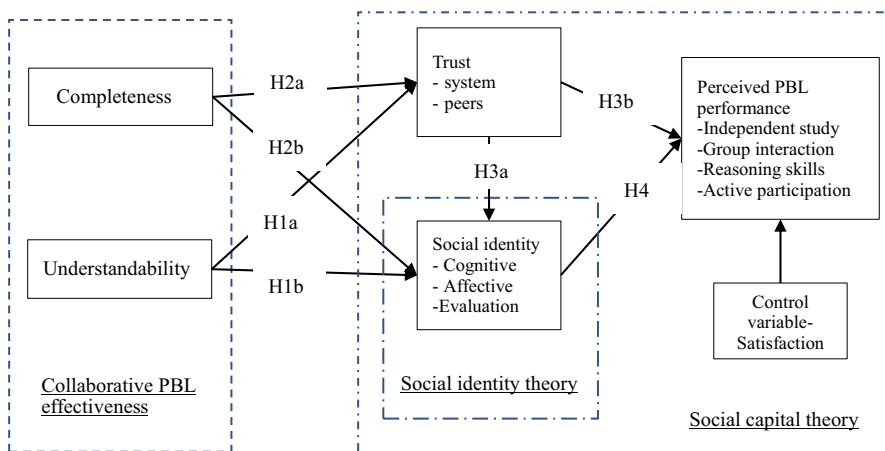


Fig. 1 Conceptual model

modify or reuse (Etien et al., 2015). It can be inferred that understandability is also related to transparency (i.e., identification, content, interaction), allowing a quick understanding of the knowledge/information of this platform (Alsaedi et al., 2022; Eldrandaly et al., 2022). Furthermore, if a system is known, shaping a user's trust in the ecosystem service of this platform is more effortless. Previous research has indicated that the understandability of a system is associated with individual trust (Lee et al., 2019; Zavolokina et al., 2020). Accordingly, the hypothesis is as follows.

- H1a. Understandability is positively related to learners' trust.
- H1b. Understandability is positively related to learners' social identity.

Previous empirical research reveals that perceived completeness is likely to influence trust, coordination, and problem solving (Gong et al., 2007; Shahzad et al., 2020; Sharif et al., 2020). Fang et al. (2013) suggest that trust can facilitate communication and knowledge transfer on self-control and coordination among partners in the context of knowledge transfer. Complete content can reduce the adverse effects of conflict on coordination (Choi et al., 2020; Hosseini et al., 2018). Ge and Helfert (2013) argued that when information structure and content are of high-quality, this will result in high levels of completeness and contain the whole meaning of a learning task. Additionally, the content's breadth and depth must be included in completeness. In the PBL context, the negative impact is powerful when learners' tasks are interdependent and relational norms are weak. Therefore, the completeness of the coauthoring might provide helpful support. Completeness can boost the transparency of the problem through a series of questions and indicators to disclose potential threats, generating their identification to solve problems. Accordingly, the hypothesis is as follows.

- H2a. Completeness is positively related to learners' trust.
- H2b. Completeness is positively related to learners' social identity.

Social relationship studies have indicated that trust plays a crucial role in understanding each partner's willingness and developing collaborative behavior (Wang et al., 2022; Zheng et al., 2021), particularly in virtual interpersonal interactions. Therefore, an individual's high confidence level is present when partners are willing to collaborate with others or offer relevant feedback in a PBL group/team. Previous studies have reported that trust is positively associated with users'/learners' learning performance (Lin & Wang, 2022; Yu, Shen, Chen, & Bao, 2022).

Additionally, previous studies have stated that trust can affect members' identification in a group/team (Chen & Li, 2021; Chen & Sharma, 2013). If individuals want to maintain a relationship with others that can help them achieve common goals, then trust may occur before identification (Dirin et al., 2022; Hsu, 2018; Fujita et al., 2018). Individuals perceive that the members of a PBL group are characterized by expert knowledge; they will likely pay more attention to their group, have deeper feelings for them, or spend more time with them. They will build a high level of trust, reciprocity, and identification. Consequently, individuals might categorize themselves and others into an in-group and an out-group based on their

perceived trust. It can be inferred that the more trust is perceived in a group/team, the more social identity is likely to be identified with the group/team (Wang & Lin, 2021; Wang et al., 2022). Accordingly, the hypothesis is as follows.

H3a. Trust is positively related to social identity.

H3b. Trust is positively related to perceived PBL performance.

Social identity can be a unique sense of belonging in a specific context or social category (e.g., group, team, organization) (Ashforth & Mael, 1989). Partners' identification can facilitate their concern with group processes and consequences because they may have the same purpose in the task's success that promotes them to engage in the study voluntarily and do their best to achieve the optimal outcomes. When partners identify with their group/team and feel proud of it, they will likely display higher engagement and learning performance in their tasks (Harris et al., 2020; Pai et al., 2022). Accordingly, the hypothesis is as follows.

H4. Social identity is positively related to learners' perceived PBL performance.

3 Methodology

3.1 Procedure

This study mainly examines the collaborative behaviors among students in wiki-based PBL activities. The research procedures of this study were approved by the ethics committee of the university governance framework for human research ethics of the authors' institute (No. 109–088-02). PBL case studies have been conducted with the wiki-based PBL teaching approach in information-related courses (i.e., the introduction of information management, digital technology application, computational thinking, etc.). Each real-world case issue of PBL activities lasted four weeks (see Table 1). Each PBL group had from four to eight students and selected one student to be the chairperson and one to be the tutor who would post the consensus on the wiki page. All participants had to be involved in defining questions, extracting keywords, searching references from journals or others, analyzing, discussing, and negotiating to generate the best solution; similarly, they contributed their solutions on the wiki page to share with all participants. The tutors or instructors would regularly check the coauthoring contents on wiki pages to observe students' understandability based on their responses or sharing and guide the direction of their inquiries or discussions using LINE applications.

Each PBL group used a class that was divided into several groups that involved a randomly selected group. Additionally, the members of a PBL group would use other information communication tools (ICT) for discussion, including LINE apps, Facebook, and others. The procedures were as follows. First, the authors discussed the PBL of real-world case issues with two lecturers of information or computer science. At the same time, we invited the instructors and their students to join this learning activity. Second, our research team posted the PBL of real-world case

Table 1 The primary learning phases of the PBL process

Week	Technique	Learning task
Zero	Pilot test	• The authors introduced the features of the wiki pages and how to use them to the participants, encouraging them to contribute their idea or opinions. • The pretest questionnaire was distributed to participants and collected by researchers.
First	Experience of the PBL process	• The instructor briefly introduced the students' and tutor's responsibilities, presented case studies, set up the PBL groups (each group had 4–8 members), and explained the meaning of PBL processes regarded as a learner-centered teaching approach. • The instructor logged in to the wikis pages, giving students the topic of real-world case issues and lecturing on PBL processes using a video for students. • Instructors explained the role of the PBL tutorial facilitators. • The authors provided written and oral explanations of this study and requested that students try to contribute their ideas on the wiki page.
Second & Third	Understand the questions	• Peers implemented the process of finding evidence from the collection, measuring, distinguishing, presenting, etc. • Peers presented their reference materials from various information or databases that discussed and gave feedback about PBL for real-world case issues. • Peers followed the problems of others and detail understood and analyzed the related materials or scenarios. • The group leader combined the elements from different feasible solutions, chose the best solution, and posted it on the wiki page.
Four	Completed PBL activities, sought or gave feedback	• All PBL groups of each class were allowed to present the evidence and answer the requirements from the classmates based on their solutions in the learning activities. • Instructors could maximize students' cognition in the above process by utilizing students' ideas and opinions of feedback or sharing on the wiki pages. • Instructors could provide problem-solving direction and encourage the revision of the whole concept among students or accept/share the ideas of others. • The students assessed the PBL activity and compared the perceived PBL performance based on their experiences.

issues on the wiki page. Additionally, in all PBL activities, informed consent was obtained from the participants and executed under the instructors' direction to solve similar real-world problems. The instructors/tutors were not involved in the students' discussions or interactive processes during the PBL activities. Finally, we requested that the instructors/tutors assess the information or content on the wiki page at the end of the PBL activities. Likewise, the instructors/tutors had to share with students the correct answers or optimal solutions, which was of benefit to them because they could analyze, compare, or integrate new knowledge or information to improve their learning performance.

3.2 Participants

This study adopted a convenience sampling method. Two of the largest universities, one research-oriented and one teaching-oriented, which were located in the metropolitan area of the researchers' university were selected as the sampling frame of this study in order to increase the level of the representativeness of the sample collected to the general population of college students in the same metropolitan area. Invitations of participation were sent via emails and various online social networking/communication services (e.g., LINE applications, Facebook) to invite instructors and their students from various universities to participate in the experiment of this study. While most instructors did not agree to participate in the research procedures associated with the use of the wiki platforms developed specifically for this study because of concerns regarding the potential interference with their original curriculum planning, instructors of six courses agreed to participate in the current study. Eventually, 244 undergraduate students of those six courses at two universities participated in the experiment of this study in the fall semester of 2021. However, four students had incomplete answers on the survey questionnaire (e.g., one or more missing values for each construct), which generated 240 valid responses.

Additionally, the participants needed to have experience taking the introduction to computer science course. Moreover, the authors' students were excluded from the participants to avoid causing a deviation from this survey result. Furthermore, the frequency of information or opinion among groups' posts on the wiki pages was used to examine each construct and found no difference. The p-values of Levene's test for completeness, understandability, trust, social identity, and perceived PBL performance are 0.17, 0.51, 0.38, 0.17, and 0.15, respectively, indicating the homogeneity of the participants from two different universities in terms of the constructs of interest of this study. Finally, a total of 138 (57.5%) participants were female. The grade distribution was as follows: 52 (21.67%) freshmen, 54 (22.5%) sophomores, 58 (24.17%) juniors, 65 (27.08%) seniors, and 11 (4.58%) master's degrees. Participants used ICT for their learning each day as follows: 40 (16.67%) less than one hour, 23 (35.83%) 2–3 hours, 65 (27.08%) 4–5 hours, and 49 (20.42%) over 5 hrs. The posts of frequency were as follows (times/groups): 103/27 (21.96%/62.79%) below ten times, 165/11 (35.18%/25.58%) ranged from eleven to twenty times, and 201/5 (42.86%/11.63%) over twenty times.

3.3 Data analysis

Partial least squares structural equation modeling (PLS-SEM) was used to examine the proposed hypotheses and the psychometric properties of the measurement model, including convergent and discriminant validity. This method has some advantages. First, it is well suited for a complex or formative research model with numerous constructs (Hair et al., 2021). Second, it has minimal restrictions regarding the small sample size and residual distributions. Therefore, in this study, we adopted PLS-SEM to investigate the formative constructs, performing the assessments in two phases: using confirmatory factor analysis (CFA) in the measurement model (e.g., reliability, convergent validity, and discriminant validity) and using a bootstrap resampling procedure with 5000 resamples in the structural model (e.g., R square, path coefficient).

Additionally, adding a single unmeasured latent method factor (LMF) to the conceptual model and obtaining the path coefficients by a statistical approach that did not improve significantly may partially out any possible common method bias (Podsakoff et al., 2003; Liang et al., 2007). This study applies LMF in the first-order factor of the structural model by the PLS method. All second-order dependent constructs in each indicator are turned into a single-order construct that is regarded as a second-order construct. Then, an LMF is put in the conceptual model. Three items of cognitive-based inertia were used in LMF. Examples: “Although I have experienced the online collaborative PBL, I would prefer to continue using my original learning method because it is (1) the best way of learning; (2) the most effective way of learning; (3) the most effective way to learn than any alternative approaches for me.” The average substantially explained variance of the indicators was 0.59, while the average method-based variance was 0.003. The gap ratio between them is significant, and this study can ignore the problem of bias (Fig. 2).

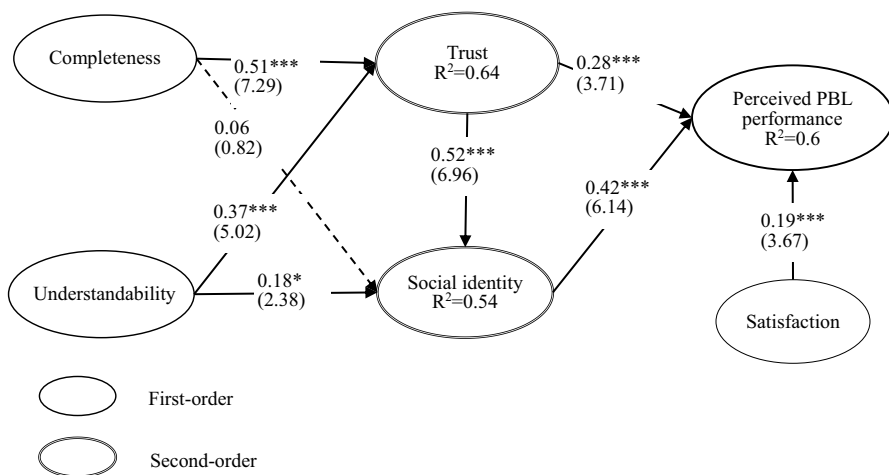


Fig. 2 Adjusted results of hypotheses

3.4 Instrument

All items for the five constructs were borrowed from the validated measures of previous studies and slightly modified to fit the study's context. All items were measured on a seven-point Likert-type scale, ranging from "1 = strongly disagree" to "7 = strongly agree," except for the demographic information. These items were pretested using a pilot survey to verify problems with content, comprehension, and wording with forty-five students before the main study. Additionally, the values of Cronbach's alpha were determined via IBM SPSS software. The results reveal that the importance of completeness (6 items), understandability (4 items), trust system (5 items), trust peers (5 items), social identity-cognitive (4 items), social identity-affective (4 items), social identity-evaluation (3 items), independent study (5 items), group interaction (5 items), reasoning skills (4 items), and active participation (4 items) were 0.9, 0.72, 0.9, 0.93, 0.85, 0.89, 0.7, 0.9, 0.94, 0.84, and 0.9, respectively. The values of Cronbach's alpha for each construct exceeded 0.70, and thus, the primary survey was conducted. After CFA, the survey items and their sources are listed in Appendix Table 4.

Control variable Satisfaction is considered a control variable composed of a single indicator in this study. The item is "How satisfied are you based on your wiki-based PBL experience?." Previous studies have shown that satisfaction significantly influences perceived learning or learning performance (e.g., Li et al., 2021; Rueda et al., 2017). It can be inferred that satisfaction might affect students' perceived PBL performance.

4 Results

4.1 Measurement model

Based on the data analysis procedures, reliability, convergent validity, discriminant validity, and common method bias were examined. First, we used first-order reflective constructs using a variance-based research model to check them. The factor loadings and Cronbach's alpha are presented in Appendix A. Additionally, Table 2 shows that some discriminant validity criteria are confirmed. (1) All factor loadings were larger than 0.7, and the convergent validity thus satisfied the convergent validity. (2) All values of average variance extracted (AVE) and composite reliability (CR) were significantly larger than reliability values of 0.5 and 0.7, respectively. (3) The square correlations between constructs were lower than the AVE values of their constructs (Fornell & Larcker, 1981). (4) All values of the heterotrait-monotrait ratio (HTMT) were smaller than 0.85. Second, as shown in Table 3, the weights, variance inflation factor (VIF), and standard error of the second-order constructs for multicollinearity were also investigated. That is, the formative and reflective research models were treated differently. Regarding

Table 2 Results of discriminant validity, HTMT, Cronbach's alpha, composite reliability, and variance inflation factor

Construct	1	2	3	4	5	6	7	8	9	10	11
1. Complete	0.66										
2. Understandability	0.48 (0.8)	0.66									
3. Trust-peer	0.4 (0.71)	0.4 (0.74)	0.67								
4. Trust-system	0.58 (0.85)	0.46 (0.79)	0.5 (0.81)	0.67							
5. Social identity-Affection	0.26 (0.58)	0.31 (0.66)	0.4 (0.72)	0.32 (0.65)	0.72						
6. Social identity-Cognition	0.31 (0.65)	0.3 (0.67)	0.38 (0.73)	0.29 (0.64)	0.44 (0.79)	0.62					
7. Social identity -Evaluation	0.26 (0.62)	0.25 (0.62)	0.32 (0.68)	0.25 (0.61)	0.44 (0.81)	0.35 (0.75)	0.69				
8. Independent study	0.33 (0.66)	0.37 (0.73)	0.28 (0.61)	0.3 (0.64)	0.32 (0.66)	0.33 (0.69)	0.27 (0.64)	0.61			
9. Group interaction	0.22 (0.52)	0.39 (0.73)	0.36 (0.69)	0.32 (0.65)	0.39 (0.71)	0.3 (0.65)	0.29 (0.65)	0.45 (0.77)	0.67		
10. Reasoning skills	0.35 (0.67)	0.33 (0.67)	0.28 (0.6)	0.36 (0.68)	0.24 (0.56)	0.27 (0.61)	0.3 (0.66)	0.49 (0.81)	0.34 (0.66)	0.74	
11. Active participation	0.18 (0.48)	0.29 (0.63)	0.24 (0.56)	0.21 (0.53)	0.27 (0.6)	0.22 (0.55)	0.21 (0.56)	0.44 (0.77)	0.44 (0.76)	0.36 (0.68)	0.71
Mean	5.28	5.42	5.43	5.24	5.14	5.24	4.98	5.34	5.49	5.38	5.38
standard deviation (S.D.)	0.93	0.86	0.93	0.93	1.01	0.89	1.05	0.88	0.84	0.97	0.94
Cronbach's Alpha	0.9	0.83	0.88	0.88	0.87	0.79	0.77	0.84	0.88	0.88	0.86
Composite Reliability	0.92	0.89	0.91	0.91	0.91	0.87	0.87	0.89	0.91	0.92	0.91
variance inflation factor (VIF)	1.62–2.88	1.61–1.98	1.84–2.46	2.09–2.45	1.82–2.71	1.5–1.78	1.52–1.88	1.59–2.43	1.93–2.5	1.92–3.16	2.12–2.42

N = 240; AVE = Average variance extracted were at the boldface and diagonal; the values of the squared correlation coefficients were at the non-diagonal; Heterotrait-Monotrait (HTMT) ratios are in parentheses

Table 3 Results of weight and VIF for examining the multicollinearity

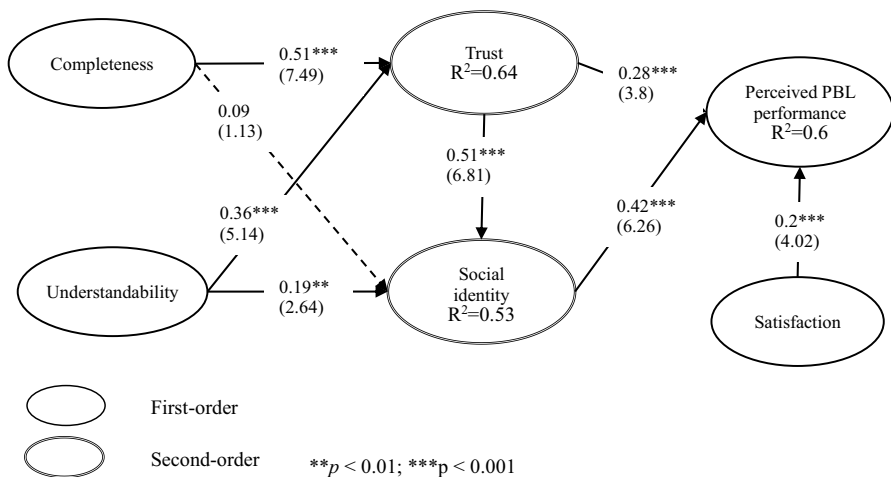
Second-order construct	First-order first-construct	VIF	Standard error	Weight (<i>t</i> -value)
Trust	Peer	2.01	0.01	0.53*** (54.08)
	System	2.01	0.01	0.55*** (45.31)
Social identity	Affection	2.26	0.02	0.4*** (26.0)
	Cognition	1.93	0.01	0.38*** (26.81)
	Evaluation	1.93	0.01	0.37*** (25.21)
Perceived problem-based learning performance	Independent study	2.66	0.01	0.3*** (25.67)
	Group interaction	2.18	0.01	0.31*** (24.38)
	Reasoning skills	2.14	0.01	0.29*** (22.67)
	Active participation	2.19	0.01	0.27*** (23.41)

*** $p < 0.001$

formative constructs, weights were adopted to evaluate the contribution of each indicator corresponding to the constructs. The formative items of trust, social identity, and perceived PBL performance have substantively contributed to their corresponding constructs.

4.2 Structural model

All hypotheses use a bootstrap resampling procedure that is performed 5000 times. Figure 3 shows the results and finds that most hypotheses were supported except H1b. First, understandability is positively and significantly related to the user's relational quality, thus supporting H1a. Second, completeness is positively and significantly associated with the user's trust and social identity, thus supporting H2a and H2b. Third, trust is positively and significantly related to social identity and

**Fig. 3** Results of hypotheses

perceived PBL performance, thus supporting H3a and H3b. Finally, social identity is positively and significantly associated with students' perceived PBL performance. Therefore, H4 is supported. Additionally, the control variable (i.e., satisfaction) greatly impacts perceived PBL performance (see Fig. 3).

5 Discussion

Drawing upon the theoretical perspective of social identity and social capital, this study describes why wikis' completeness and understandability are associated with students' trust (H1a, H2a) and social identity (H2b). These results are in line with those of previous studies (e.g., Alsaedi et al., 2022; Eldrandaly et al., 2022; Gong et al., 2007; Lee et al., 2019; Shahzad et al., 2020; Zavolokina et al., 2020). H1b is insignificant; thus, we examined the mediating effect of trust by using Hayes process macro techniques of bootstrapping with a 95% confidence interval (CI) with 5000 resamples (Hayes, 2012). The results reveal that trust has a substantial mediating effect on the relationship between completeness and social identity, which is consistent with the findings of Chen and Li et al. (2021). The coefficient between the two variances was significant ($\beta=0.45$, $se=0.07$), and the 95% CI did not cross zero (ranging from 0.35~0.55). The framework of this study asserts that students' trust and social identity are determined by both wikis' effectiveness, accounting for 64% and 53% of their variance, respectively. Additionally, trust has a significant and positive effect on social identity (H3a) and students' perceived PBL performance (H3b), which is consistent with previous studies (e.g., Dirin et al., 2022; Chen & Sharma, 2013; Hsu, 2018; Yu, Shen, Chen, & Bao, 2022). Finally, social identity significantly and positively affects students' perceived PBL performance (H4), which is in line with previous studies (Harris et al., 2020; Pai et al., 2022). The results show that relational social capital predicts students' perceived PBL performance. This means that students' perceived PBL performance is primarily explained by students' trust belief and social identity, accounting for 60% of its variance.

5.1 Implications of educational research

As outlined in the literature review, based on instructional design and a theory-driven approach, there is not yet a consensus regarding incorporating social technologies into classrooms to achieve better learning outcomes. This study's results can enrich the theoretical application and teaching design of wiki-based PBL teaching in the education research field. First, in PBL learning activities, the completeness of reference and understandability of a specific application are essential dimensions of platform/system effectiveness that are critical factors in the success of PBL teaching. Additionally, both appear necessary and helpful for students to maintain their relationships with peers in learning activities. This extends the application of the relational dimension of social capital theory, which provides valuable insights to help students identify unique learning resources and understanding mechanisms (Burgess et al., 2020; Chen & Sharma, 2013; Heidari et al., 2020; Wang et al., 2022).

Additionally, this study embeds social identity theory in social capital theory, which emphasizes identity-based attachment among students, causing them to be willing to cooperate and have discussions with peers. Both theories also have potential implications for emphasizing students' psychological and motivational needs in the learning process and being critical and effective in their learning outcomes. Individuals' willingness to contribute self-opinions or ideas on wiki pages is a personal decision that also depends on their repertoire of accumulated knowledge and interactive social ability (Bliuc et al., 2011; Cao et al., 2022; Fujita et al., 2018; Guo & Li, 2016).

Finally, discussions in PBL groups can be challenging and can be dispersed over subjects. Thus, based on relational capital theory, group knowledge sharing mainly relies on trust or identification among participants; likewise, they need to have similar levels of understandability. Such a case may benefit them to obtain a common consensus regarding an ill-structured PBL topic in a wiki-based PBL context. That is, individual self-study, interaction, participation, and reasoning skills are relevant to the collective discussion, thus improving their learning outcomes about new information or knowledge.

5.2 Implications for education practice

This study has a number of practical implications. First, it is found that integrating the use of collaborative PBL approaches with the wiki platforms is effective in terms of addressing the criticism of the poor feasibility of collaborative PBL approaches in educational settings (Mavengere & Ruohonen, 2018). To be specific, such an integrated teaching setting that has high degrees of understandability and completeness can minimize students' social loafing or feeling of isolation in PBL groups and enable them to behave in a self-disciplined and self-controlled manner, and thus encourage them to actively engage in the focal learning activities to obtain new knowledge in a more effective manner by taking advantage of the wiki's feedback and visualization functions (Zhu & Zhang, 2022). Therefore, it is suggested that instructors can encourage students to engage in more technological resource-based learning activities in which meaningful PBL tasks are used to facilitate students' collaboration with peers and obtain better learning experiences in collaborative PBL processes (Resta & Laferrière, 2015; Tiernan, 2015).

Additionally, functions of wiki platforms can be utilized using the common operating skills for using various technological products with which most people are familiar. Therefore, using wiki can potentially reduce the learning costs of students to engage in the focal learning activities, thus increasing their sense of autonomy, convenience, and perceived flexibility (Barajas & Frossard, 2018). Wiki may encourage students actively engage in collaborative learning activities and jointly take responsibility for learning (Bizami et al., 2023; Mohammadi Zenouzagh et al., 2023). Thus, this study suggests that similar PBL activities can take advantage of the functions of wiki platforms (e.g., coauthoring and the tracking and recording functions of the coauthoring process) to customize their learning content and to better support students' learning processes (e.g., capturing information about PBL

cases, creating organized knowledgebase, facilitating student collaboration to synthesize critical learning issues of PBL cases, and developing communication skills) in order to improve their learning performance.

Finally, some key factors must be considered carefully to ensure the effectiveness of the application of PBL-related educational processes. These factors include students' psychological states (e.g., trust and social identity) and the advanced functions of wiki platforms (e.g., previewing articles or discussion pages and the interlinks among collaborative editions). Wikis that offer those functions mentioned above can benefit students in reconciling conceptual conflicts and solving problems collaboratively during the coauthoring and interaction processes (Bringula & Atienza, 2022; Bruguera et al., 2022; Chaker & Impedovo, 2021; vanOostveen et al., 2019). In such an online collaborative PBL context, wikis can help students observe the competencies of peers to generate their trust in the peers and increase their social identity regarding the learning groups. This enables the students to reduce their uncertainty regarding the credibility of the knowledge learned along with their peers during the PBL processes and then absorb the knowledge learned in a more comprehensive manner (Pellas & Kazanidis, 2015; Salem, 2019; Stockleben et al., 2017; Wang & Lin, 2021). Therefore, instructors can use wikis to organize similar PBL activities that can help students gain a better learning experience in order to effectively achieve the various teaching goals in the limited class hours.

5.3 Limitations

Drawing on previous theories and empirical findings, this study mainly investigated an instructional method of wiki-based PBL to explore students' behavior. Thus, the validity results reveal some limitations. First, our research design does not include control groups. Future research is strongly recommended to employ the comparisons of experiment and control groups; similarly, this is best performed under controlled experimental environments. Second, the average frequency of comments or opinions by each PBL group on the wiki page is low ($469/43 = 10.91$); thus, we cannot exclude conformity behavior among participants regarding the conclusion of the PBL case study. Future research can consider executing similar experiments in different settings (i.e., workshops, courses, or online programs) and comparing the differences in the PBL groups. Third, the participants were recruited from two universities using a non-random sampling approach. Therefore, there is room for improvement in the level of the generalizability of the research results of this study. Future studies that aim to extend the contributions of the current study can employ more robust sampling methods to collect empirical data in order to enhance the generalizability of their research findings. Finally, assessing perceived PBL performance manifests certain disadvantages and advantages (i.e., tutor guidance, engagement, search, and problem-solving abilities), which might not be the best measure of learning performance. It is suggested that future research could collect participants' actual learning scores and investigate subjective and emotional learning experiences after completing such activities.

Appendix

Table 4 Measurement items

Construct	Items
Completeness (Ali & Younes, 2013; Wixom & Todd, 2005)	1. This wiki-based cowriting platform includes the necessary values or information about the PBL case/question. 2. This wiki-based cowriting platform is sufficiently complete for my information needs about the PBL case/question. 3. This wiki-based cowriting platform covers the needs of our task about the PBL case/question. 4. This wiki-based cowriting platform can provide sufficient breadth and depth for our task about the PBL case/question. 5. If necessary, I can find complete PBL case/question information in this wiki-based cowriting platform. 6. The information in this wiki-based cowriting platform is sufficient for our task about the PBL case/question.
Understandability (Laumer et al., 2017; Lee et al., 2002)	1. It is easy to read the writing about the PBL case or information/knowledge from this wiki-based cowriting platform. 2. The meaning of this PBL case writing or information/knowledge is difficult to understand from this wiki-based cowriting platform. * 3. Within this wiki-based cowriting platform, PBL case writing or information/knowledge is clear in its meaning. 4. Within this wiki-based cowriting platform, PBL case writing or information/knowledge is easy to comprehend.
Trust in wiki platforms (Koufaris & Hampton-Sosa, 2004)	1. This wiki-based cowriting platform is consistent in quality and service. 2. This wiki-based cowriting platform is known as one where promises and commitments are kept. 3. The interest of the user is considered on this wiki-based cowriting platform. 4. There is a high degree of integrity on this wiki-based cowriting platform. 5. I trust this wiki-based cowriting platform.
Trust in peers (Shen et al., 2014)	1. This wiki-based cowriting platform is consistent in quality and service. 2. This wiki-based cowriting platform is known as one where promises and commitments are kept. 3. The interest of the user is considered on this wiki-based cowriting platform. 4. There is a high degree of integrity on this wiki-based cowriting platform. 5. I trust this wiki-based cowriting platform.

Table 4 (continued)

Construct	Items
Social identity- cognitive (Tsai & Bagozzi, 2014)	1. Peers in the group have substantial similarities. 2. There is a close similarity of values between peers in my group. 3. I am willing to accept the group (identity) based on consciousness-based adjustments. 4. I am accepted by the PBL group and share the same defining attributes of the group with peers.
Social identity-affective (Tsai & Bagozzi, 2014)	1. I have a strong emotional attachment to the group. 2. I have strong belongingness/identification with the group. 3. My group has positive responsiveness to me. 4. My group is appealing and capable of improving peers' social identity.
Social identity-evaluative (Ho et al., 2012)	1. I become irritated when I hear others from outside groups criticize my peers. 2. I talk up my group to my friends as a great group to work for. 3. My group's image in the PBL groups represents me well.
Independent study (Valle et al., 1999)	4. I am persistent in studying the PBL case writing or information content. 5. I am motivated to know more. 6. I implement assigned tasks to achieve the learning objectives 7. I show initiative in studying the PBL case writing or information content. 9. I accomplish tasks agreed upon by the peers of the group.
Group interaction (Valle et al., 1999)	1. Accepts suggestions about their work. 2. Adjusts to differentiate their roles 3. Shows respect to their peers. 4. Accepts decisions made by the other peers of the PBL group. 5. Listens attentively to other peers in other peers of PBL group.
Reasoning skills (Valle et al., 1999)	3. I would carefully scrutinize before accepting or rejecting a hypothesis on well-based foundations 4. I would carefully analyze different components of the PBL case/question. 5. I would carefully clarify the facts, concepts, and terminology of the PBL case/question. 6. I would carefully identify information relevant to the PBL case/question.
Active participation (Valle et al., 1999)	1. I would give feedback (reflections, ideas, and suggestions) to the peers of the PBL group. 2. I would help my peers clarify the PBL group's ideas. 3. I would participate in case discussions of the PBL case/question. 4. I would share knowledge with the other peers in the group.

*= reverse score

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Data availability Data will be made available on reasonable request.

Declarations

Conflict of interest No potential conflict of interest was reported by the author.

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