Education Tech Research Dev
https://doi.org/10.1007/s11423-023-10202-7

DEVELOPMENT ARTICLE

# Tackle implementation challenges in project-based learning: a survey study of PBL e-learning platforms

**Nanxi Meng**[1] · **Yan Dong**[2,3] · **Dorian Roehrs**[1] · **Lin Luan**[2,4]

Accepted: 20 January 2023


**Abstract**
Project-based learning (PBL) has been identified as an effective pedagogy for instructors to help students to learn interdisciplinary knowledge, problem-solving skills, modes of thinking, and collaborative practices through solving problems in a real-world context. However, previous studies reported that instructors from K-12 to tertiary learning environments found it challenging to implement such a pedagogy for various reasons. The emergence of PBL E-learning platforms in the recent decade has attracted increasing interest in adoption and seems to provide a solution to tackle the difficulties in PBL implementation. Yet little is known about designing these platforms and how they facilitate the PBL learning process and management. In the current study, we conducted a multiple case survey study on 16 PBL learning platforms in English and Chinese, collected data on their features and functions, categorized them according to their services provided, and analyzed how they tackle the implementation challenges. Additionally, we identified four trends in PBL development as pedagogy, the skills, and competence required for teachers and students to successfully carry out PBL via e-learning platforms and provide suggestions to improve and refine the platform design for educational technologists and related stakeholders. The limitations of this study and the future research direction are included.

**Keywords** Project-based learning · E-learning platforms · Implementation difficulties · Project management

## Introduction

Project-based learning (PBL) is a systematic and transformative pedagogy that advocates for students to gain knowledge and skills through working for an extended period to investigate and respond to an authentic, contextualized, complex question, problem, or challenge (Thomas, 2000). Students demonstrate their knowledge and skills by creating tangible or intangible artifacts and presenting them to real audience group(s). As a result, students develop deep content knowledge and skills like critical thinking, collaboration, creativity, and communication (Barron & Darling-Hammond, 2008). Studies have identified the

✉ Yan Dong
yan.dong@bnu.edu.cn

Extended author information available on the last page of the article

positive impact PBL had on students, including increased design proficiency, improved confidence and willingness to approach challenges (Thomas, 2000), developed thinking skills (Anazifa & Djukri, 2017), and interdisciplinary competence (Brassler & Dettmers, 2017).

Despite the usefulness and effectiveness of PBL pedagogy, concerns were voiced against adopting PBL, as many teachers found it challenging to implement and manage the learning process (Aldabbus, 2018). Often, teachers were responsible for providing learning materials, keeping up with students' personal and in-group collaboration progress, checking up on students' learning performance, providing timely feedback, and supporting sufficient interactions among students, teachers, and content. Hence, a solution that assists teachers in managing the mentioned efforts was highly desired.

With the development of technologies in education and the digitalization of learning, adopting electronic learning (e-learning) platforms, especially in elementary and secondary schools, has seen a rapid evolution (Cavus et al., 2021). E-learning platforms have become an indispensable component of the education experience for students, teachers, and other stakeholders. Provides the technical infrastructure on which e-learning activities can take place. The various functions embedded in e-learning platforms help teachers complete teaching duties, administrative and management assignments, and practice the e-learning platforms and teaching method (Kassymova et al., 2020), like project-based learning.

Seeing the increasing popularity of PBL worldwide and the need to manage the learning process, the e-learning platforms specialized in supporting PBL emerged and have gained interest from teachers and educational institutes. PBL learning platforms like Project Pals developed by the U.S., Dreamdo Schools by Finland, Cura by Australia, and EPBL by China were good examples. Their user groups have been growing. However, though all claimed to be PBL e-learning platforms, they were distinctive in the rationale of design, features and functions, and the mechanism supporting PBL practice and development.

Since 2020, the Covid-19 pandemic has deeply affected the global economy and profoundly changed the form of education. Numerous schools shut down during the pandemic, and the uncertainty of face-to-face instruction accelerated the transition to online and digitalized learning, making e-learning platforms a core component in K-12 education. Prior to 2022, the top challenges of online learning for K-12 learners include inequity of technology and materials, lack of online teaching knowledge (Vinson & Caukin, 2021), unstable internet connection, and unfamiliar with the learning platforms and software (Zuo et al., 2021), among many others. Looking into the post-pandemic era, many schools and districts continue to use e-learning technologies to assist students to achieve learning success (Mann et al., 2021). On the other hand, the emergence of PBL e-learning platforms posts challenges for educators to choose the right platform for the targeted learners. In the current study, we propose surveying the available PBL platforms in both the English and Chinese worlds to explore how these platforms support PBL practice and development.

## Literature review

### Project-based learning (PBL)

PBL is a student-centered pedagogy and an overall approach to the design of the learning environment (Krajcik & Blumenfeld, 2006). There are five key features of the PBL learning environment and procedures (Krajcik et al., 2003). PBL starts from a driving

question or a real-world problem to be solved. Then, students engage in authentic, contextualized inquiry to explore the driving question and learn to apply essential ideas in the discipline. Third, students, teachers, and community members engage collaboratively in activities to find solutions to the driving question, which mirrors the process of solving challenges in a real-world context. Fourth, learning technologies provide scaffolds for students to expand their ability and engage more profound in the inquiry process. Last, students create tangible products to address the driving question and share the artifacts publicly with the stakeholders. After decades of research, researchers have established four constructive principles of PBL (Krajcik & Blumenfeld, 2006): (1) contextualized learning. Learning in an authentic, real-world context allows students to see the value and meaning of the tasks and activities they perform and generalize better to a broader range of situations. (2) Active construction of knowledge. PBL allows students to actively construct their knowledge through participating in real-world activities similar to those that experts from different fields engage in, to solve problems and develop artifacts. (3) Social interactions. In PBL, students achieve learning goals through social interactions and the sharing of knowledge, which creates a community of learners. (4) Apply cognitive tools for scaffolding. Technological tools amplify and expand what students can learn. Specifically, cognitive tools can help students with data collecting, accessing and visualizing, collaboration, project planning, implementation, and learning output through various formats (multimedia, digital board, etc.).

Research has revealed the positive impact of PBL in improving the learning outcomes of students, including the affective outcomes (perceptions of the benefits and experience of PBL), cognitive outcomes (knowledge and cognitive strategies), behavioral outcomes (skills and engagement), and artifact outcomes (Guo et al., 2020). Despite the majority of research on PBL's positive effects being conducted with students from higher education as participants (Verstegen et al., 2016), studies also identified positive learning results from K-12 learners worldwide (i.e., Kokotsaki et al., 2016). In terms of the learning experience, implementing PBL can improve the quality of learning for elementary students (Fauzia & Kelana, 2021), yield higher learning outcomes (Amini et al., 2019), and increase the affective connection (Virtue & Hinnant-Crawford, 2019). Implementing PBL improves students' academic achievement and knowledge retention (Al-Balushi & Al-Aamri, 2014), increasing the student's science process skills and cognitive learning outcomes (Nasir et al., 2019). Behaviorally, PBL improves students' informational reading skills (Duke et al., 2021), social-emotional skills (Culclasure et al., 2019), collaboration and conflict-solving skills (Lee et al., 2015), problem-solving and critical thinking skills (Trisdiono et al., 2019). Studies with large effect sizes show the predominant benefits of PBL on K-12 learners.

The covid pandemic permanently changed learning behavior worldwide. Prior to 2022, the top challenges of online learning for K-12 learners include inequity of technology and materials, lack of online teaching knowledge (Vinson & Caukin, 2021), unstable internet connection, and unfamiliar with the learning platforms and software (Zuo et al., 2021), among many others. Yet looking into the post-pandemic time, many schools and districts used online learning to respond to the pandemic and continue to use e-learning technologies to assist students to achieve learning success (Mann et al., 2021). Owens and Hite's (2022) study reported implementing a STEM learning experience using a virtual global collaboration project-based learning approach using Canvas as the learning platform and achieved satisfying learning results. Given these, e-learning platforms and learning applications help teachers and students overcome the learning challenges and will continue to play important role in K-12 learning, especially in the PBL context.

**Table 1** Challenges of PBL implementation

| Categories | Challenges |
|---|---|
| Beliefs and understanding of PBL | Teachers see implementing PBL as giving up control of class (Aksela & Haatainen, 2019) |
| | Mix inquiry-based learning in PBL with hands-on activities (Aksela & Haatainen, 2019) |
| Project design and planning | Choose and contextualize significant content (Aldabbus, 2018) |
| | The mismatch between the school curriculum and PBL learning goals and practice (Mentzer et al., 2017) |
| | Familiarize students with the PBL learning process (Mentzer et al., 2017) |
| | Make students realize the learning goal of PBL (Lewis et al., 2019) |
| | Balance the needs of all PBL stakeholders (Lewis et al., 2019) |
| | Design and carry out authentic, multi-dimensional assessments (Aksela & Haatainen, 2019; Wilson, 2021) |
| Implementation management | The time-consuming nature of PBL, lacking time management skills (Habok & Nagy, 2016; Kokotsaki et al., 2016; Mentzer et al., 2017) |
| | The difficulty of accommodating the regular school schedule (Marx et al., 1997) |
| | Require teachers to pay great attention to details in the learning process (Habok & Nagy, 2016) |
| | Students lack collaborative knowledge and skills, challenging to support teamwork (Lewis et al., 2019) |
| | Students cannot raise investigable driving questions (Marx et al., 1997) |
| | Difficult to monitor, keep track and review individual/team learning progress (Lewis et al., 2019) |
| | Provide sufficient assistance to help students/teams (Lewis et al., 2019) |
| | Overstate the product and artifact, and understate the learning process (Aldabbus, 2018) |
| Support | Lack of financial support (Aldabbus, 2018) |
| | School culture doesn't support innovative pedagogy (Wilson, 2021) |
| | Lack of support/co-teaching opportunities from other colleagues (Lam et al., 2010; Lewis et al., 2019) |
| | Students cannot get access to technology through the learning process (Marx et al., 1997) |
| | Lacking Information and Communication Technologies (ICT) skills (Aksela & Haatainen, 2019; Aldabbus, 2018) |
| | Missing school-parent collaboration and parents' support (Aldabbus, 2018) |

## Problems and challenges of PBL implementation

Despite the advantages of PBL mentioned above, implementing PBL in K-12 classrooms is documented as challenging. The challenges in K-12 classrooms are mainly four: beliefs and understanding of PBL, project design and plan, implementation management, and support. The challenges are listed in Table 1.

From the numbers of challenges reported in Table 1, project implementation and management were the top concerns of teachers, followed by project design and planning,

support and beliefs, and understanding of PBL. Despite the challenges mentioned above, empirical evidence has demonstrated that PBL is a practical pedagogy and a must-have experience for students to enter the knowledge-based economy with 21st-century skills. Kokotsaki et al. (2016) listed five facilitating factors to smoothen the implementation of PBL instruction, including (1) adopting digital technology to engage students in designing and developing the project with guidance and support, (2) engaging students in collaboration and peer interaction with positive interdependence, individual accountability, equal participation, and social skills, (3) effectively scaffolding students' learning, (4) providing support from administrators, (5) adopting two-phase PBL approach, for students to first acquire the sufficient competence by developing required knowledge and skills, before design and make products independently. Lewis et al. (2019) also proposed that educational technologists should be considered to aid, scoping, curriculum, and coordinating tools to facilitate the implementation of PBL.

Identifying the facilitating factors is only the first step, without properly solving the challenges can hinder teachers and their passion for adopting PBL continuously in their classrooms. The challenges instructors perceive in the classroom practices should fuel educational technologists to overcome these challenges and communicate the benefits (Rogers, 2003). Given the rapid development of educational technologies, it is promising to seek solutions to the abovementioned issues and put the proposed strategies into practice.

## E-learning and E-learning platforms

With the development of technology and its impact on education, it is almost impossible to teach and learn without the support of ICTs today. E-learning refers to using ICTs to facilitate and support learning (JISC, 2014). ICTs here could be applications, programs, objects, websites, etc., as long as it provides learning opportunities for individuals (Moore et al., 2011). The e-learning platforms could be e-learning systems, learning management systems (LMS), course management systems (CMS), virtual learning environments (VLE), or other websites and mobile applications that support learning. After decades of development, e-learning platforms are equipped with versatile functions, they provide a range of tools and facilities to help the interactive learning process. For instance, students and teachers can upload and get access to learning materials in a great variety of formats, interact with each other through communication tools like the message, forums, chats, and videoconferences, collaborate with peers, support assessment and reflection, and many more (Choudhury & Pattnaik, 2020; Donkers, Verstegen, de Leng, & de Jong, 2010). For students, e-learning increases the accessibility of learning (Dziuban et al., 2018). It allows students to have more control over the learning process (Blount, 2016) hence improving knowledge retention and learning performance (CITE), making learning flexible (Lara et al., 2014) and cost-effective (Farhan et al., 2018). For teachers, e-learning makes it easy to reuse, update and arrange course materials (Blount, 2016), and allows teachers to track learning data generated by students' learning behaviors. These advantages of e-learning have convinced educational institutes worldwide to adopt it as part of the learning service for students (Toth-Stub, 2020).

In PBL implementation, adopting educational and technological tools is an essential practice that differentiates PBL from other pedagogies (Krajcik & Blumenfeld, 2006). Kokotsaki et al. (2016) listed technological tools as the primary enabler for students to engage smoothly with the PBL process. PBL practitioners and researchers have integrated various tools to facilitate teaching and learning in K-12 classrooms. Two tools are applied:

individual tools with specific functions and existing e-learning systems that can partially support the PBL process. Individual tools used in PBL include contextual information providers like Google, Bing, and YouTube (Iwamoto et al., 2016), performance assessment tools like Performance Assessment Resource Bank (PARB, Guha et al., 2018), ICT tools for facilitating communication (Habók & Nagy, 2016), and collaboration tool like mentioned in the study of Rongbutsri (2017). E-learning systems applied as PBL management and facilitation tools include but do not exclude Google Classroom (Ramadhani et al., 2019) and Moodle (Wu & Wu, 2020). These systems are mainly applied to deliver information, facilitate communication and collaboration, and conduct assessments (Alverson et al., 2019). Despite the versatility of the embedded functions provided in the existing systems, instructors typically need to integrate additional tools to support PBL implementation, which increases the cognitive load for students and hampers the optimization of the learning outcome.

In recent years, a noticeable trend has been the emergence of e-learning systems specialized in supporting PBL worldwide. Platforms like ProjectPals from the US, Dreamdo School from Finland, and EPBL from China are attracting more and more K-12 users. The COVID-19 global pandemic has served as the catalyst and accelerated the progress of the transformation of educational institutes (Adnan & Anwar, 2020). PBL learning platforms are embracing their rapidly growing clientele. Yet little is known about these platforms, especially their rationale of design, features, functions, and how they tackle the implementation challenges and support PBL.

The study on PBL e-learning platforms is still in its infancy. The heterogeneity in instructional design and other features of the platforms are rarely explored and understood with empirical evidence. In the current study, we intend to conduct an exhaustive search in both the English and Chinese worlds on PBL e-learning platforms and seek to understand their innovative mechanism of supporting PBL. The research questions of this study are:

1. What are the properties of the selected PBL e-learning platforms, and what functions do they possess?
2. How do the platforms tackle the PBL implementation challenges?
3. How is PBL as a pedagogy understood differently through the design of the platforms?

The aim of the study is not to prove the usability or efficiency evaluation of these platforms but to uncover how PBL as pedagogy is understood differently through the design of the platforms, how these platforms solve challenges of the PBL practice, and how they facilitate PBL in different learning modes and environment. With the gained insights, we propose to holistically understand the wisdom of supporting PBL worldwide, provide guidance and recommendation for teachers, students, schools, and districts to select appropriate platforms, and shed light on how educational technologists could optimize the design of these platforms.

## Methodology

In the current study, we adopted the multiple case study approach to explore the selected PBL platforms. Compared to single case studies, a multiple case study design allows researchers to develop a more in-depth understanding of the phenomena (Stake, 2013). This research design was appropriate for this study due to the nature of the research

questions. Each selected PBL platform is an individual case, studied independently before drawing significant comparisons across cases.

## The selection of the online PBL learning platforms

To answer the research questions, the researchers first conducted a platform search. The search was carried out both in English and in Chinese. All the searches were completed before September 2021. In the Google search engine, researchers first input the terms "project-based learning platform" and "global project-based learning platform" in English. There were 11 and five (5) results claimed to be PBL platforms. Besides google searching, researchers also identified one (1) platform mentioned in the educational technology review blogs. Excluding the overlapped results, there were 13 PBL platforms in English. The Chinese search was conducted by searching the same term with the Google search engine in both simplified and traditional Chinese and received three (3) results in simplified Chinese and one (1) result in traditional Chinese. The search result in traditional Chinese overlapped with one of the results in English.

There are four criteria we applied when selecting platforms from the results. Specifically, we eliminated: (1) platforms that support multiple pedagogies instead of focusing mainly on PBL; (2) platforms that provide only one or several functions associated with PBL (collaboration support, learning portfolio, etc.); (3) platforms only support the learning of one subject (i.e., language or programming); and (4) new PBL learning platforms with no actual users. In total, 16 (13 in English and 3 in Chinese) platforms were included in this study, they 13 platforms in English are: ProjectPals (PP, hwww.projectpals.com/), Foundry (FD, https://www.projectfoundry.com/), Defined Learning (DL, https://www.definedlearning.com/), Educurious (EDC, https://educurious.org/), LiftLearning (LL, https://liftlearning.com/), Headrush Learning (HR, http://www.headrushlearning.com/), Sprocket (SK, https://sprocket.lucasedresearch.org/), Echo (https://newtechnetwork.org/echo/), PBL Works (PBLW, https://www.pblworks.org/), Dreamdo Schools (DDS, https://edu.dream.do/en), Cura (CR, https://www.curaeducation.com/), iEARN (https://www.iearn.org/), and PenPal Schools (https://www.penpalschools.com/). The three platforms in Chinese are: EPBL (EPBL, http://epbl.aicfe.cn/epbl/), GoPBL (GPBL, https://www.gopbl.com/), Creative Knowledge PBL Platform (CK, http://xms.forclass.net/). The information on all the platforms, including their full name, URL, country of origin, initiator and property, are briefly introduced in Table 2 in Appendix 1.

## Data collection and validation

To guarantee the trustworthiness and validity of the collected data, we followed the data triangulation procedures and collected data from more than one source using more than one method (Connaway & Radford, 2016). The qualitative data collected for this study were from three different resources in different ways: (1) researchers' observational journals and notes from visiting the website of each platform, (2) researchers' user experience journal logged from using the platforms with the provided free trial account, and (3) the interactions researchers had with platform staff via the scheduled demonstration and follow-up emails. All the data included was collected before October 2021. Any updated or new functions added to the studied platforms were not included.

When visiting each platform's website, the researchers first captured all the text presented for the coding later. The observational journals and notes for each platform were

collected from two separate researchers before consolidating into one excel sheet for analysis. When using the free trial account on each platform, the researchers went through the entire platform to familiarize each function and adopted the think-out-loud method to keep the usability notes, which were transcribed and coded later for analysis.

When preparing the collected data for coding, the English discourse data were transcribed and coded with NVivo 12. The Chinese discourse data was transcribed with iflyrec.com and coded in an excel sheet in Chinese, and the results of the data analysis were conveyed in English to guarantee accuracy. All the quotes translated from Chinese into English were sent back to each participant to verify their correctness, especially those words and phrases that could not be directly translated into English. We followed Tie, Birks, & Francis (2019)'s guidance. Two researchers in the research team first completed the initial coding, did the constant comparative analysis, and established cross-case analysis.

## Results

We organized the coded data from three sources into tables (Table 2 in Appendix 1 and Table 3 in Appendix 2) to summarize the standard features within the same type of platforms and distinguish the differences across to answer the research questions. We first present the findings from the following aspects: properties, unique features and functions, problems and challenges solved, and rationale of the design.

### General properties

The name of each platform, the coded name, and their URL are listed in Table 2 in Appendix 1. The 16 platforms came from five countries: The United States (10), China (3), Spain (1), Finland (1), and Australia (1). The targeted users were mainly K-12 educators and learners, except three platforms indicate supporting post-secondary users. All the platforms were web-based or websites, two claimed to have mobile applications, yet researchers could not identify them in the primary application stores. 13 platforms offer free-to-try or partially free-to-use accounts for individual users. Through interacting with the platform technologists, we identified four types of platform developers: entrepreneurs with K-12 classroom teaching or counseling experience, researchers and developers of higher educational institutes, global or domestic non-profit organizations, and educational corporations.

### Special features and functions

Nine themes related to platform features and functions emerged from coding. We organized them into nine categories of functions: (1) project planning and building, (2) project management, (3) competency, (4) rubric, assessment, and feedback, (5) evidence and products, (6) learning analytics, (7) teacher professional development, (8) PBL community and ecosystem, and (9) learning mode and tech support. Table 3 shows functions embedded in each platform to the best of the researchers' knowledge. Although all claimed to be PBL platforms, their services are diversified. We conducted a cross-case analysis and identified four types of PBL platforms: learning management platforms, content providers, communication and community facilitator, and service provider, as shown in Fig. 1. It is worth noting that one platform can provide multiple types of services. Hence, we focused on

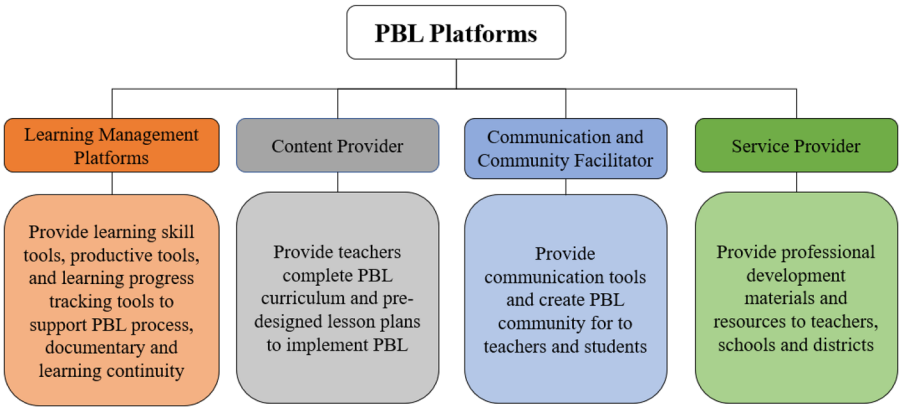


**Fig. 1** Four Types of PBL Platforms

their featured service(s) when categorizing them. We elaborate on the features of each type below.

## Learning management platforms

According to our study, learning management platforms account for 62.5% of the total studied platforms. There were ten platforms designed to manage the learning process of PBL. They were PP, FD, HR, LL, Echo, DL, DDS, EPBL, GPBL, and CK. This result matched our literature review that project management was the top concern of practitioners. Multiple technologists from the above platforms mentioned the rationale for them to create their products include: (1) the difficulty of managing the learning process, (2) the importance for teachers and students to acquire project management skills, and (3) the authenticity of a learning experience as the primary reasons for designing learning management platforms. As the designer from PP stated:

> ……. Companies are using software like Trello, Monday, and Jira to communicate not just within companies, countrywide and worldwide…… Project management in 2025 will become an 8 billion business, but we don't see much of that in education……teachers are not project managers, a big part of the success in PBL is to know how to manage projects……Students are expected to work as team members on projects when they enter the workplace. They should learn in the same way……

Similarly, the designer of GPBL also voiced the urgency of developing a management platform to guarantee the successful implementation of PBL, as he stated:

> A learning project that allows students to display their learning agency requires teamwork, personalized learning tasks, timely assessment, and feedback, but facing a class with more than 30 students? It is an impossible mission for the teacher. There has to be a platform to support teachers if we are serious about implementing PBL.

Learning management platforms covered most functions across all nine categories, especially in project planning and designing, project management, interaction and communication, assessment and feedback, documentation and product, learning analytics, and teacher professional development. These platforms guided users through similar

learning phases during the projects (terms varied), including project launch (discover, understand, plan, design), investigate (collaborate, manage), manage (monitor, track, capture), and share (report, adapt, reflect, reflect, thrive). Due to the various functions and the relatively long learning process, most platforms provide teacher training and familiarize teachers with the platform navigation. Some platforms (i.e., PP and GPBL) even make teacher training compulsory to reduce the anxiety and frustration that might be caused by cognitive overwhelming.

Depending on the service-providing mode and target users, the learning management platforms could be further divided into two subtypes: individual users and institute users. Platforms for individual users are PP, DL, HR, DDS, EPBL, GPBL, and CK. Although the trial use was issued only upon request, these platforms not only gave a single license for individual users to register as teachers or students but also supported institutional users in implementing learning projects. The flexibility of these platforms allows digitalized PBL to be implemented in a diversified learning context. As the technologist from DL stated:

> ……We also issue a single license to teachers of summer camps. All teachers are welcome to use our platform, for short or long. Our platform is flexible, as long as teachers want to try it…

The representative management platforms for institute users are FD, LL, and Echo. They offer customized services to assist the institute-wide transformation to PBL and fulfill the personalized needs of schools and districts. These three platforms did not provide a free trial to account; therefore, their functions marked in Table 3 only highlight their expertise.

The infrastructure in the classroom is an essential factor in how the project learning process is supported, which clustered the learning management platforms into (1) evidence-based documentary platforms and (2) process-oriented platforms. GPBL and CK are two good examples of evidence-based learning documentary platforms. They prioritize supporting the implementation of assessment plans, establishing learning portfolios by allowing uploading learning evidence of different formats throughout the learning process, and digitally showcasing the learning outcomes. GPBL and CK were both from China. According to the technologists, their platforms were evidence-based for two reasons. First, computers and other smart mobile devices were generally not provided beyond information technology classes. Students could not get constant access to devices during the project learning. Second, due to the tradition of entrance examination in middle and high schools, PBL is typically implemented in elementary education before students heavily engage in academic learning. Elementary school students had limited digital competency to carry out project learning and sharing purely online. Therefore, students typically use the platform at the end of each learning session to collect and store the fine pieces of digital learning evidence to form a learning portfolio and provide continuous tracking of their project learning experience.

Platforms like PP and HR are the representatives of process-oriented platforms. Both are designed for classrooms in which computers are accessible for students throughout the projects. Beyond learning evidence documentation, process-oriented platforms intended to bring the authentic experience of how projects are completed in real-world workplaces by allowing teachers and students to create projects from scratch, with various scaffolding tools embedded (i.e., visual organizers, analysis tools, event templates, etc.). By collaboratively drafting and editing the project pages and leaving comments on each created event, students can enhance their collaborative learning, problem-solving and critical thinking skills. The constructive learning process facilitates students' learning agency. Additionally,

allowing teachers to check personal and team learning progress can help track students' performance and contribution in a group.

The anticipated learning environment is an essential factor. The technologists from the ten platforms unitedly stated that PBL should ideally implement in a traditional face-to-face classroom setting in K-12 education for a better experience of contextualized learning and close collaboration. It explained why platform that supports synchronous learning (i.e., videoconference) were rarely observed.

Although focusing on learning management, the ten LMPs were distinct from the traditional LMSs. In addition to serving the information delivering function, LMPs also embedded a number of pre-designed projects to help teachers familiarize themselves with the navigation and prepare them to customize and create their projects. DL and EPBL were content-intensive. Both platforms provided hundreds of pre-designed projects and scaffolding activities. The designers from both platforms emphasized the importance of supporting teachers by providing ready-to-use materials and their intention to establish a curriculum-based learning projects warehouse soon.

The LMPs were designed to solve a series of challenges in project planning, implementation, and support by providing the abovementioned functions. For students, the learning management platforms helped them to: (1) become familiar with the PBL learning process by providing the learning menu, (2) to keep up with the learning goal of the projects by referring to the embedded learning goal and project rubrics, and (3) supporting team collaboration by providing team learning space and data on learning progress. For teachers, the LMPs (1) integrated all the resources, materials, and information demanded by a project without leaving out the detail, (2) allowed teachers to monitor the learning process and keep track of individual/team learning progress, (3) provided sufficient a/synchronous assistance to help individual students and teams, and (4) empowered teachers to design and carry out authentic, multi-dimensional assessment, with referring to the different types of learning data. For external project facilitators, the platforms allowed them to join via invitation. They could contribute to enhancing the support of external experts and promoting school-parent collaboration, ultimately building the PBL learning ecology.

### Content provider platforms (CPP)

Three platforms were categorized as CPP: EDC, SPK, and CR. EDC and SPK listed teachers as the target users and provided strong examples of PBL curricula and flexible teaching resources for students in grades 3–12 on various subjects. SPK materials were under a Creative Commons license as open educational resources (OER). Both platforms provided detailed project teaching materials on individual subjects or areas of study (i.e., biology, English, science, and social studies). EDC provided PBL courses designed jointly with local employers[1] to promote career-connected learning, which increased the authenticity of the learning projects. However, the project content on SPK was OERs created by teachers who joined the community of practice.

CR took a different route and provided pre-designed, self-paced PBL courses and learning modules directly to students. The technologist of CR defined it as a content platform. By delivering the asynchronous learning materials and scaffolding templates (i.e., team contract template, debate preparation form), CR intends to provide a PBL learning

[1] A good example is the *Port of Seattle Units* at https://educurious.org/courses/.

experience with the two-phase learning approach. In phase one, students should be familiar with the knowledge and skills related to the project's theme and prepare for the collaborative and creative work in phase two.

The content from the CPPs aligns with the pre-existing curriculum in their respective regions and countries, which contributed to solving two challenges: the mismatch of curriculum and PBL learning goals and practices and the difficulty of choosing and contextualizing important content.

### Community organizer and communication facilitator platforms

Although platforms EDC, SPK, DDS, iEARN, and PPS branded themselves as PBL learning platforms, they specialize in creating professional learning and teaching communities and facilitate communication among students, teachers, and external facilitators. In the previous subsection, we listed EDC and SPK as the CPP, but both platforms also showed strong domestic social attributes. SPK created an online community and communication tools for teachers to share their experience adopting the provided materials and implementation insights. SPK also encourages teachers to collectively enact the curriculum materials and update and enhance the project-based programs to meet the needs of their local contexts. EDC provided an expert network by recruiting experts from diverse fields to contextualize their learning and help students tackle the challenges. DDS, iEARN, and PPS facilitated connecting teachers and students globally to communicate and collaborate on various projects via messages, discussion forums, and videoconference tools. Specifically, projects in iEARN aligned with the sustainable development goals of the United Nations and promote the endeavor of improving the quality of life worldwide.

Many LMPs support external teachers and facilitators collaboratively in designing, implementing, monitoring, and assessing the learning process. But the collaboration heavily relies on teachers' personal networking and connections. One of the significant advantages of the organizer and facilitator platforms like EDC, SPK, and DDS was that they created a community for like-minded teachers and students to experience authentic, cross-cultural collaboration in action. The platforms facilitating communication helped solve teachers' lack of pedagogical support and co-teaching opportunities, creating opportunities for students to learn projects cross-contextually and cross-culturally.

### Service provider

PWS was the only platform we categorized as a PBL service provider, as it provides neither support directly to classroom learning nor curriculum to teachers, but professional development training and materials like videos, planning forms, rubrics, and blogs to teachers, to deepen the understanding of PBL as a pedagogy. Although only a limited number of projects were provided, these projects were designed to walk teachers through each step of project design following the project design rubrics. Unlike SPK provided discussion forums to group teachers to different topics and grade levels, PWS recruited faculty nationwide to create content and professional development materials on various world-concerned topics to tackle the frequently encountered challenges. The service of PWS went beyond supporting PBL practice, and it played the driving force behind the development of PBL pedagogy and its related research.

## Understanding of PBL as a pedagogy

Through cross-case analysis, we observed that PBL as a pedagogy was understood differently through the design of the platforms. Specifically, the differences focused on four facets: (1) single subject vs. interdisciplinary learning projects, (2) teacher-led vs. student-led learning, (3) career-connected learning and the authenticity of PBL, and (4) PBL as a pedagogy for fostering global competence.

### Single subject vs. interdisciplinary learning projects

PBL provides students opportunities for real-world challenges and questions, which are often interdisciplinary by nature (Repko et al., 2019). Among the studied platforms, we observed a divided understanding between PBL as a single subject and an interdisciplinary approach. On teacher-oriented platforms like SPK and all three platforms from China (EPBL, GPBL, and CK), projects were organized by subject (i.e., math, physics, biology). In contrast, platforms supporting students' learning process (i.e., PP, HR, DL) projects organized by areas of subjects showed more interdisciplinary nature. Besides the cultural differences in education, the emerging platforms providing interdisciplinary projects may act as a promoting force for implementing interdisciplinary learning in K-12.

### Teacher-led vs. student-led PBL

With the collaborative and management features, many LMPs were designed to provide students more opportunities to develop the ownership of the projects and experience and increase students' learning agency by enabling personalized learning task assignments and collaboration. Yet the design of LMPs and their product discourse divided them into teacher-led (i.e., DL) and student-led (i.e., PP). DL was designed for teachers to lead student-centered learning. The teacher was the authorized party to cherry-pick and assign learning tasks from various materials according to the goal and objectives. In comparison, PP provided scaffolding tools and templates for students to establish a project from scratch or for teachers and students to co-create and co-plan. Students play the dominant role in their learning.

### Career connected learning and the authenticity of PBL

Beyond supporting PBL, we observed platforms DL and EDC also featured for their career-connected learning (CCL). On DL, a similar product named Defined Careers™ provided a personalized career assessment and hands-on project learning for students to explore all career paths. On EDC, career-connected learning was a separate course unit that offered opportunities for high school students to participate in planning their future actively. Students could advocate themselves to employers and recruiters by completing the learning units.

The authenticity feature of PBL requires students to do work that is real to them, or the work directly impacts or uses in the real world. The goal of CCL is to connect learning to the real world, allow students to understand academic content in a way that is relevant to them, and help them develop knowledge, skills, and experiences to help them enter the world after school (Meeder & Pawlowski, 2020). Exploring the career path and

being career ready are highly relevant to each student. Integrating CCL into PBL with academic content could be a viable path to preparing students to succeed in the global economy. Besides the currently available approaches mentioned in the work of Meeder and Pawlowski (2020), PBL platforms with CCL integrated may have the potential to support authentic CCL activities systematically.

### PBL for global competence

Platform DDS, iRN, and PPS were all devoted to connecting students and classrooms worldwide, and they all had many users. Globally concerned issues were designed to be learning projects, and students from different countries and cultural backgrounds learned to compare, contrast, collaborate and contribute to solving the problems. Although the learning tasks on these platforms were not strictly following the typical learning phases, and students' collaboration was primarily through videoconferencing and writing, these platforms showed an innovative function of PBL: fostering global competence. With the themed communication promoted by these platforms, we also observed the trend that PBL broke the wall of individual classrooms and enhanced the development of cross-cultural competence.

To sum up, we studied 16 PBL platforms designed in English and Chinese-speaking regions, identified nine clusters of functions, and categorized the platforms into four types. Project management was the top challenge in PBL practice. We identified platforms that tackled the challenges by providing services to different user groups, learning environments, and learning modes. We also identified platforms specialized in delivering the content, facilitating the forming of learning and teaching communities, enabling communication beyond the classroom, and enhancing the understanding of PBL as a pedagogy. Reflected from the design of the platforms, PBL applied as a student-led or teacher-led pedagogy, an approach to develop career readiness and foster global and cross-cultural competence.

## Discussion and implication

In this section, we discuss four observations based on studying PBL platforms and the skills and competence required for teachers and students to implement PBL successfully with the researched platforms.

### Traditional LMS and LMPs

PBL LMPs, as a subcategory of LMS, were designed to provide for the unique needs of PBL. They offered not only the learning, communication support, and productivity functions but also the flexibility to accommodate the needs of K-12 teachers and learners within and beyond the learning projects. LMPs were different from the traditional LMS in at least three facets. First, LMPs went beyond information delivery and learning management functions (Kraleva et al., 2019) and provided teachers with both teaching materials and tools to facilitate the PBL design, implementation, teacher professional development, and

advanced the development of PBL as a pedagogy. Second, LMPs realized personalized and collaborative learning through team member management tools, personalized learning task assignments, and learning progress tracking, which emphasized both the personalized learning experience and the collective effort to the overall success of the projects. Third, through co-plan and co-creation of learning projects, LMPs promoted students' ownership through the learning process and participated in the projects with equal identity compared to the traditional LMS.

### PBL platforms as warehouses and student autonomy

As mentioned previously, multiple platforms provided ample project examples and intended to build learning projects, activities, and tasks warehouses. Platforms (i.e., DL) even provide multiple investigation routes and formative assessment plans for students and teachers, which seemed to be a feasible way to encourage more teachers to adopt PBL. Studies also showed that teachers who felt well supported were more motivated to implement and persist in using PBL (Lam et al., 2010). Designing PBL platforms as warehouses may solve the difficulty of teacher project design and planning, lowering the challenge for students to raise driving questions and lead the investigation. Yet, it might compromise the opportunities to develop student autonomy.

Student autonomy was identified as one of the five essential characteristics of learning projects, and authentic PBL projects "do not end up at a predetermined outcome or take predetermined paths" (Thomas, 2000, p. 4). Previous studies also identified that student choice and autonomy throughout the PBL process were helpful for students to develop a sense of ownership and control over their learning (Kokotsaki et al., 2016). How to balance and moderate the support for teachers to incorporate student autonomy, choice, unsupervised work time, and responsibility according to their competence should be considered for future platform design.

### The trend of global classroom connection

The emergence of PBL communication facilitating platforms signaled the trend of globalization of education in K-12 and the importance of fostering students' global competence. Unlike traditional LMS organizing learning mainly institute-wide or nationwide, PBL communication facilitating platforms built the globally connected classroom. Through the experience of studying the same projects and exchanging cultural and contextual information, students from different countries can collaborate synchronously and asynchronously through the discussion board, emails, and chats to collaborate and contribute to the globally concerned issues. This learning experience can improve their global digital citizenship, significantly impacting youth over the next decades (Harris & Johns, 2021). With the restricted international traveling during COVID and online and blended learning as the new normal in the post-COVID era, LMPs and communication facilitation platforms will play an essential role in fostering global competence. Various technologies that could bring students immersive experiences like augmented reality (AR) and virtual reality (VR) should integrate to simulate the hands-on international collaborative learning experience.

## The proposed new skills

To fully appreciate the convenience of the PBL platforms, new skills are required for students and teachers: digital competence for students, TPACK knowledge and pedagogical digital competence for teachers, and project management skills for both.

To get teachers ready to effectively adopt PBL platforms, acquiring sound TPACK knowledge is a must. TPACK is featured to enable teachers to make intelligent pedagogical uses of technology (Koehler et al., 2007). It encompasses teachers' expertise in technology integration, and focuses on teachers' capacity of designing content, pedagogy, and knowledge of technology at all levels. When adopting the PBL platform, it is crucial for teachers to possess not only the relevant content and pedagogical knowledge but the technological and pedagogical technological knowledge (Koehler & Mishra, 2009). Specifically, teachers should actively keep up with the evolution of the development of the available e-learning platforms, think about how teaching and learning would change when platforms are used to support certain learning activities, and apply them productively to assist students to achieve their learning goals and help them internalize their skills of information technology adaption (Harris, 2016).

Pedagogical digital competence (From, 2017) requires the teacher to consider the interrelationships between knowledge, skills, attitudes, technology, learning theory, subject, context, and learning. With a thorough understanding, teachers could consistently plan, conduct, evaluate and revise ongoing teaching practice with theory, current research, and proven experience in a technology-supported teaching context to best support students learning. The innovative nature of PBL and PBL platforms requires teachers to improve their information and data literacy, digital communication and collaboration skills, create content digitally, problem shooting for teaching on the platforms, and innovatively implement PBL and develop it as a pedagogy.

Project management skills are another critical component for successfully implementing PBL. In the current study, we found that despite the differences, the PBL platforms, especially the learning management platforms, share the similar learning and teaching processes to a certain extent and can be break into three learning phases: (1) project planning, key words include discover, connect, define goals, plan, (co-)design, adopt and adjustment, (co-)create, and build, (2) launching and implementing, key words include launch, collaborate, monitor, respond, transform, track, capture, report, support, communicate, manage, assess, and (3) reporting and reflection, key aspects include report, reflect, adapt, publish, application, demonstration, showcase, evidence collection. These key words overlap with the skillsets required for successful project management in the real world.

Project management skills are essential for professions in organizations with upper management and multiple teams and departments involved in several extensive projects, like engineering, manufacturing, and construction (Cleland, 2007). PBL is featured for providing an authentic learning experience, which demands two types of project management skills for teachers: simulate the project management in the real-world context to demonstrate good project management skills for students, and help students to become good project managers by assisting them in organizing groups and monitoring their progress, improving their technical management skills like planning and forecasting, tracking and monitoring progress, enhance their subject matter expertise, and foster the soft skills like time management, leadership, and

adaptability (Meredith et al., 2017). These will help maximize the benefit of adopting PBL pedagogy.

## Conclusion, limitation, and future research

This article presented a multiple case study of 16 PBL platforms available in English and Chinese to tackle the difficulties and challenges of implementing PBL. As the result of this study, we found the PBL platforms were from five countries, serving predominantly K-12 users. According to the services provided, these platforms could be categorized into four types: learning management platforms, content providers, community organizers, communication facilitators, and service provider. Most platforms (10 out of 16) were for learning management, intended to address the major challenge of implementing PBL in regular classrooms. Five out of 16 platforms facilitated the establishment of the professional learning community domestically and internationally for teachers and globally connected classrooms for students. We then conducted the cross-case analysis to see how PBL as a pedagogy was understood through the design of the platforms. In discussion and implication, we discussed the differences between traditional LMS and LMPs, the trend of global classroom connection, and the proposed new skills for teachers and students.

This study has some evident limitations. First, as one of the first studies on PBL e-learning platforms, this study did not involve actual users. Hence the usability and efficiency remain unclear. Despite the researchers' unbiased observation of the platform by accessing the trial versions could provide insights into the platform's capabilities, it is unclear if these platforms offer the facility for teachers to implement PBL-based instruction successfully, as well as for students to adopt and learn efficiently. An empirical study with actual users will be the next step to deepen the understanding of how these platforms can support learning in various classroom contexts, how they coordinate and facilitate the learning process, and to what extent they can help to solve the implementation challenges, especially if the platforms will offer accessibility features in the near future, and how these features will support the learning process of students with learning challenges. Second, how to balance and moderate the support for teachers and foster students' autonomy should be given more thinking and consideration in platform design and improvement. Additionally, studies are also desired to explore how to prepare pre-service and in-service teachers pedagogically and digitally ready to successfully implement PBL with the support of PBL platforms to achieve the optimal learning outcome for students.

## Appendix 1

See Table 2.

**Table 2** The features of PBL platforms

| Name (name abbre.) country of origin, URL | Initiator & property | Student group & highlights | Summary of the platform features |
|---|---|---|---|
| Project Pals (PP, U.S.) https://www.projectpals.com/ | K-12 Educator initiated; For-profit; Website; Free to try | Grade 4-college; Problem-solving, collaborative learning | A PBL management platform that helps teachers streamline and enhance student-centered inquiry; Helps improve students' 21st-century and project management skills; Provides scaffolding tools and event templates<br>Learning process: Plan—Collaborate—Monitor & Respond—Share |
| Foundry (FD, U.S.) https://www.projectfoundry.com/ | K-12 educator; Non-profit; webpage + mobile app; Paid | Grade 6–12; Communication & Collaboration, Character & SEL, Critical Thinking, College & Career Preparation | A comprehensive LMS helps schools to manage workflow and students' learning data; it provides learning management solutions and real-time analytics to meet the needs of teachers and schools to foster a more profound learning experience and transformation<br>Learning process: Discover, design, build, transform, thrive<br>Teacher workflow: Build—share—manage—track—report |
| Defined learning (DL, U.S.) https://www.definedlearning.com/ | K-12 educator; Non-profit; Webpage; Free to try | Grade PK-12 STEM-PBL, career-based learning, | A STEM-PBL learning platform helps school districts and teachers to prepare students to be STEM career-ready through authentic PBL. Help students to be proficient in stem subjects through differentiating task type (performance, career, or literacy) and provide lesson plans and other teaching resources<br>Teacher workflow: Define goals—sample alignment—customize implementation plan—complimentary training—teacher PD |

**Table 2** (continued)

| Name (name abbre.) country of origin, URL | Initiator & property | Student group & highlights | Summary of the platform features |
|---|---|---|---|
| Educurious (EDC, U.S.) https://educurious.org/ | K-12 educator; Non-profit; Webpage; Free to try | Grade 6–12 critical thinking | A PBL platform help teachers to position students as developing experts. By putting students in touch with real-world exports and guides, Educurious helps foster the analysis and communications skills through leveraging a variety of digital and traditional tools<br>Learning process: Launch – investigate – define and design – create and celebrate |
| Lift learning (LL, U.S.) https://liftlearning.com/ | Educator; For-profit; Web-based app; Free to try | Grade 4–12 competency-based learning, | A competency-based PBL learning management platform targeting schools and districts to provide customized PBL service; Highlighting students' learning evidence by emphasizing learning performance; Providing student learning portfolio function to continuously demonstrating learning progress<br>Adoption workflow: Personalized Attention—Strategic & Tactical Understanding—Framework Design—Training & Support—Alignment Checks—Customization |

**Table 2** (continued)

| Name (name abbre.) country of origin, URL | Initiator & property | Student group & highlights | Summary of the platform features |
|---|---|---|---|
| Headrush learning (HR, U.S.) http://www.headrushlearning.com/ | Educator; For-profit; Web-based app; Free to try | Grade K-12 | A learning platform assisting PBL implementation management; Highlights student-led, teacher-designed, and co-created learning experiences to promote self-directed learning; Provides planning tools and student-initiated workflows; Integrates competency-based assessment and reporting to communicate achievement<br>Learning process: Plan—do—capture—reflect—adapt and flex with each iteration |
| Sprocket (SK, U.S.) https://sprocket.lucasedresearch.org/ | Educator; OER; Website; Free | Grade 3–12 teacher community of practice | A free online platform for teachers, providing full year PBL curriculum and courses. It also creates an online teaching community for teachers to share ways to implement and adapt the courses<br>Workflow not applicable |
| Echo (U.S.) https://newtechnetwork.org/echo/ | Commercial developer; For-profit; Webpage; Paid | Custom service | A PBL LMS support innovative teaching practice; Supports K-12 deeper learning skills for college and career. With digital tools, project exemplars, course starter sets, professional development, and access to a community of educators to create a powerful platform<br>Adoption workflow: Strategic & Tactical Understanding—Framework Design—Alignment Checks—Customization—Training and Adoption |

**Table 2** (continued)

| Name (name abbre.) country of origin, URL | Initiator & property | Student group & highlights | Summary of the platform features |
|---|---|---|---|
| PBL works (PBLW, U.S.) https://www.pblworks.org/ | Educator; Website; Free to use | Grade K-12 teacher professional development | A platform exclusively focuses on providing PBL service and resources to build the capacity of teachers to design and facilitate quality PBL, and the capacity of school and system leaders to set the conditions for teachers to implement projects with students<br>Workflow not applicable |
| Dreamdo schools (DDS, Finland) https://edu.dream.do/en | K-12 educator; Non-profit; Web-based app + Mobile App; Free to use | Grade 1–12; Communication & Collaboration, Critical Thinking | A PBL platform encourages school classes worldwide to engage in PBL by providing global network, available in 25 countries; Allow users to build connections with global classroom and seek to collaborate on a project around a particular issue that both sets of students could document<br>Learning Process: Create—launch – connect—co-design—collaborate—publish |
| Cura (CR, Australia) https://www.edustemonline.com/ | Commercial developer; For-profit; Web-based app; Paid | Grade 9–12 (Aus. year 7–10); | An integrated PBL platform provide both curriculum content and PBL learning management system; Supporting the blended PBL learning model, experiment learning components require students to complete in the classroom; Highlights competency development; Internationally available<br>Learning Process: Launch—self-paced learning—application—demonstration |

**Table 2** (continued)

| Name (name abbre.) country of origin, URL | Initiator & property | Student group & highlights | Summary of the platform features |
|---|---|---|---|
| iEARN (iRN, Spain) https://www.iearn.org/ | Non-profit; Website; Partially free to use | Grade K-16 | Provide K-12 service-learning projects designed and facilitated by teachers and students. To fulfill the curriculum needs and answer the questions at the world level in a sustainable manner. Focuses on foster global citizenship and encourage student peers to collaborate worldwide<br>Learning Process: Connect—co-create—communicate—collaborate—publish |
| PenPal schools (PPS, U.S.) https://www.penpalschools.com/ | Commercial developer; Non-profit; Web-based app; Free | Grade 2–12 | The largest collaborative learning community connects students from 150 countries; Through reading and writing to collaboratively solve global issues with peers; Emphasizes fostering digital citizenship, social-emotional education; Scalable assessment on multiple dimensions available<br>Learning Process: Connect—co-create—communicate—collaborate—demonstrate |

**Table 2** (continued)

| Name (name abbre.) country of origin, URL | Initiator & property | Student group & highlights | Summary of the platform features |
|---|---|---|---|
| EPBL (EPBL, China) http://epbl.aicfe.cn/epbl/ | Higher Ed researcher; Non-profit; Web-based app; Free | Grade 1–12 | A learning management platform emphasizes on supporting evidence-based PBL learning. Provide precise project recommendation and learning plan matching for teachers when search on the platform. Captures the learning data of students and provide intelligent assessment<br>Learning Process: Design—collaborate—monitor & management—assessment—evidence collection |
| GoPBL (GPBL, China) https://www.gopbl.com/ | K-12 educator; Non-profit; Web-based app; Free | Grade 1–16 | A STEM-PBL learning platform help teachers standardize, simplify and streamline PBL teaching procedure and achieve efficient instructional design and practice<br>Learning process: Adopt & adjustment—monitor & management—collaborate—showcase |
| Creative knowledge PBL platform (CK, China) http://xms.forclass.net/ | Commercial developer; For-profit; Web-based app; Paid | Grade 1–12 | A student-led platform provides a great number of subject-based projects for 1–12 learners. A scoring system embedded to encourage project learning accumulation and competition. A showcase area designed for students to share comments<br>Learning process: Adopt & adjustment—monitor & management—collaborate—showcase |

## Appendix 2

See Table 3.

**Table 3** Functions embedded in each PBL platform

| Categories | Feature and Function | PP | DL | HR | EPBL | GPBL | CK | FD* | Echo* | LL* | EDC | SPK | CR | iRN | PPS | DDS | PWS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Project Planning & Designing | Single subject projects | | | | √ | √ | √ | | | | √ | √ | √ | √ | √ | | |
| | Pre-designed lesson plans | √ | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | √ | √ | √ |
| | Embed curriculum info | | √ | | | | | | √ | | √ | √ | √ | | | | |
| | Provide scaffolding tools | √√ | √ | √ | √ | √ | | | √ | | √ | √ | √ | √ | | | √ |
| | Embed learning standards | √ | √ | | √ | | | | √ | | √ | √ | √ | | | | |
| | Allow create or customize projects | √√ | √ | √√ | √ | √ | √ | √ | √ | | | √ | | | | √ | |
| | Support uploading various formats of documents | √√ | √ | √√ | √ | √ | √ | | | | | | | | | √ | |
| | Students co-create or co-plan | √ | | √ | √ | √ | √ | | | | | | | | | | |
| Project Manage-ment | Learning task menu | √ | √ | √ | √ | √ | √ | √ | | | | | √ | | √ | | |
| | Team member | √ | √ | √ | | √ | √ | √ | | | | | | | | | |
| | Team assignments | √ | √ | √ | | √ | | √ | | | | | | | | | |
| | Personal progress checkpoint | √ | √ | √ | √ | | | | | | | | √ | | | | |
| | Team progress checkpoint | √ | √ | √ | | | | | | | | | | | | | |
| Interaction and Communication | Support in-class (C)/domestic(D)/ international (I) collaboration | C, D | C, D | C, D | | D, I | | D | C, D | C | D | | | D, I | D, I | D, I | |
| | In-project communication tool | √ | √ | √ | √ | √ | √ | | | √ | | | √ | √ | √ | √ | |
| Assessment & feedback | Create or embed rubrics | √ | √ | √ | √ | √ | √ | | √ | | | | | | √ | | |
| | Embed academic assessment | √ | √ | √ | √ | √ | √ | | | | | | | | √ | | |
| | Competency-based assessment | √ | √ | √ | √ | √ | √ | | | √√ | | | | | √√ | | |
| | Teacher feedback | √ | √ | √ | √ | √ | √ | | | √ | | | | √ | √ | | |
| | Self/peer feedback | √ | √ | √ | √ | √ | √ | | | √ | | | | | √ | | |
| | Reflection or reflection prompt | √ | √ | √ | √ | √ | √ | | | | | | √ | | √ | | |

**Table 3** (continued)

| Categories | Feature and Function | PP | DL | HR | EPBL | GPBL | CK | FD* | Echo* | LL* | EDC | SPK | CR | iRN | PPS | DDS | PWS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Documentation and Product | Learning documentation or portfolio | √ | √ | √ | √√ | √ | √ | √ | √ | √√ | | | √ | | √ | | |
| | Choice of product formats | √ | √ | √ | √ | √ | | | | | | | | | √ | | |
| | Learning outcome sharing | √ | √ | √ | √ | √ | √ | √ | √ | | | | | | √ | √ | |
| | Linking to credits | | | √ | | | | | | | | | | | | | |
| | Continuously tracking progress across projects | √ | √ | √ | √ | √ | √ | √ | | | | | | | | | |
| Learning Analytics | Learning log and data analytics | √√ | √ | √ | √ | | √ | √√ | | | | | | | √ | | |
| Teacher PD | Provide teacher training | √ | √ | √ | | √ | √ | √ | √ | | √ | | √ | √ | | | √ |
| PBL community & ecosystem | Teacher PBL Community of Practice | √ | | | | | | √ | √√ | | √ | √√ | | √ | | √ | √ |
| | Guest participants | √ | | √ | √ | | √ | | | | | | | | √ | √ | |
| | Out-of-school expert network | | | | | | | | | | √√ | | | | | | |
| | Career connection | | √√ | | | | | | | | √√ | | | | | | |
| Learning mode & Tech support | Embed into the existing LMS | | √ | √ | | | | | | | √ | √ | | | | | |
| | Support self-directed learning | √ | √√ | √ | √ | √ | √ | √ | | √√ | | | √√ | √ | √ | | |

Platforms marked with * provide customized services and did not provide free trial account, therefore their functions marked only highlight their proposed expertise

**Author contributions** This research is conducted by four researchers. All four authors contributed to the study conception and design. NM: conceptualization, data curation, methodology, visualization, and writing. YD: funding acquisition, investigation, supervision, reviewing & editing. DR: methodology review, literature review, writing, reviewing, editing. LL: writing, reviewing, editing. All the authors read and approved the final manuscript.

**Funding** This work was supported by two sources: International Joint Research Project of Huiyan International College, Faculty of Education, Beijing Normal University [Grant Number ICER201902]; The General Program of National Natural Science Foundation of China. Research on Brain Synchronization Mechanisms and Strategies of Multi-person Interaction in STEM Educational Context, Beijing Normal University [Grant Number 62177011].

**Data availability** The data used and analyzed during the current study are available from the corresponding author on reasonable request. Please contact author for data requests.

## Declarations

**Conflict of interest** There is no conflict of interest in this article from any of the authors.

**Ethical approval** Ethical approval APA ethical standards were followed in the conduct of the study, and we received approval from the Beijing Normal University institutional review board.

**Consent to participate** Informed consent was obtained from all individual participants included in the study.

## References

Adnan, M., & Anwar, K. (2020). Online learning amid the COVID-19 pandemic: Students' perspectives. *Online Submission, 2*(1), 45–51.

Aksela, M., & Haatainen, O. (2019). Project-based learning (PBL) in practise: active teachers' views of its' advantages and challenges. In Integrated Education for the Real World 5th International STEM in Education Conference Post-Conference Proceedings. Queensland University of Technology.

Al-Balushi, S. M., & Al-Aamri, S. S. (2014). The effect of environmental science projects on students' environmental knowledge and science attitudes. *International Research in Geographical and Environmental Education, 23*(3), 213–227.

Aldabbus, S. (2018). Project-based learning: Implementation & challenges. *International Journal of Education, Learning and Development, 6*(3), 71–79.

Alverson, J., Schwartz, J., & Shultz, S. (2019). Authentic assessment of student learning in an online class: Implications for embedded practice. *College & Research Libraries (C&RL)*,80.

Amini, R., Setiawan, B., Fitria, Y., & Ningsih, Y. (2019). The difference of students learning outcomes using the project-based learning and problem-based learning model in terms of self-efficacy. *Journal of Physics: Conference Series, 1387*(1), 012082.

Anazifa, R. D., & Djukri, D. (2017). Project-Based learning and problem-based learning: are they effective to improve student's thinking skills? *Jurnal Pendidikan IPA Indonesia, 6*(2), 346–355.

Barron, B., & Darling-Hammond, L. (2008). *Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning book excerpt*. George Lucas Educational Foundation.

Blount, E. V. (2016). *A qualitative phenomenological study exploring lived experiences of employees and managers and their engagement with e-learning courses*. Northcentral University.

Brassler, M., & Dettmers, J. (2017). How to enhance interdisciplinary competence—interdisciplinary problem-based learning versus interdisciplinary project-based learning. *Interdisciplinary Journal of Problem-Based Learning, 11*(2), 12.

Cavus, N., Sani, A. S., Haruna, Y., & Lawan, A. A. (2021). Efficacy of social networking sites for sustainable education in the era of COVID-19: A systematic review. *Sustainability, 13*(2), 808.

Choudhury, S., & Pattnaik, S. (2020). Emerging themes in e-learning: A review from the stakeholders' perspective. *Computers & Education, 144*, 103657.

Cleland, D. I. (2007). *Project management: strategic design and implementation*. McGraw-Hill Education.

Connaway, L. S., & Radford, M. L. (2016). *Research methods in library and information science*. ABC-CLIO.

Culclasure, B. T., Longest, K. C., & Terry, T. M. (2019). Project-based learning (Pjbl) in three southeastern public schools: Academic, behavioral, and social-emotional outcomes. *Interdisciplinary Journal of Problem-Based Learning, 13*(2), 5.

Duke, N. K., Halvorsen, A. L., Strachan, S. L., Kim, J., & Konstantopoulos, S. (2021). Putting PjBL to the Test: The Impact of Project-Based Learning on Second Graders' Social Studies and Literacy Learning and Motivation in Low-SES School Settings. *American Educational Research Journal, 58*(1), 160–200.

Dziuban, C., Graham, C. R., Moskal, P. D., Norberg, A., & Sicilia, N. (2018). Blended learning: The new normal and emerging technologies. *International Journal of Educational Technology in Higher Education, 15*(1), 1–16.

Farhan, M., Aslam, M., Jabbar, S., & Khalid, S. (2018). Multimedia based qualitative assessment methodology in eLearning: Student teacher engagement analysis. *Multimedia Tools and Applications, 77*(4), 4909–4923.

Fauzia, N. L. U., & Kelana, J. B. (2021). Natural science problem solving in elementary school students using the project based learning (PjBL) model. *Jurnal Ilmiah Sekolah Dasar, 4*(4), 596–603.

From, J. (2017). Pedagogical digital competence-between values. *Knowledge and Skills. Higher Education Studies, 7*(2), 43–50.

Guha, R., Wagner, T., Darling-Hammond, L., Taylor, T., & Curtis, D. (2018). The Promise of Performance Assessments: Innovations in High School Learning and Higher Education Admissions.

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research, 102*, 101586.

Habók, A., & Nagy, J. (2016). In-service teachers' perceptions of project-based learning. *Springerplus, 5*(1), 1–14.

Harris, A., & Johns, A. (2021). Youth, social cohesion and digital life: From risk and resilience to a global digital citizenship approach. *Journal of Sociology, 57*(2), 394–411.

Harris, J. (2016). Inservice teachers' TPACK development: Trends, models, and trajectories. In M. Herring, M. Koehler, & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge for educators* (2nd ed., pp. 191–205). Routledge.

Iwamoto, D. H., Hargis, J., & Vuong, K. (2016). The effect of project-based learning on student performance: An action research study. *International Journal for the Scholarship of Technology Enhanced Learning, 1*(1), 24–42.

JISC Digital Media. (2014). Guide introduction toe-learning. Retrieved from http://www.jiscdigitalmedia.ac.uk/guide/introduction-to-elearning.

Kassymova, G., Akhmetova, A., Baibekova, M., Kalniyazova, A., Mazhinov, B., & Mussina, S. (2020). E-Learning environments and problem-based learning. *International Journal of Advanced Science and Technology, 29*(7), 346–356.

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60–70.

Koehler, M. J., Mishra, P., & Yahya, K. (2007). Tracing the development of teacher knowledge in a design seminar: Integrating content, pedagogy and technology. *Computers & Education, 49*(3), 740–762.

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools, 19*(3), 267–277.

Krajcik, J. S., & Blumenfeld, P. C. (2006). Project-based learning (pp. 317-34). na. https://knilt.arcc.albany.edu/images/4/4d/PBL_Article.pdf

Krajcik, J. S., Czerniak, C. M., Czerniak, C. L., & Berger, C. F. (2003). *Teaching science in elementary and middle school classrooms: A project-based approach*. McGraw-Hill Humanities.

Kraleva, R., Sabani, M., & Kralev, V. (2019). An analysis of some learning management systems. *International Journal on Advanced Science, Engineering and Information Technology, 9*(4), 1190–1198.

Lam, S. F., Cheng, R. W. Y., & Choy, H. C. (2010). School support and teacher motivation to implement project-based learning. *Learning and Instruction, 20*(6), 487–497.

Lara, J. A., Lizcano, D., Martínez, M. A., Pazos, J., & Riera, T. (2014). A system for knowledge discovery in e-learning environments within the European higher education area-application to student data from Open University of Madrid, UDIMA. *Computers & Education, 72*, 23–36.

Lee, D., Huh, Y., & Reigeluth, C. M. (2015). Collaboration, intragroup conflict, and social skills in project-based learning. *Instructional Science, 43*(5), 561–590.

Lewis, D. G. R., Gerber, E. M., Carlson, S. E., & Easterday, M. W. (2019). Opportunities for educational innovations in authentic project-based learning: Understanding instructor perceived challenges to design for adoption. *Educational Technology Research and Development, 67*(4), 953–982.

Mann, B., Li, W., & Besnoy, K. (2021). Digital Divides: K-12 Student Profiles and Online Learning. *Education Policy Analysis Archives*, *29*(112), n112.

Meeder, H., & Pawlowski, B. (2020). Preparing our students for the real world: the education shift our children and future demand. National Center for College and Career Transitions, Columbia. https://www.nc3t.com/wp-content/uploads/2020/02/Preparing-Our-Students-for-the-Real-World-021720.pdf.

Mentzer, G. A., Czerniak, C. M., & Brooks, L. (2017). An examination of teacher understanding of project-based science as a result of participating in an extended professional development program: Implications for implementation. *School Science and Mathematics, 117*(1–2), 76–86.

Meredith, J. R., Shafer, S. M., & Mantel, S. J., Jr. (2017). *Project management: A strategic managerial approach*. John Wiley & Sons.

Moore, J. L., Dickson-Deane, C., & Galyen, K. (2011). e-Learning, online learning, and distance learning environments: Are they the same? *The Internet and Higher Education, 14*(2), 129–135.

Nasir, M., Fakhrunnisa, R., & Nastiti, L. R. (2019). The implementation of project-based learning and guided inquiry to improve science process skills and student cognitive learning outcomes. *International Journal of Environmental and Science Education, 14*(5), 229–238.

Owens, A. D., & Hite, R. L. (2022). Enhancing student communication competencies in STEM using virtual global collaboration project based learning. *Research in Science & Technological Education, 40*(1), 76–102.

Ramadhani, R., Rofiqul, U. M. A. M., Abdurrahman, A., & Syazali, M. (2019). The effect of flipped-problem based learning model integrated with LMS-google classroom for senior high school students. *Journal for the Education of Gifted Young Scientists, 7*(2), 137–158.

Repko, A. F., Szostak, R., & Buchberger, M. P. (2019). *Introduction to interdisciplinary studies*. Sage Publications.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). The Free Press.

Rongbutsri, N. (2017). *Students using online collaborative tools in problem-oriented project-based learning*. Aalborg University.

Stake, R. E. (2013). *Multiple case study analysis*. Guilford press.

Thomas, J. W. (2000). A review of research on project-based learning. San Rafael, CA: Autodesk Foundation. https://scirp.org/reference/referencespapers.aspx?referenceid=631638

Trisdiono, H., Siswandari, S., Suryani, N., & Joyoatmojo, S. (2019). Multidisciplinary integrated project-based learning to improve critical thinking skills and collaboration. *International Journal of Learning, Teaching and Educational Research, 18*(1), 16–30.

Verstegen, D. M., de Jong, N., van Berlo, J., Camp, A., Könings, K. D., van Merriënboer, J. J., & Donkers, J. (2016). How e-learning can support PBL groups: A literature review. *Educational Technologies in Medical and Health Sciences Education, 5*, 9–33.

Vinson, L., & Caukin, N. (2021). eLearning for K-12: challenges and solutions. *International Journal of the Whole Child, 2021*(6), 27–35.

Virtue, E. E., & Hinnant-Crawford, B. N. (2019). "We're doing things that are meaningful": Student perspectives of project-based learning across the disciplines. *Interdisciplinary Journal of Problem-Based Learning, 13*(2), 9.

Wilson, K. (2021). Exploring the challenges and enablers of implementing a STEM project-based learning programme in a diverse junior secondary context. *International Journal of Science and Mathematics Education, 19*(5), 881–897.

Wu, T. T., & Wu, Y. T. (2020). Applying project-based learning and SCAMPER teaching strategies in engineering education to explore the influence of creativity on cognition, personal motivation, and personality traits. *Thinking Skills and Creativity, 35*, 100631.

Zuo, M., Ma, Y., Hu, Y., & Luo, H. (2021). K-12 students' online learning experiences during COVID-19: Lessons from China. *Frontiers of Education in China, 16*(1), 1–30.



**Nanxi Meng** is a senior lecturer in the Department of World Languages, Literatures and Cultures at the University of North Texas. Her research interests include project-based learning, STEM education, teacher professional development and technology-enhanced learning.

**Yan Dong** is a Full Professor and the Associate Dean of the School of Educational Technology at the Beijing Normal University. She also serves as an adjunct faculty in the School of Education at the Zhejiang University. Her research interests include teachers' TPACK knowledge, feedback, and technology-enhanced learning.

**Dorian Roehrs** is a full professor of the Department of World Languages, Literatures and Cultures at the University of North Texas. His research interests include second language acquisition and technology-enhanced language learning.

**Lin Luan** is an associate professor at the School of Humanities at Beijing University of Posts and Telecommunications, and currently a Ph.D. candidate at Beijing Normal University. Her research interests include technology-enhanced language learning, and second language acquisition.

## Authors and Affiliations

**Nanxi Meng[1] · Yan Dong[2,3] · Dorian Roehrs[1] · Lin Luan[2,4]**

Nanxi Meng
Nanxi.meng@unt.edu

Dorian Roehrs
roehrs@unt.edu

Lin Luan
luanlin@bupt.edu.cn

1 Department of World Languages, Literatures and Cultures, University of North Texas, Denton, TX, USA

2 Faculty of Education, Beijing Normal University, Haidian District, Yanbo Building, No.19, Xinjiekouwai St, Beijing 100875, People's Republic of China

3 School of Education, Zhejiang University, Hangzhou, China

4 Department of Foreign Languages, Beijing University of Posts and Telecommunications, Beijing, China