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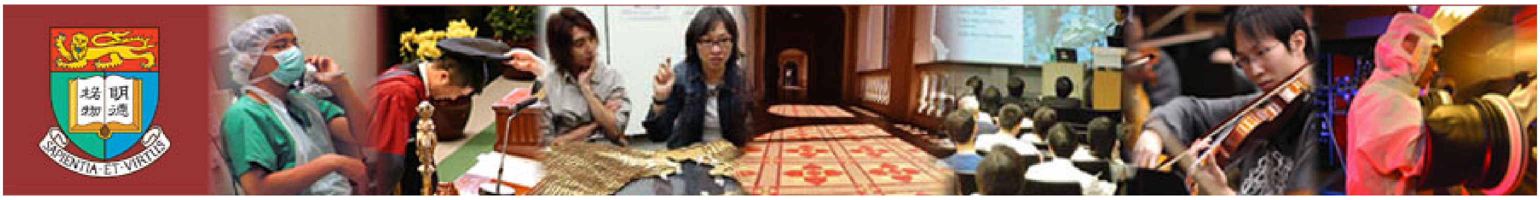

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Combining Smart Web-based Learning Environments with Teaching and Learning Analytics to Support Reflection on Project-based Programming Education

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ABSTRACT

Project-based learning (PjBL) is a promising approach for supporting learning of computer programming by addressing the gap between the attainment of abstract knowledge and the application of this knowledge to authentic programming tasks. The World Wide Web has considerable potential to expand and improve PjBL environments. However, making implicit aspects of a programming task accessible to learners and instructors to support reflection and improvement can be challenging. This paper discusses the challenge of PjBL in programming education and outlines a set of key aspects and an analysis framework to inform design and analysis of PjBL programming in web-based environments, by exploiting the emerging field of Teaching and Learning Analytics. Based on the proposed analysis framework, the design of an empirical study is outlined, capitalizing on a novel web-based PjBL environment that makes complex cognitive processes accessible and affords the analysis of its effects on learning programming in multiple aspects.

CCS Concepts

• **Applied computing→Education** • **Social and professional topics→Professional topics.**

KEYWORDS

Computer programming; Project-based learning; Web-based learning; Technology-enabled learning; Learning Analytics; Teaching and Learning Analytics

1. INTRODUCTION

Learning on the World Wide Web has been widely employed in educational practice. Web-based applications can expand and improve learning environments by offering flexible and ubiquitous access to learning resources and activities, and supporting effective communication and interaction throughout the learning process.

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Moreover, web-based applications can afford rich learning experiences by virtue of interactive multimedia, immersive environments, and adaptive support for self-directed/regulated learning.

In computer programming education, web-based learning has been increasingly adopted especially with the rapid growth of the industry demand for programmers and the learners' interest in programming. Indeed, cultivating learners' programming competences has become a core priority for educational policies around the world and industry workforce requirements are increasingly being shifted towards attaining such competences.

Computer programming is considered a hard subject to (teach and) learn [1, 2]. A programmer needs to master programming knowledge (such as concepts, syntax and semantics) as well as programming skills and strategies [3]. The latter refers to general and specific skills and strategies for synthesizing and applying programming knowledge to perform programming tasks by planning, designing, and implementing solutions. In contrast to programming knowledge, programming skills and strategies are more implicit and harder to capture, yet critical for attaining programming proficiency [4]. Traditional programming education focuses on elaborating abstract knowledge rather than on linking knowledge to specific contexts as well as on synthesizing and applying this knowledge to programming tasks. As a result, many learners possess disconnected and inert programming knowledge and fail to demonstrate the ability to apply this knowledge to authentic problems, as reflected by high drop-out rates on programming courses [3].

To address the gap between the learning of abstract knowledge and the application of the knowledge to authentic programming tasks, a variety of instructional approaches, such as project-based learning [5, 6], problem-based learning [7, 12], and case studies [9] have been incorporated to programming education. Among them, project-based learning (PjBL) has received wider attention. PjBL engages learners in investigating authentic problems and tasks and developing an end artifact such as a design plan or computer program. Different from problem-based learning, PjBL highlights the development of realistic products closer to professional reality and the assessment of the product quality [10, 11, 12].

PjBL has been found to contribute to meaningful learning of abstract knowledge and the development of skills for social communication and problem solving. Nevertheless, its effects on improving programming performance are reported to be inconsistent and inconclusive [6]. A major concern is that computer programming tasks involve complex cognitive processes; such complexity has overwhelmed many learners and failed to improve their motivation and emotions and learning outcomes [6, 11, 13]. Additionally, these complex cognitive processes are not always made evident to the (learners and) instructors, due to the inherent difficulty of tracking and capturing them, therefore limiting their capacity to scaffold learners and understand how teaching practices can be improved to better accommodate learners' needs.

In this context, the design and analysis of PjBL in programming education has been considerably dependent on the personal experiences, expertise, and insights of the instructors. There is little consensus and data-based evidence regarding pragmatic instructional strategies that can enhance the benefits of PjBL for learners. In addition, PjBL was reported to require a wide range of learning activities and hands-on practice, making it difficult to implement without sufficient time, manpower and resource [6, 11].

The World Wide Web has significant potential to expand and improve PjBL environments by affording flexible learning activities and effective utilization of resources. However, the complexity of learning with sophisticated tasks remains in both classroom and technology-mediated learning environments, making learners unable to engaged in deeper learning and achieve desired learning outcomes [14]. Recent research has explored the approaches to externalizing and scaffolding complex cognitive processes involved in learning with sophisticated tasks, showing their promising effects on learning achievement [15]. Moreover, capitalizing on the data tracking affordances of state-of-the-art web-based learning environments, previously undetected learning processes and tasks can be unraveled and become available for investigation using novel Teaching and learning Analytics methods.

The proposed study will capitalize on both state-of-the-art online learning environments for supporting PjBL programming learning as well as innovative educational data analytics for holistically improving the teaching and learning conditions of learners, namely Teaching and Learning Analytics [16]. In particular, the proposed study discusses an innovative design of online learning environment for PjBL in combination with a Teaching and Learning Analytics framework to tackle the issue of making tacit programming skills and strategies accessible (throughout the learning process) for supporting learners' self-improvement as well as instructors' self-reflection on their teaching designs.

Considering the lack of studies investigating how the potential of PjBL can be realized by making complex cognitive processes accessible to learners and instructors through effective design and analysis of PjBL in web-based environments, the proposed study will aim to tackle a significant global challenge. In the following sections, we will discuss relevant learning theories and analytics frameworks, based on which we will outline a set of key aspects to be taken into account in the design and analysis of PjBL in web-based environment.

2. RELEVANT LEARNING THEORIES AND ANALYTICS FRAMEWORKS

2.1 Situated Learning

Deriving from constructivism learning theory, Situated Learning has been regarded as a means to fill the gap between the learning of subject matter knowledge in a formal instructional environment and the application of the knowledge in a realistic setting [17, 18]. Knowledge is rooted in both physical and social contexts; meaningful learning will only take place in the situations where knowledge is created and applied.

Accordingly, learning in real-world situations, especially with authentic problems and whole-task experience (e.g., inquiry learning, project-based learning, and problem-based learning) has become the central aspect of educational practice. In the proposed study, the core principles of Situated Learning are realized by engaging learners in project-based activities, which require them to devise solutions to authentic problems and formulate tangible outcomes by applying their knowledge.

2.2 Cognitive Apprenticeship

Carrying out a sophisticated task or solving a complex problem usually involves implicit processes. The complexity of such processes may generate heavy cognitive load to learners [19], but is often underestimated by instructors or experts for whom many of the requisite processes have become largely subconscious because of years of experience. According to the cognitive apprenticeship model, making complex task processes visible for novices to observe and practice with expert help is crucial to learning in complex situations [20].

The cognitive apprenticeship model also suggests a set of strategies, namely modeling, articulation, scaffolding, coaching, exploration, and reflection, to support learning in complex task situations. Modeling and articulation focus on the externalization of complex processes; scaffolding and coaching focus on the provision of expert help; reflection focuses on the individual's own self-assessment. In the proposed study, the principles of Cognitive Apprenticeship will be supported through educational data technologies in order to allow learners and instructors obtain transparent overviews of the complex tasks performed during PjBL.

2.3 Four-Component Instructional Design (4C/ID) Model

With respect to scaffolding and coaching for complex tasks, the four-component instructional design (4C/ID) model presents a guiding framework to support the learning with complex tasks [21]. The model involves four interrelated components: learning tasks, supportive information, procedural information, and part-task practice. In particular:

- Learners should be provided with concrete and authentic *learning tasks* organized in the simple-to-complex order;
- *Supportive information* for non-recurrent aspects of learning tasks should be offered as guidance to learners together with feedback to individual performance;

- *Procedural information* for recurrent aspects of learning tasks can be recalled as just-in-time alert to students during the task process;
- If needed *part-task practice* can be used to improve routine skills to reach a required level of automaticity.

In this work, these components of the 4C/ID model will be included in the PjBL scenarios and the web-based PjBL environment, as discussed in section 4.2.

2.4 Teaching and Learning Analytics

Teaching and Learning Analytics (TLA) refer to an emerging educational data Analytics framework, comprising a research synergy to exploit the potential of the individual Teaching Analytics and Learning Analytics strands [18]. More specifically, as Sergis and Sampson argue [16], TLA posits the need for methods and tools that will exploit:

- the potential of *Teaching Analytics* to analyze the educational designs in the constituent elements (e.g., learning and assessment activities and educational resources/tools) and the interrelations between these elements (e.g., [22]).
- the potential of *Learning Analytics* to measure, collect, analyse and report on learners' educational data and the learning context that they are generated, aiming to improve the learning conditions for individual learners or groups of learners [23].

The key standpoint of TLA is that the insights of Learning Analytics (related to learner performance) in isolation, can offer limited insights to instructors for systematically improving the teaching and learning experience of their learners. This is due to the fact that such insights are commonly studied in separation from the learning context that generated them, which in web-based education mainly refers to the teaching design and the digital environment that hosts the teaching and learning process.

Therefore, TLA argue that the insights generated by Learning Analytics methods should be mapped to the analyzed (through Teaching Analytics methods) elements of the teaching design that generated them. Providing novel methods to generate this mapping is regarded as an important challenge and is argued as beneficial to support instructors (and potentially learners) better understand the learning process and how the teaching context (i.e., design) can impact it [16, 24].

Therefore, in the context of this work, Teaching and Learning Analytics will be adopted as the overarching analysis framework for investigating the largely under-explored, but significant, challenge of tracking, unraveling and, ultimately, improving learners' complex cognitive processes during programming in PjBL scenarios.

3. THEORY-DRIVEN DESIGN AND ANALYSIS

On the basis of the aforementioned theories and models, we outline a set of key aspects to be taken into account in the design and analysis of PjBL programming in web-based environments.

3.1 Design of Accessible Web-based PjBL Environment

Based on the aforementioned learning theories and models, the design of web-based learning environment for PjBL computer programming needs to take into account the following aspects to address the challenge of making complex cognitive processes accessible to learners and instructors.

3.1.1 Exploratory and Progressive Learning Context

An exploratory problem context needs to be provided to allow learners to access programming tasks or problems and explore relevant solutions. Moreover, the learning tasks should be organized in the simple-to-complex order to facilitate progressive learning. Through a progression of increasingly complex problems, the learners' skills will gradually improve until they are able to solve complex problems.

3.1.2 Decomposing a Complex Task into a Set of Actions

To make complex learning accessible, a complex task can be decomposed into a set of actions based on heuristics or disciplinary strategies. The purpose is to scaffold or facilitate learner thinking and actions in complex situations. Indeed, evidence has shown that providing such guidance to support learners' engagement in complex tasks is essential for effective learning [25]. Based on relevant literature, a complex programming task can be decomposed into the following actions shown in Table 1.

Table 1. Main actions of a programming task

Action	Description
Problem understanding	The first step of a programming task is to formulate a clear understanding of the problem such as its goal, requirement, given information, and expected output.
Modular design	Based on the understanding of the problem, a program can be organized as a set of distinct modules or functions that can be developed independently and then plugged together.
Process design	The processes within and cross the modules need to be outlined to illustrate a solution or algorithm for a given problem, mainly by showing the steps and the connections between them.
Coding	Based on the modular design and process design, the solution to a problem can be translated into programming codes.
Evaluation and reflection	A completed program needs to be evaluated for possible improvement mainly by testing and debugging as well as by reflection on the comments from the expert and the solutions of others.

3.1.3 Making Implicit Processes Visible

Although a complex programming task can be decomposed into a set of actions as mentioned above, some actions still involve complex processes inaccessible to learners. The implicit aspects of the task process can be externalized using visual representations or graphic forms, which have advantages in representing complex ideas in flexible ways (both verbally and spatially). For example, a structured form allows an explicit understanding of a complex problem; a module diagram supports a visible representation of the modular design of a program; and a program flowchart depicts the process of a program by showing the steps as boxes of various kinds, and their order by connecting them with arrows.

3.1.4 Providing Instructions and Guidance

In addition to making implicit processes visible, relevant instructions and guidance on how to go through the complex processes (e.g., formulating a clear understanding of the problem, decomposing the problem into appropriate modules, and designing a logic and appropriate flow of the program) should be provided to learners. General and specific programming strategies should be introduced to learners, allowing them to become conversant with the ways and norms of thinking and actions that are widely adopted in the discipline. Making disciplinary strategies or norms explicit to learners will help guide their learning and performance towards important aspects of the experience.

3.1.5 Feedback to Individual Performance

In addition to general instructions and guidance, learners should be provided with individual feedback based on the observation and analysis of their performance, with a view to fostering reflective learning from task experience. Sharing of solutions from peers and experts will also support reflective learning. The analysis of programming task performance becomes important in this context, which is directly related to both assessment of learners' engagement and performance in PjBL as well as supporting instructors to understand how their teaching design impacted these dimensions of learner activity.

3.2 Analysis of PjBL using Teaching and Learning Analytics

Appropriate analysis of the learning process and the performance of learners against the designed activities is conducive to both facilitating learners to obtain a deep and reflective learning and long-term knowledge retention as well as to supporting instructors to reveal how learners are engaging with their teaching design and improve it to better meet the needs of learners.

Paper-based examinations or tests have been widely used in programming courses, however these summative assessment tools can lack sensitivity and granularity in the insights they can offer to unravel learning in task or problem contexts. For example, many learners with good grades in knowledge tests were found to have problems with actual programming tasks. Therefore, it can be argued that extending the assessment and monitoring methods employed during PjBL is essential to generating the evidence needed to effectively support both learners and instructors plan for improvement.

Capitalizing on the standpoints of Teaching and Learning Analytics, PjBL can be analyzed against two dimensions, namely teaching design and learner activity / performance educational data.

3.2.1 Teaching Analytics

Regarding the analysis of **teaching design** (Teaching Analytics), an outline in terms of core elements is needed such as [16]:

- the types of the learning and assessment activities, to allow instructors to trace how learners are engaging and performing in each of the designed activities,
- the types of the educational resources and tools selected to support the activities, to allow instructors to unravel whether/how learners are exploiting the provided educational resources and/or tools.

3.2.2 Learning Analytics

Regarding the analysis of **learner educational data**, a diverse set needs to be collected, so as to create a detailed picture of learners' learning process and performance. More specifically, capitalizing on the state-of-the-art in Learning Analytics in terms of solid indicators of learners' activity and performance in web-based environments, the following broad types of educational data relevant to the problem at hand will need to be collected:

- **Learners' performance** in PjBL. This performance should include problem-solving skills and task performance reflected in the learning process and final products, in addition to subject knowledge tests. Prior studies on PjBL in computer programming have emphasized on correctness, efficiency, reliability, and readability in assessing the quality of computer programs [26], though there is a lack of wide consensus on the assessment approaches and standards. The programming products should consider not only the final artifacts, i.e., the programming code, but also other educational data records generated during the task process such as problem understanding, modular design, and program flowchart.
- **Learner's engagement with the learning activities**. These types of educational data capture how individual learners accessed and engaged with each activity of the PjBL scenario [27]. This has been reported to be a significant indicator of their final performance in online environments [28], therefore exploiting these data is argued to be meaningful for obtaining a better overview of the learning process in programming for individual learners.
- **Learner's engagement with the educational resources and/or tools.** These types of educational data have also been reported to provide a sound measure of learners' performance. Furthermore, these data can also supplement the aforementioned analyses regarding what learners do within each activity, by providing additional information on the learning process and strategies of individual learners as depicted in their use of the relevant resources or tools.
- Learners' **motivation** and **emotions** during the learning process. These data should also be taken into account as they have been attributed with a substantial influence on learning outcomes. Indeed, these characteristics are core elements of learners' self-regulation, which is considered essential for effective learning in the context of (ill-defined) problem-solving activities (a prime example of which are programming tasks).
- **Learner perceptions** of the learning system. These data have been found to have a significant impact on learning in such contexts. Unless the system is properly designed and implemented to the extent that learners

find it acceptable and satisfactory, further investigation into the effect of the approach on learning may not produce reliable and meaningful results.

4. EMPIRICAL STUDY

Based on the proposed design and analysis framework, an empirical study will be carried out using a design-based research approach, in particular by the design of web-based PjBL environment that makes complex learning accessible to both learners and instructors and by the analysis of its effects on programming learning to inform both teaching and learning practices. Moreover, capitalizing on the data tracking affordances of state-of-the-art web-based learning environments, previously undetected learning processes and tasks can be unraveled and become available for investigation.

4.1 Design-Based Research Approach

The proposed study will be structured against a Design-based research approach. As shown in Figure 1, design-based research is a systematic methodology that creates, builds, and evaluates innovative artifacts or interventions to solve identified problems [29].

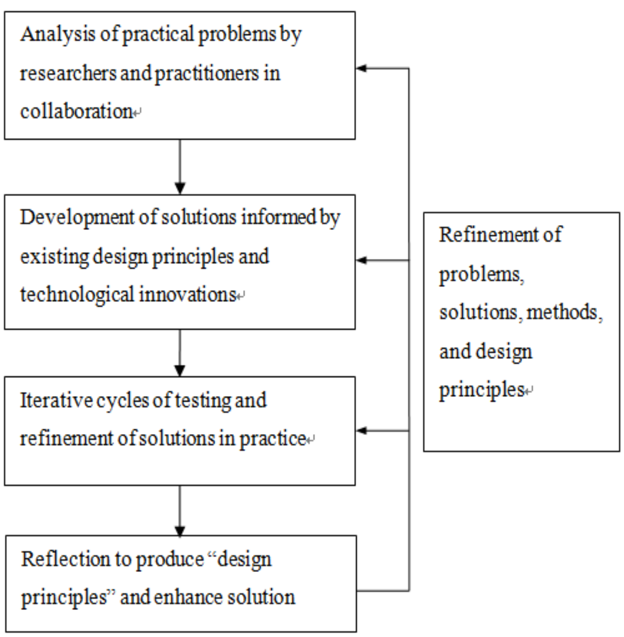

Figure 1. A design-based research procedure.

As shown in Figure 1, design-based research features iterative analysis, design, development, and implementation as well as close collaboration among researchers and practitioners in real-world settings, leading to contextually-sensitive design principles and theories. Design-based research is particularly suited to situations in which complex and ambitious educational reform policies are ill-specified and the implementation process is uncertain.

4.2 Web-based PjBL environment Design

To collect the educational data and generate initial evidence from the empirical study, a prototype web-based PjBL environment to support PjBL computer programming is under development based on close collaboration among the researchers, programming teachers, learners, and domain experts.

Figure 2 shows the scaffolded learning process proposed in the PjBL environment, where a programming task is decomposed into the previously mentioned set of actions including problem understanding, modular design, process design, coding, and evaluation and reflection (section 3.1.2). By a click on the icon of each action, learners can enter into the task space for each action so as to complete a programming task.

Figure 2. Project-based learning process.

Diagramming tools are provided for learners to present their modular design and process design in a visual format when they work on a programming task, as shown in Figure 3 and Figure 4.

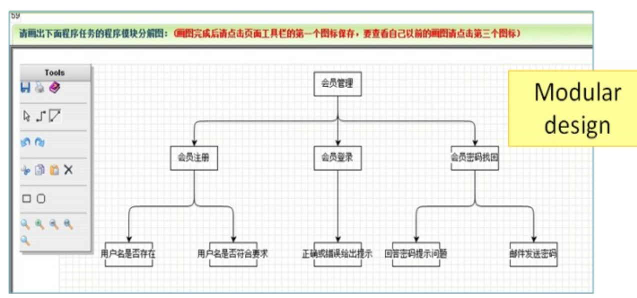

Figure 3. Visual representations of modular design.

This process can benefit learners (by allowing them to create a clear solving strategy), but they also provide useful data to the instructor for unraveling the learners' understanding, misconceptions as well as their capacity to employ their knowledge to solve an actual problem.

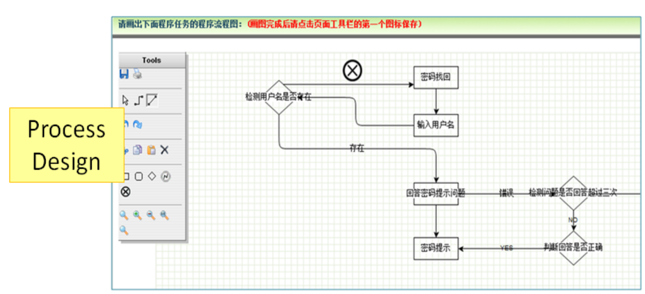

Figure 4. Visual representations of process design.

Figure 5 presents the expert feedback to be provided to learners on their individual performance in multiple aspects including problem understanding, modular design, process design, and coding. A solution to a task generated by an expert can also be accessed by learners for reflection at appropriate time. At this point, data related to learner performance can be elicited in relation to each programming task.

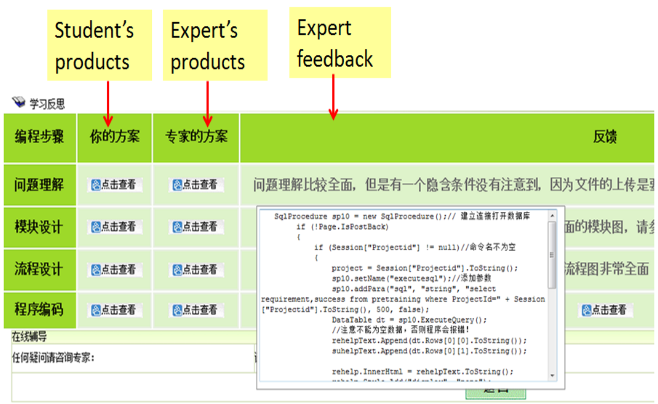

Figure 5. Expert feedback.

4.3 Analysis Method

The developed web-based PjBL environment will be used in empirical study by college students for their PjBL of computer programming. As aforementioned, from the Teaching Analytics dimension, the PjBL scenarios will be analyzed in terms of the constituent design elements and their inter-relations, in order to support follow up analyses against learners' educational data. Moreover, learners' educational data related to the effects of the PjBL environment on programming learning will be examined in several aspects.

- First, a questionnaire survey will be used to collect learner perceptions of the PjBL environment in terms of usefulness, ease of use and intention to use. Their motivation, meta-cognition and emotion activated by the study will also be collected through questionnaire surveys. Also, think-aloud protocols can be employed to capture learners' strategies during programming tasks and complement other collected data types.
- Second, the programming products including learning records generated by learners as well as data from experts' feedback throughout the learning process will be collected and analyzed to examine their programming performance in terms of problem understanding, modular design, process design, and programming codes.
- Third, the log data from the PjBL environment will be used to depict the engagement of learners with the design elements of the PjBL scenario.
- Fourth, pre- and post-tests will be used to assess the overall learning outcomes reflected in knowledge tests.
- Fifth, semi-structured interviews will be arranged with learners to collect their comments on the PjBL environment and learning experience as well as their suggestions for improvement of the learning program.

Based the findings from the empirical study, novel insights will be generated regarding not only how individual learners engage in complex programming tasks but also how this level of engagement on different types of programming tasks throughout the learning process can affect their performance and self-regulation. Also, the PjBL environment and the assessment methods will be refined for further experiment and analysis.

5. CONCLUSION

Making the complex, implicit aspects of PjBL accessible to learners is a pressing yet difficult issue. Computer- and Web-based technologies have potential to support complex learning by externalizing and guiding sophisticated cognitive processes of complex tasks and by tracing learners' activity and performance in a more detailed and continuous manner.

This paper has outlined a set of key aspects to be taken into account in the design and analysis of PjBL programming education in web-based environments, with a focus on making complex cognitive process accessible, trackable, and attainable. The proposed study is expected to have a significant impact on research and practice in technology-enabled PjBL and programming education, given the existing dearth of research works that explicitly investigate learners' complex cognitive processes and offer systematic evidence on how to effectively scaffold these processes from the perspective of both learners and instructors.

The findings will be utilized to explain how the potential of PjBL can be realized by effective design and analysis of PjBL in web-based environment. Also, the findings of the study will offer novel and holistic understanding of learner activity, complex cognitive processes, and performance in web-based environments, which are currently under-explored despite the global need to support them, not only for programming education, but for the technology-enhanced learning field in its entirety [30].

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