

Problems of Problem-Based Learning: Exploring Meta-Agency in Problem-Based Cybersecurity Learning in College Education

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Abstract

In college cybersecurity education, problem-based learning has been introduced to promote student agency in solving a complex problem. However, a dilemma of balancing the student agency persist and previous research has focused on students' cognitive, metacognitive, and regulatory to enhance the efficacy of PBL. Given the importance of students' self-awareness of their agency, this study suggests a concept of meta-agency as an essential learner characteristic that influences the effectiveness of student agency in PBL. Four dimensions of meta-agency, perceptions of productive struggle, expectation alignment between instructor and students, strategies for regulating agency, and familiarity with PBL tasks, were qualitatively explored with student interview data. Features of meta-agency and how students' meta-agency level develop through cybersecurity PBL sessions were further investigated.

1. Introduction

1.1. Student agency for deeper learning in problem-based cybersecurity learning

In college cybersecurity education, an increasing number of researchers and practitioners have introduced and implemented the problem-based learning (PBL) approach to provide students with an agency in solving a complex real-world problem (Peteva et al., 2021; Shivapaurkar et al., 2020). Problem-based learning (PBL) emphasizes the importance of student agency in learning. It rejects the traditional roles of instructors and students: Instructors are no longer required to transfer knowledge to students and students are no longer positioned as recipients of the transferred knowledge. Students are encouraged to exercise agency (or control) in constructing knowledge (i.e., self-directed learning; Hmelo-Silver, 2004) and instructors support their knowledge construction by offering scaffolding as needed (Hmelo-Silver et al., 2007). In other words, knowledge construction is primarily led by a student's "I need to know" not an instructor's "because you should know" (Lenz et al., 2014, p.68). It is the students who are responsible for determining and managing what and how they explore to complete the given problem in PBL.

Relatively recent research has focused on the role of student agency in pursuing a way of promoting transferrable knowledge, which results from 'deeper learning' (National Research Council, 2012). Deeper learning, defined as "the process through which an individual becomes capable of taking what was learned in one situation and applying it to new situations, can be effectively achieved in learning situations where students control their learning processes (p.5). In this regard, PBL is an effective way of facilitating student agency and promoting deeper learning. As a constructivist curriculum model, PBL provides students with a) an authentic task to engage with, b) cognitive and social challenges to grapple with for the best solution among alternative options, and c) opportunities for reflection on both learning processes and outcomes to apply what they have learned to other similar situations (Savery & Duffy, 1991). A substantial number of meta-analysis research on PBL

have reported that PBL is not only beneficial in acquiring content knowledge but also in improving various skills (i.e., application of knowledge), such as heuristics, problem-solving, decision-making, and/or self-regulative and metacognitive strategies (Dochy et al., 2003; Walker & Leary, 2009; Wilder, 2015).

1.2. Problems of PBL: Is more agency better?

For successful implementation of PBL, however, maintaining the balance in the degree to which students take the agency in learning is crucial. Sawyer and colleagues (2017)' experimental study addressed the dilemma of how much student agency can benefit students the most. According to their result, students who were allowed for low degree of freedom in controlling their learning gained greater learning outcomes than those with high degree of and no freedom in learning control, even though students in the condition of less freedom in learning control exhibited more unproductive behaviors in the process. Luo et al. (2019) also reported contradicting evidence to potential benefits high degree of student agency that students in low agency condition (e.g., teacher-led decision makings in in-class discussions and problem-solving in flipped classroom) outperformed other students in high and medium agency conditions. As moderating factors for the effects of level of agency on learning outcomes, they reported self-study time which may indicate diligence and student personality such as extroversion.

Similarly, other researchers have also delved into this dilemma and investigated what possibly impacts the effectiveness of student agency on learning outcome. For example, in hypermedia learning environments where students can explore the learning materials in multiple ways as they can control the learning pathways, several learner characteristics such as level of prior knowledge, self-regulation skills, and attitudes towards learning, etc., moderated the effectiveness of learner agency (Scheiter & Gerjets, 2007). Corbalan et al. (2011) also argued that level of students' perceived relevance with explicit task features can affect the effectiveness of student agency (or control) since the perceived personal relevance can facilitate students to use their prior knowledge to integrate new information within their schema.

In PBL, learning (or knowledge construction) occurs as students struggle and overcome challenges they face. However, not all students struggle productively as evidenced in numerous studies of scaffolding (Hmelo-Silver et al., 2007). Regarding this individual differences, students' recognition of their agency seems to take significant role in determining the productiveness of their struggles in PBL. Recently, Iwamoto et al. (2016) reported that students who highly recognized their agency in controlling the learning process outperformed others who showed relatively lower levels of perceived control over their learning. However, the investigations on the individual characteristics that affects the productiveness of student struggle have focused on students' cognitive, metacognitive, and regulatory processes in PBL, such as prior knowledge, self-regulation, attitudes, personalities, and perceived relevance with explicit task features as mentioned above (Scheiter & Gerjets 2007). Research on learner characteristics has not sufficiently addressed how students are aware of their agency and how different level of such awareness can affect the way they handle their agency. This is problematic given the fact that students' recognition on their agency and control may possibly affect how they exercise their agency and how well they learn from student-led learning contexts (Iwamoto et al., 2016).

2. The present study

Regarding learner characteristics in PBL, this paper suggests the concept of meta-agency as an essential characteristic of learners that affect the effectiveness of learner agency in PBL. This paper defines meta-agency as individuals' perception, recognition, and regulation about their agency that

affects the enactment and control of agency in learning. Having a meta-agency allows students to recognize the agency or controls that are given to them in learning processes and thus help them to proactively and persistently self-direct their learning.

As preliminary research on investigating how meta-agency affect the effectiveness of student agency in PBL, this paper conducts student interviews in online cybersecurity PBL sessions and attempts to qualitatively examine a) what features of meta-agency individual students experience and exercise in PBL and b) how students' level of meta-agency develops as they go through PBL sessions.

3. Theoretical framework

In sociology, researchers have defined agency across three dimensions: projectivity, practical evaluation, and iteration (Erimbayer & Mische, 1998). Arnold & Clarke (2014) adapted the three dimensionality to define student agency for educational research purpose: Individuals' capacity of taking actions purposefully to achieve their personal goals (i.e., projectivity), of evaluating potential actions for a given context using available resources (i.e., practical evaluation), and of selectively iterating discursive practices (i.e., iteration). That is, student can proactively evaluate and decide what to do next and selectively utilize classroom discourses to enact their agency in learning. Given this definition of student agency in learning, by meta-agency, this paper refers to students' perception, recognition, and regulation about their agency that affects the enactment and control of such capacities.

To explore how students experience and exercise meta-agency in PBL, this paper further operationalizes meta-agency in PBL, in which students control their learning to make sense of to-be-learned knowledge, across four dimensions: a) perceptions of productive struggle, b) expectation alignment between instructor and students, c) strategies for regulating agency, and d) familiarity with PBL tasks. The first two dimensions concern with knowledge variable, and the third dimension concerns with strategy variable, while the last dimension concern with task variable of meta-agency. Authors assume that students' characteristics across these four dimensions are closely related to and influence their perception, recognition, and regulation of agency in learning. Table 1 summarizes the features of and rationales for each dimension consisting of meta-agency.

Table 1
Features of and rationales for four dimensions of meta-agency

Related variable	Dimensions of meta-agency	Feature	Rationale
Knowledge about meta-agency	Perceptions of productive struggle	Students understand their experiences of struggle as <i>essential or adverse</i> components for productive learning.	Understanding the role of productive struggle in PBL affects how student perceive and recognize why they should enact agency and proactively face and overcome such struggles (Keen & Sevian, 2022)
	Expectation alignment between instructor and student	Students understand what the instructor's expectations and intentions are in providing students with agency.	Understanding instructors' intentions and trying to meet their expectations affects how students approach and persist through their roles and responsibilities in learning processes (Rovers et al., 2018)

Strategies for meta-agency	Strategies for regulating agency	Students can apply proper strategies to regulate their agency in learning processes.	For exercising meta-agency, strategies such as planning, monitoring, reflecting on, self-evaluating, and improving their agency should be properly applied in learning processes
Task-related variable	Familiarity with the PBL tasks	Students are familiar with the learning through solving problems, the to-be-learned contents, and the learning tools and technologies implemented (if any).	How much students are familiar with the PBL tasks (i.e., prior knowledge and experiences) affects the other dimensions of meta-agency (i.e., perception of productive struggle, expectation alignment, and strategies for regulating agency)

4. Methods

4.1. Context and participants

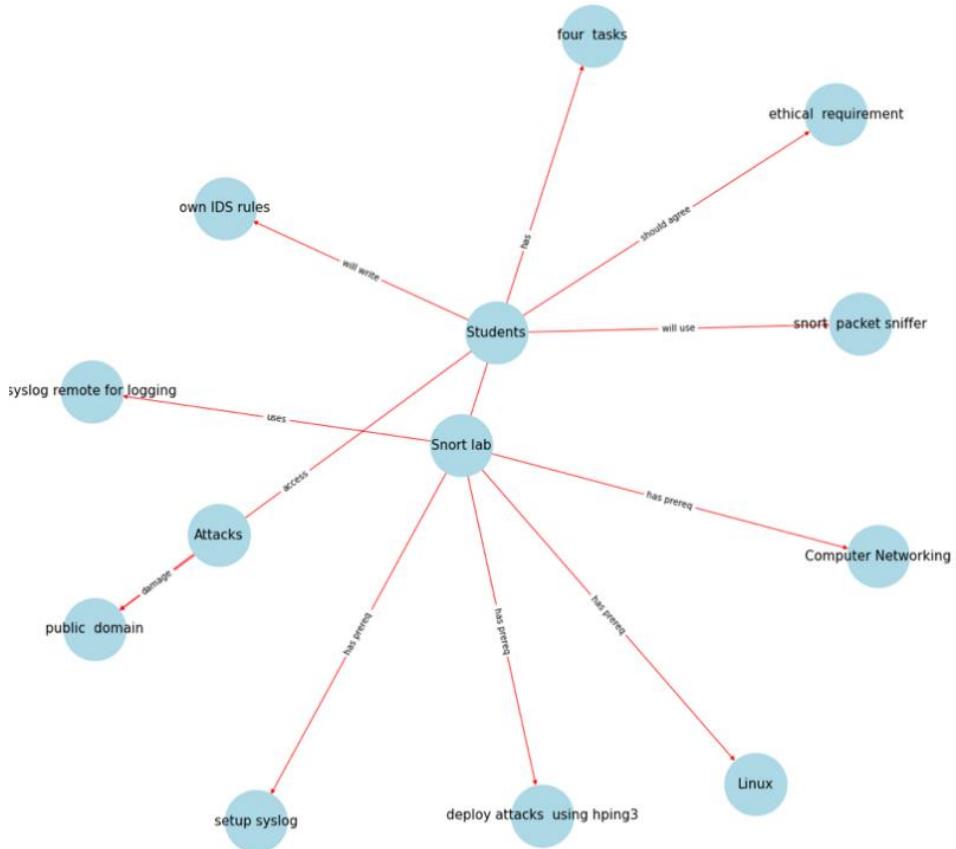
This study was conducted at two cybersecurity courses across two semesters at a large public university in Southwest United States: One in Fall 2021 semester and the other in Summer 2022 semester. Two different instructors taught at each course but implemented the same format of PBL sessions; three PBL sessions were implemented. 57 and 27 students enrolled in each course and 18 students (12 from the Fall 2021 and 6 from the Summer 2022) voluntarily participated in the after-course interviews.

4.2. Problems to solve and AISeKG

In PBL sessions, students were required to solve authentic complex problems of cybersecurity issues using computer programming skills (e.g., “Build an elastic application that can automatically scale out and in on-demand and cost-effectively by using the PaaS cloud”). Also, knowledge graphs, AI-powered knowledge structure representation tools, were developed for each PBL session and provided to students to scaffold their learning through problem-solving. The knowledge graphs for cybersecurity problem-solving, named AISeKG, were developed by using natural language processing techniques (NER) and relation extraction (RE) to extract the components and relations in knowledge structure. Figure 1 shows an example of AISeKG offered in PBL sessions.

Figure 1

AISeckG representing knowledge structure associated with a PBL task



4.3. Data collection and analysis

Authors conducted online interviews with students after each PBL session via ZOOM. Out of 18 students, 8 students participated in both rounds of interview. The interviews were transcribed for analysis. The constant comparative method based on the grounded theory approach was applied to analyze the interview data (Boeije, 2002) and generate a coding book whose categories include positive and negative experiences, suggestions, and learning strategies.

Then, authors then reexamined the interview data by applying a micro-level analysis (Atkinson et al., 2011). Based on the theoretical framework presented earlier (see Table 1 above), we first explored students' experiences in terms of the four dimensions of meta-agency: perception of productive struggle, instructor-student expectation alignment, strategies for regulating agency, and familiarity with PBL tasks. Regarding the first research question, additional features of each dimension were identified and added in the framework during the analysis process.

Lastly, authors incorporated the four dimensions with added features during data analysis into a meta-agency rubric to further analyze the quality (or level) of students' meta-agency, which was inferred from their experiences shared during the interviews. Table 2 presents the Meta-agency Rubric generated and used during the analysis process. For each PBL session, students' levels of meta-agency across the four dimensions were measured according to the rubric to answer the second research question.

Table 2
Meta-agency rubric in PBL

Dimensions of meta-agency	Level 1 (0 ~ 2)	Level 2 (3 ~ 4)	Level 3 (5 ~ 6)
Perceptions of productive struggle	Students do not understand the value and role of their experiences of struggling in PBL	Students understand the value and role of their experiences of struggling, but do not engage with struggling by avoiding/ignoring such moments in PBL	Students understand the value and role of their experiences of struggling and proactively engage with struggling in PBL
Expectation alignment between instructor and student	Students do not understand what instructor's intention was in letting students lead the learning processes in PBL	Students understand what instructor's intention was in letting students lead the learning processes, but they do not want to enact their agency in PBL	Students understand what instructor's intention was in letting students lead the learning processes and enact their agency as expected by instructors in PBL
Strategies for regulating agency	Students do not employ strategies to regulate their agency at all in PBL	Students employ ineffective strategies to regulate their agency (e.g., reflecting on their agency when such regulations are not necessary)	Students employ effective strategies to regulate their agency (e.g., monitoring and reflecting on their agency in the planning phase or in the face of struggles, and make changes on their agency if necessary)
Familiarity with the PBL tasks	Students are not familiar with the cybersecurity problem and AISeKG	Students are moderately familiar with the cybersecurity problem and AISeKG	Students are familiar with the cybersecurity problem and AISeKG

5. Results

5.1. Features of each dimension of students' meta-agency in PBL

Four dimensions of meta-agency outlined in the theoretical framework were explored by micro-level analysis of student interview data. As a result, additional features for each dimension were identified. Table 3 summarizes the identified features and corresponding statements of students.

Table 3
Identified features for each dimension of meta-agency and associated statement examples

Dimensions of meta-agency	Feature	Example of student statements
Perceptions of productive struggle	Students in PBL <ul style="list-style-type: none"> Understand that they should encounter difficulties and challenges in their exploration for better learning outcomes (i.e., the role of productive struggle) 	Nori: <i>"I've always believed that, that for any effort understanding any concept really well, if you put it to use if you do something practical with it. You would learn more. So I guess having that challenging assignments, the projects, it sort of help me understand"</i>

	<ul style="list-style-type: none"> • Chose to struggle, rather than avoid, the challenges to make progress in their learning. • Do not see potential productiveness if the problem is not authentic 	<p><i>things in a better way, so I feel that it was necessary for me to learn more.</i></p> <p>Harry: “<i>(...) but I also felt it was unproductive because in a real application you don't do that, and you basically use... you don't link them together in the way that we link them together it just doesn't make sense in a real application.</i>”</p>
Expectation alignment between instructor and student	<p>Students in PBL</p> <ul style="list-style-type: none"> • Understand students, not instructors, should direct and control the learning processes • Understand instructors are always available as facilitators, not lecturers, to help them when they need supports 	<p>John: “<i>I think this might be the like kind of the professor of like sharing the knowledge and experience of like previous basis to have with us so that we can solve those issues for ourselves that we might face the same issues</i>”</p>
Strategies for regulating agency	<p>Students in PBL</p> <ul style="list-style-type: none"> • Monitor and reflect on how they are exercising their agency and make judgements if adaptations are needed • Revise current strategies and/or enact new strategies to exercise their agency properly and effectively 	<p>Henry: “<i>My whole idea of like I did face a lot of difficulties like I said I did not find this assignments to be easy, they were difficult so for every single error that I was facing while running the codes. While applying these I had to sort of understand where I was going wrong, so my approach to this is always I mean it's been the same vibe like for other assignments related to programming as well. We try to distinguish what exactly the error is, what exactly is causing the error. Once we found find out what is causing that, then we could go search for how to fix it.</i>”</p>
Familiarity with the PBL tasks	<p>Students in PBL</p> <ul style="list-style-type: none"> • Being able to recall prior experiences and knowledge associated with the problem and learning environments/tools 	<p>Smith: “<i>(...) because I already had experience in the individual project so that's why I was much more confident in that project. They're big projects too, so I also get a lot of confidence and a lot of my knowledge base was sharpen and understood...</i>”</p>

5.2. How students' level of meta-agency develops across PBL sessions

With data from eight students who participated in both rounds of interview, this study examined how their level of each construct of meta-agency develops when they went through two PBL sessions. Meta-agency level was assessed using the meta-agency rubric whose scores range from 0 to 6. Figure 2 present how the scores of meta-agency changed from project 1 to project 2 for each student.

Figure 2
Students' meta-agency scores assessed after projects 1 and 2



6. Conclusion and future research

This study explored the four dimensions of meta-agency through theoretical examination and qualitative analysis of student interview data collected from cybersecurity PBL sessions. The findings of this study contribute to both theory and practice of cybersecurity PBL. First, problems of PBL have been investigated in terms of student agency. While previous research has focused on students' cognitive, metacognitive, and regulatory processes that affects the efficacy of PBL, this study gives theoretical implications on the conceptualization of meta-agency: How students are aware of the role of productive struggle, and of instructors' intentions, how they exercise their agency, and how familiar they are with PBL tasks and learning tool (i.e., AISecKG in this study). Also, it was an intriguing finding that most students perceive their struggling experiences are essential for productive learning, while some students recognize it unproductive when they think that the problem itself or the problem-solving process does not align with real-world practices in cybersecurity. Thus, it can be suggested in practice that designing authentic PBL tasks are one of the crucial factors that influence the effectiveness of students' agency in cybersecurity PBL.

Acknowledgement

This work was supported by the National Science Foundation under Grant No. 2114789. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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