An AI-Enable Knowledge Graph and Student's Agency in Productive Struggle During Problem-Based Learning in Cybersecurity Education

Inging Ratrapee Techawitthayachinda, Arizona State University, United States
Yuli Deng, Arizona State University, United States
Zhen Zeng, Arizona State University, United States
Huan Liu, Arizona State University, United States
Ying-Chih Chen, Arizona State University, United States
Dijiang Huang, Arizona State University, United States

The IAFOR International Conference on Education in Hawaii 2022
Official Conference Proceedings

Abstract
Problem-based learning (PBL) is adapted to support students' learning in cybersecurity courses. However, students frequently lack learner agency and require step-by-step instruction. With an instructor's minimum help, students struggle with integrating coherent target concepts, applying those concepts to solve real-world problems, and managing their learning progress. To respond to the national challenge on the workforce development in AI for Cybersecurity, we propose a novel AI-enabled CyberSecurity knowledge graph (AISecKG) in the hands-on labs to simulate real-life cybersecurity scenarios, support students to engage in productive struggle, and enhance learner agency in Cybersecurity problem-solving. We interviewed twelve students after two projects to understand what dimensions affect their learner agency and if AISecKG, an AI-enabled knowledge graph, help them develop learner agency in solving Cybersecurity problem. The results reveal four dimensions of learner agency in problem-solving: productive struggle during the projects, alignment between instructor and student expectation, familiarity with the PBL tasks, strategies for sensemaking. The rubric scores showed that students used AISecKG in productive struggle, alignment between instructor and student expectations and sensemaking strategies and generally improved their learner agency after the second project.

Keywords: Knowledge Graph, Student's Agency, Problem-Based Learning, Cybersecurity Education

Introduction

Cybersecurity education is mostly problem-based learning (PBL) in nature. Cybersecurity issues usually involve complex, multifaceted real-world problems that demand students actively engage in productive struggle, adopt an adaptive learning strategy to identify problems and solutions, evaluate and manage their learning progress. However, traditional lecture-based instruction is insufficient in engaging students in real-world problems and hands-on experience and systematically providing effective guidance for students to build their understanding from diverse learning history and backgrounds. Leaning results are often composed of fragmented information, and students lack problem-solving transferability in the new contexts. Without the instructor hand-holding students through step-by-step instruction, students have difficulty developing their agency to advance their problem-solving process.

The roles of learner agency on learning have been explored as a critical factor for learning success. Learner agency has defined as, for example, an individual's will and capacity to act (Gao, 2010) and learners' capacities for autonomous, self-regulated behavior (Bown, 2009). Manyukhina and Wyse (2019) conceptualize learner agency into 1) learners' personal sense of agency (i.e., belief in their ability to make changes in their learning and 2) learners' agentic behavior (i.e., the actual acts to take active control in their learning process). Recently, many researchers adopted complexity theory and situate learner agency in a complex dynamic system, beyond just students, and their cognitive and willpower control (Manyukhina & Wyse, 2019). This paradigm takes a more balanced view between students and learning space as they co-exist and view equal significance in both the individual and the context (Blaschke, Bozkurt, & Cormier, 2021; Mercer, 2011).

Building on our previous work, we implemented state-of-art technology to create environments and networks that promote learner agency (e.g., Deng, Lu, Hung, Chung, & Lin, 2019). We propose AISecKG, an AI-enabled knowledge graph, to enhance learner agency and address cybersecurity education challenges. AISecKG was built based on an interdisciplinary approach to address the identified cybersecurity education challenge in two highly interdependent research focuses: 1) employ ML/AI approaches to build new cybersecurity guidance by measuring and setting up similarities and dependencies among cybersecurity learning targets (or problems) that can be used for both study planning and learning-outcome assessment; and 2) design an effective learning outcome measurement framework to design cybersecurity curricula, scaffold student cognitive engagement, and improve students' learner agency and learning outcomes through a multi-level assessment approach.

This study examines students' learning experience in AISecKG, the critical components of learner agency, and whether AI for Cybersecurity can improve learner agency. With the notion that individuals as learning agents can *interact* with their contexts, rather than just *react* to them (Mercer, 2011), AISecKG provides an active learning environment expected to create active learners and agency in problem-solving. AISecKG enables self-directed, connected network learning to support students in developing the authorship of their problem solving -- actively taking control, monitoring, and progressing their learning. That AISecKG guides the active problem-solving (i.e., local agency) support students encountering struggles for deep understanding, managing their learning process, gradually developing sustainable problem-solving transferability (i.e., global learner agency).

Methodology

Research Design

This study is conducted at a cybersecurity course of a public university located in the Southwest United States. Fifty-seven students are enrolled in the course. Students are required to engage in two PBL projects that address real-world complex problem scenarios with the support of a virtual lab environment and AISecKG scaffold. Twelve students were selected for interviews at the end of the first project. The same set of students, but eight, remained for interviews at the end of the second project to understand their initial perceptions and changes in their learning experience and strategies when using AISecKG.

AISecKG - Knowledge Graph

At the beginning of the semester, we introduced AISecKG to support students in solving the problem on the given projects. AISecKG is an integrated machine learning (ML) and artifact intelligent (AI) and cybersecurity knowledge graph to generate learning-related and domain-specific knowledge. We used our existing AI and cybersecurity projects and lab descriptions to create problems to concepts mapping, in which each task and subtasks are converted to a problem. We can then use Natural Language Processing (NLP) to extract concepts embedded in the corresponding task and subtask description. Using AISecKG, we can perform a learning material indexing and correlation procedure by creating individual hands-on labs' subgraphs of AISecKG (represented as subKG). A subKG presents each lab's main learning concepts, with which we can present its correlations (i.e., concepts overlapping) with other labs. In this way, we can present a three-level knowledge representation from the top course project (or lab) to a set of problems and concepts at the bottom.

Analysis

After each project, we interviewed twelve students with Zoom video conference. The interviews were transcribed into texts for further analysis. We utilized the constant comparative method based on the grounded theory approach to develop the coding book iteratively. The final coding book captures positive experiences, negative experiences, suggestions, and learning strategies. Based on the coding book, we closely examine what learning aspects support or hinder students' learner agency – the ability to control actively, monitor, and progress their learning.

The exhaustive examination of the coding book reveals the four dimensions of learner agency in problem-solving. Whether students will be able to solve the problem and actively control their learning progress depends on 1. productive struggle during the projects, 2. alignment between instructor and student expectation, 3. familiarity with the PBL tasks, and 4. strategies for sensemaking. *Productive struggles* demonstrate how much students engage in productive problem-solving struggles when they encounter difficulty. *Alignment between instructor and student expectation* is defined by the gap of the learning process and project product expectation between instructors and students. *Familiarity with the PBL tasks* indicates how much students are familiar with and feel comfortable with cybersecurity domains or knowledge graphs. *Strategies for sensemaking* involve students' strategies to make sense of problems and overcome them.

Learner Agency Rubric

We later incorporated the four dimensions into Learner Agency Rubric to advance theory on learner agency and assess students' learner agency progress after using AISecKG in the two projects in the cybersecurity course. Each dimension was further defined and assigned a score ranging from 1 to 3. A score of 1 means students are at the beginning of that given dimension and have a large area of learner agency growth. A score of 2 means students become authorship of their learning, but some learning aspects are underdeveloped. A score of 3 indicates that students demonstrate the desired level of learner agency. After engaging in productive struggle during problem-solving, students are expected to have a realistic alignment with instructors, feel familiar/confident with the problem solving and knowledge graph, and use high-level strategies to solve problems. The full definition of the rubric is below (See Table. 1)

Dimensions	Basic (1)	Transition (2)	Advance (3)
Productive Struggle	Students engage in **unproductive struggles** that do not facilitate learning and need to **remove** them	Students engage in **unproductive struggles** that do not facilitate learning, but they can **be productive struggles** with instructional design. Students engage in **some productive struggles**	Students engage in **productive struggles** as they involve the below problem-solving process when they encounter difficulties such as: 1. Identify problems/ knowledge gap 2. Explore potential solutions 3. Evaluate all solutions to identify the best one 4. Apply knowledge to the new situation Students realize what they learn from the struggles and **appreciate** the learning opportunity stemming from difficulty.

Alignment between instructor and student expectation	Student expectation on learning process and products does **not alight** with an instructor	Student expectation on learning process or products does **not alight** with an instructor	Student expectation on learning process and products **alight** with an instructor
Familiarity with the PBL tasks	Students are **not familiar** with Cyber Security domains or knowledge graph	Students are **moderately familiar** with Cyber Security domains or knowledge graph	Students are **familiar** with Cyber Security domains and the knowledge graph.
Strategies for Sensemaking	Students use **low-level strategies** to engage in **unproductive struggle.**	Although students use **high-level strategi**es to solve problems, they engage in **unproductive struggle.**	Students engage in **high-level strategy**, use several strategies to solve the problem, and engage in **productive struggle**.

Table 1: Learner Agency in Problem Solving Rubric

Results

Problem-Solving Experience with AISecKG Support

The results showed that students positively consider that the struggles with the support of AISecKG help them develop a deep understanding of cybersecurity knowledge through PBL. The design of AISecKG guides students in the global view of learning paths, which indicate concepts and their relationship in given problem domains. AISecKG facilitates students to recognize, identify, conceptualize, and integrates all necessary cybersecurity concepts needed to solve the problem as students commented that:

It's very helpful because it gives like the student a hint on what he is about to do. And what is expected and, like the areas that he is supposed to be not knowledgeable but should be

I found to be extremely helpful, I definitely was able to use the knowledge graph to see like okay here are the concepts that I need to know.

And I had that open and then I also had this knowledge graph open another window, so that I could like if I saw something in the IP you know, in the IP tables lab document I could go to the knowledge graph, and it would quickly take me to the wiki link with a few clicks that was that was pretty convenient.

I pull knowledge graph up real quick, so I can actually have a visual reference to it because I did use it throughout the labs.

Students also use the connected network and multimedia in AISecKG to enhance their learning, such as correcting their misunderstanding and expanding their knowledge from what has been learned in the course to what has been practiced in authentic cybersecurity settings. These behaviors driven by AISecKG are associated with active learning or what we defined here as an immediate, local learner agency. This kind of local learner agency happens when students manipulate information and control their learning process to promote their global learner agency in productive struggle through problem-solving as students asserted:

yeah for me the video tutorials where we're more helpful.. I was formatting it incorrectly from the text.. just in general, if I learned a lot better through something that is visual like a video
One of the things that I would like is, you know how there's a little hyperlink on the far right there's a little circle to expand it if that was changed to just.

Go back and just click on this little link right here and immediately go back and see what is that, how do I use this, how do I implement this.

Go to the knowledge graph and it would quickly take me to the Wiki link with a few clicks that was that was pretty convenient

The sense of agency can be sustained and flourished if students are aware, own to their actions, and appreciate their ownership, as students mentioned:

It makes us more confident on doing the next lab because we've debugged all everything, we did everything by ourselves, this is our work, this is our understanding.

Learner Agency Progress

We interviewed twelve students to develop Learner Agency in Problem Solving Rubric. The rubric has two-fold benefits 1) theoretical advancement to identify the critical components of learner agency in problem-solving and 2) measurement construction to evaluate students' learner agency and their progress.

The rubric scores from the eight students on interview after 1st project and 2nd project showed that at the end of 2nd project, students have the closer expectation to an instructor, engage in more productive struggle, and employ high-level strategies to solve a problem during a productive struggle (See Figure 1). Students reported the learning process and outcomes alignment between student and instructor expectations. They expect less spoon-feed support from an instructor and invest their time in productive struggle, trying to overcome challenges while learning from the struggle. Also, they have a better understanding of outcome expectations and can concretely visualize the expected artifacts/products. The excerpts below demonstrate Josh's.

Project1_Josh*: "I feel less confidence in my execution, and so I was just* ***having a lot of struggle understanding what I was supposed to turn in"*** *(Score 1)*

Project2_Josh*: "I definitely was able to use the **knowledge graph** to see like okay here are the **concepts that I need to know**. All of the it's almost like if you were **baking cake,** it's like I want you to bake the cake here's **what the final thing should look like**. And I have a **general understanding** okay it's a cake, so it probably need sugar it probably needs flower, but then it's my job to go out and find. How does all of this work together." (Score 3)"*

Although students got lost in the first project, spent the most time figuring out what they needed to do, and spent less time working on problem-solving, they later developed high-level strategies to handle challenges and learn from productive struggle. Students described that they get lost in the first project since they are uncertain about what they are doing, what they need to do, for what reason, and what outcomes may happen. Thus, they rely on lower strategies such as trial-and-error and reread materials. However, after they started to use AISecKG, they utilized the knowledge graph to productively handle the struggle, such as problematizing, identifying concepts needed to solve a problem, and developing solutions.

*Project1_Sony: This lab was to open, I mean, for me it was like too broad, I should say so **it was really hard to get what I was doing** the beginning, which was to like really long time to figure out what I was actually need to do" (2)*

*Project2_Sony: It sort of direct me to the answers. Like if I know my question and I know my answers, but if I don't know my question like sometimes I just stuck on something, but I don't really know what's, the problem is, **then I have to figure out the problem first**" (Score 3)*

*Project 1_Nadia: "Actually I didn't make it too much use of the knowledge graph. **I read lecture slides again**, if I have any problem." (2)*

*Project 2_Nadia: "I got stuck would check the knowledge graph and see **if I miss something**.. that can help me understand **different levels of knowledge** is I mean just just look at just like what to the knowledge graph." (3)*

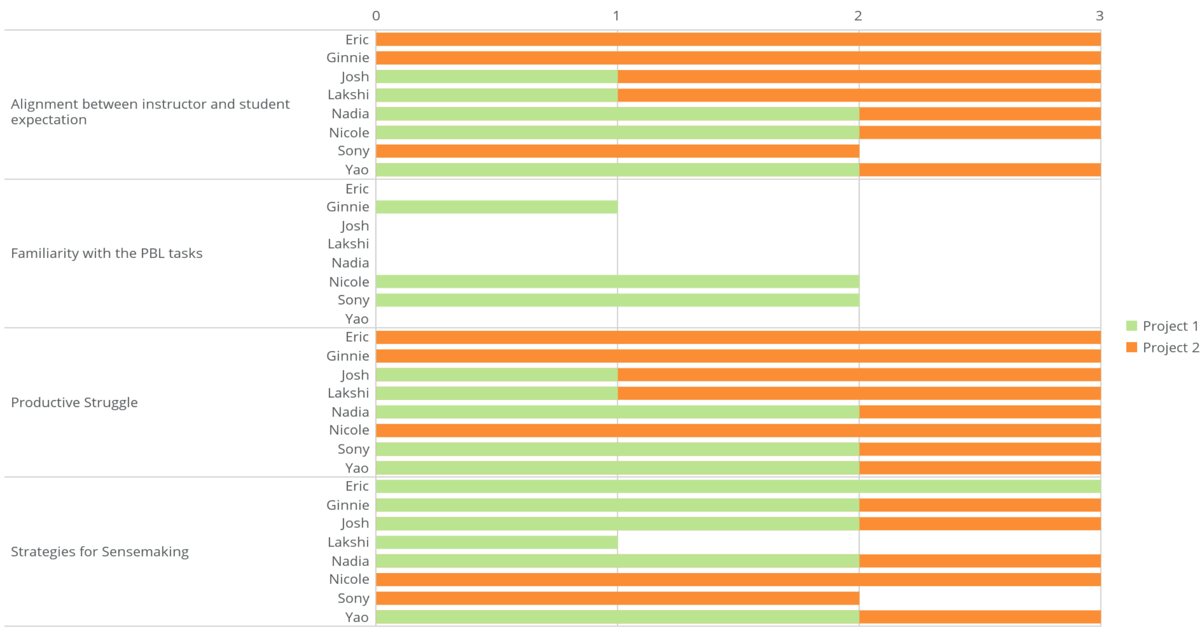

Figure 1: Learner Agency Progress

Conclusion

The learner agency influence students' experience, process, and outcomes. We found that productive struggles, alignment between instructor and student expectation, familiarity with the PBL tasks and strategies for sensemaking involve in students developing learner agency in problem solving. The rubric scores showed that students using AISecKG in productive struggle and sensemaking strategies generally have a closer alignment with an instructor's expectations and improved their learner agency after the second project.

Acknowledgement

This research is supported by the National Science Foundation under grants DGE-1723440 and 2114789.

References

Blaschke, L. M., Bozkurt, A., & Cormier, D. (2021). Learner agency and the learner-centred theories for online networked learning and learning ecologies. *Unleashing the Power of Learner Agency*.

Bown, J. (2009). Self‐regulatory strategies and agency in self‐instructed language learning: A situated view. *The Modern Language Journal*, *93*(4), 570-583.

Deng, Y., Lu, D., Huang, D., Chung, C. J., & Lin, F. (2019, May). Knowledge graph based learning guidance for cybersecurity hands-on labs. In *Proceedings of the ACM conference on global computing education* (pp. 194-200).

Gao, X. (2010). *Strategic language learning: The roles of agency and context*. Clevedon: Multilingual Matters.

Manyukhina, Y., & Wyse, D. (2019). Learner agency and the curriculum: a critical realist perspective. *The Curriculum Journal*, *30*(3), 223-243.

Mercer, S. (2011). Understanding learner agency as a complex dynamic system. *System*, *39*(4), 427-436.

Contact email: ratrapee@asu.edu