Supporting Collaborative Problem Solving in a Game-Based Learning Environment

Asmalina Saleh, Yuxin Chen, Cindy Hmelo-Silver, Krista Glazewski
asmsaleh@iu.edu, yc58@iu.edu, chmelosi@iu.edu, glaze@iu.edu
Indiana University

Bradford Mott, Robert Taylor, Jonathan Rowe, James Lester
bwmott@ncsu.edu, rgtaylor@ncsu.edu, jprowe@ncsu.edu, lester@ncsu.edu
North Carolina State University

Abstract: In this Special Interactive Session demonstration, we present our story-centric game-based learning environment, CRYSTAL ISLAND: ECOJOURNEYS, to highlight how the design is informed by problem-based learning (PBL), a constructivist instructional approach driven by an inquiry framework. We present key features of CRYSTAL ISLAND: ECOJOURNEYS: 1) the interactive story, 2) the whiteboard, and 3) the collaboration scaffolds, and discuss trace data of student interactions as they engage in the story and contribute to the chat and whiteboard tool. In line with CSCL 2019's theme, our design of the game highlights a complex ecosystem that illuminates how aligning tools in the game and a social-constructivist approach to learning, while challenging, was instrumental in supporting student learning.

In problem-based learning (PBL), students work in small groups to address ill-structured problems, drawing on individual's, peers', and instructor's expertise. Game-based learning environments, especially those that feature rich narratives, have the potential to engage students in such problems and support the development of expertise. In line with CSCL 2019's theme of 4E learning, collaborative games provide a complex ecosystem that allow students to learn by doing (i.e., *embedded* learning) and to distribute cognition or *extend* expertise via scaffolds that both support and take on this expertise (Quintana et al., 2004). This, in turn, allows us to understand the *enactive* nature of learning. However, there are some tensions in designing collaborative games that draw upon PBL. One challenge is the relatively open-ended inquiry of PBL environments compared to the well-ordered yet complex problems in traditional games (Adams et al., 2012). Another challenge is how to support synchronous collaboration in the classroom and to augment facilitation through both agent-based and human-based scaffolds. Finally, there is also the issue of aligning tools in the game and our commitment to a social-constructivist approach to learning. How can we account for these epistemological commitments in our design of the tools in the game, such as the narrative or a virtual whiteboard? In this demonstration, we present CRYSTAL ISLAND: ECOJOURNEYS, and share how we addressed these tensions in our design. We highlight how designing for synchronous collaborative interactions can be supported by providing well-ordered interactions that align to the PBL inquiry cycle and provide agency by supporting negotiation in the problem-solving process. By integrating our design with principles of PBL, we were able to leverage advantages associated with the immersive, interactive and narrative nature of games coupled with a pedagogy that has consistently shown benefits for deep learning.

Theoretical Motivations

Problem-based learning is an instructional approach that has its origin in social-constructivist assumptions of learning, namely, the interactional nature of learning, cognitive puzzlement, and social negotiation (Savery and Duffy, 1995). A PBL classroom typically consists of students utilizing peer expertise and instructor facilitation as they work in small groups to solve problems (Hmelo-Silver, 2004). During the PBL process, students define and identify learning issues under the assistance of facilitators. To support inquiry, students often utilize a collaborative tool, *a PBL whiteboard*, that allows them to share ideas and track their progress. Facilitators and tools such as the whiteboard constrain and support students' inquiry and encourage students to take ownership of the learning process and develop solutions.

When designing a collaborative game-based learning environment, designers need to balance student agency, immersive inquiry, and the need for complex but relatively well-defined problems. This is especially salient in story-centric games that poses a 'narrative paradox' (Louchart & Aylett, 2003), which consists of maintaining authorial control over story development while providing players a sense of agency. However, challenges occur when leveraging PBL with game-based learning (GBL). First, while students' individual learning can be negatively influenced by an increased immersion in the narrative (Adams et al., 2012), we do not yet know the extent to which social regulation and collaboration can address this observation. Secondly, because of documented beneficial

outcomes associated with social-constructivist frameworks of learning, it is crucial to support the development of student content expertise in ways that might lead to successful and meaningful problem solving. Moreover, we had to attend to the nature of collaboration: what were the advantages and disadvantages of synchronous collaboration? Further, how can intelligent-based agents support collaboration and the teacher, as well as mitigate the issue of differential student progression as it relates to collaboration? Finally, designing for ill-defined problems also means attending to complex rules that underpin game mechanics, which lead to a delicate balance between the principles of constructivism such as providing agency yet maintaining pre-determined paths to support learning analytics and assessment.

CRYSTAL ISLAND: ECOJOURNEYS

With these considerations in mind, we developed the CRYSTAL ISLAND: ECOJOURNEYS prototype learning environment, which allows for rapid development of collaborative problem-solving scenarios. In the prototype, students are presented with 2D representations of locations and characters as they progress through the story. Students participate in the story by navigating to locations, interacting with characters through branching dialogue, and completing activities related to the problem-solving scenario (Figure 1). The prototype environment collects fine-grain behavior logs of all student interactions within the environment. For example, trace data recorded by the environment includes information such as how long students spend on each task, which dialogue options were selected while interacting with characters, and whether students completed an activity.

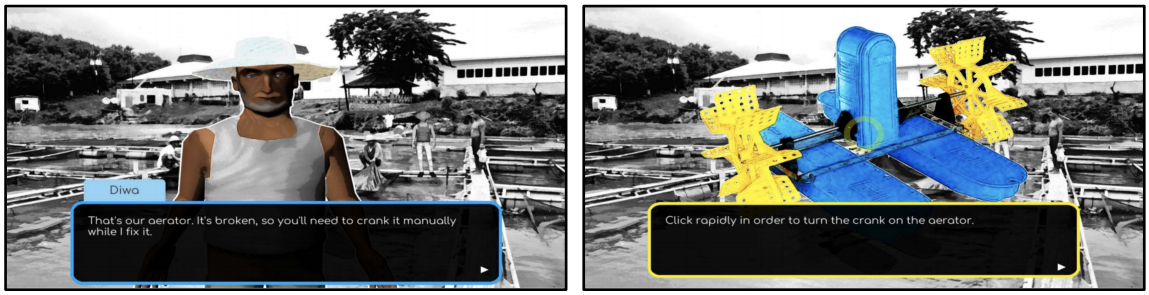

Figure 1. Interacting with character and objects in the prototype learning environment.

To include the PBL inquiry cycle in the design, the team focused on two elements: the narrative and a collaborative PBL whiteboard to support team development of hypotheses linked to evidence. Figure 2 provides an overview of student progression in CRYSTAL ISLAND: ECOJOURNEYS narrative and the interactions that they have through chat and the whiteboard. To ensure that students developed different expertise, we assigned students to interact with various stakeholders within the narrative who had different information to share. To ensure that students all had access to critical pieces of information, critical data was provided to at least two students (i.e., similar data sets and facts).

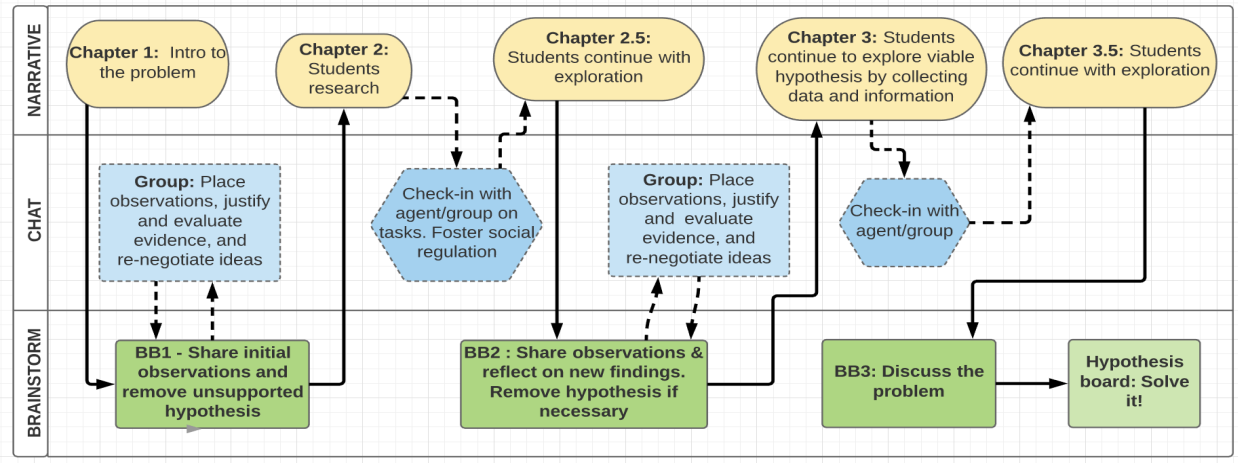

Figure 2. Overview of the narrative structure and activities in CRYSTAL ISLAND: ECOJOURNEYS.

To support students' progression through the narrative, the team also developed an in-game whiteboard (Figure 3). In the game, students interacted with a virtual whiteboard, which was designed to support the following interactions between a small group of students: 1) sharing information, 2) selecting which pieces of information could be used as evidence to support specific hypothesis, 3) evaluating the evidence by stating which pieces of evidence support, does not support, or might support a given hypothesis. These interactions were heavily shaped by the PBL inquiry process. To support sensemaking, we designed an agreement indicator. If all students in the group agree that the evidence supports a given hypothesis, the evidence will turn green. If a piece of evidence has not yet been evaluated, it remains orange, and if there is disagreement, it will turn red. Students must negotiate and resolve any disagreements related to the evidence using in-game chat. Similarly, students must also justify why the team agrees. After each round of data collection (i.e., end of each chapter as depicted in Figure 2), students decide if they should remove any hypotheses that do not have supporting evidence.

It should be noted that the design of the whiteboard took several iterations; we conducted a series of focus group studies and small classroom pilot studies to understand the nature of student interactions with the whiteboard for over a year. In the first iteration, the whiteboard tasked students with generating an explanation by creating a model. In that version, students utilized the Phenomenon-Mechanism-Component framework (Hmelo-Silver, Jordan, Eberbach & Sinha, 2017). This meant that the focus of collaboration was around the content rather than the process of knowledge building. From these studies, we found that students could develop their models but needed a lot support in managing the process of creating the model.

Because the process of inquiry is critical in PBL, we then shifted to using a KWL chart (Know, Want to Know and Learned; Ogle, 1986) in a subsequent classroom study. In this iteration, we also examined how a human facilitator can support student interactions in the chat interface especially as they sort through information and attempt to solve the problem when using the whiteboard. Based on the findings from the classroom study, we sought to support the process at the whiteboard by integrating the PBL steps as part of the whiteboarding experience (i.e., share, discriminate, evaluate, and negotiate). In hindsight, our initial challenge was the lack of alignment in the development of the whiteboard (i.e., model-building rather than integrating the inquiry process). Thus, in our work, one advantage of integrating the PBL inquiry process into the whiteboard was that the current whiteboard design support ed collaboration, managed group regulation and provided agency.

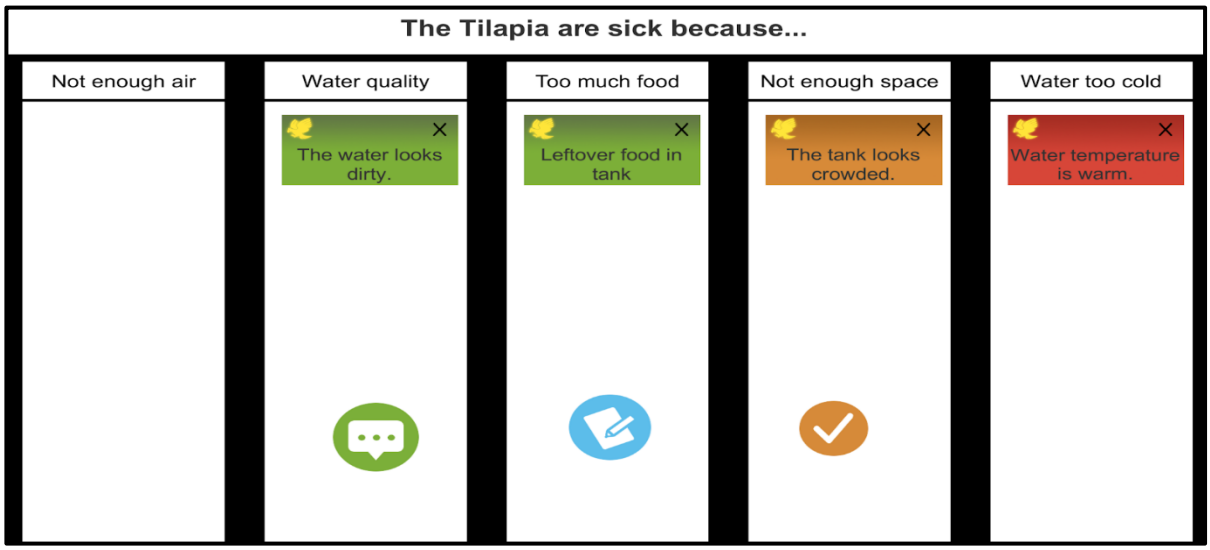

Figure 3. An overview of game features; the whiteboard, chat (green chat icon), student notebook (blue journal icon), and the task list (checkmark icon).

Our approach towards designing the game by supporting agency when using the whiteboard is different than story-centric games. In story-centric games, the focus is to provide players with agency by authoring the narrative in such a way that players choices' have consequences. Our approach was to ensure that students have access to the information that they need in the story, but otherwise allow them freedom to make mistakes as they evaluate different hypotheses when using the whiteboard. As students progress in the relatively linear story, the game does not provide students with any hints about the correct answer. Instead, there are prompts asking students to depend on their peers, by regulating and managing the group goals and learning outcomes. However, it is also critical to note that the game

currently tracks students' problem-solving behaviors through trace data, and provide updates about student collaboration and learning progress via a teacher dashboard that is currently under development. The team is currently in the process of creating the teacher dashboard and hope that the interactive session will allow us to solicit feedback on its design.

Another important element that we have attended to in our design is the attention to the nature of facilitation. In adaptive collaborative learning systems, the focus is to scaffold individual students as they complete tasks. In our design, we extend this system to include the classroom ecology. Although we will be gathering facilitation data to eventually train an automated agent to support collaboration, we also designed specific participant structures in the classroom to provide more support for teachers and students. We adopt a jigsaw approach, wherein students have access to two groups, 1) an expert group in a physical setting and 2) work online with their in-game team. The in-game team consists of students who have met different in-game characters. On the other hand, the expert groups provide additional opportunities for students to engage in group regulation processes and to support them in the fact-finding process. Similar to the brainstorming board interactions, these groups are not explicitly constrained but are instead asked to make sure that students support each other as needed.

Significance

Our work highlights how we embedded the PBL inquiry cycle into two game elements, the narrative and in-game whiteboard. Because of the value of synchronous interactions in the PBL process, we ensured that progression through the narrative would not hamper students' collaboration at the whiteboard. Specifically, students are encouraged to review the tasks via their task checklist and support re-distribution of tasks as necessary. Moreover, based on our recent data collection, the PBL-inquiry steps that students undertake at the whiteboard also supported students' process management and more importantly, productive discussions without constraining their agency. While there were challenges in designing these interactions, our commitment to PBL, a social-constructivist approach to learning ultimately helped shaped the nature of students' collaborative problem-solving in productive ways.

Technology Platforms Supported

Given that CRYSTAL ISLAND: ECOJOURNEYS is delivered through the web and designed to be played in a web browser, we will only need Internet access through a wi-fi access point to demonstrate the game on between 2 to 6 laptops. Further, CRYSTAL ISLAND: ECOJOURNEYS is designed to support wide range of computers, such as Chromebooks, which mean that conference participants can use their own laptops to play the game.

Acknowledgements

This work is supported by the National Science Foundation through grants DRL-1561655 and DUE-1561486. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

Adams, D. M., Mayer, R. E., MacNamara, A., Koenig, A., & Wainess, R. (2012). Narrative games for learning: Testing the discovery and narrative hypotheses. *Journal of educational psychology*, *104*(1), 235.

Gee, J. P. (2005, June). Good video games and good learning. In *Phi Kappa Phi Forum* (Vol. 85, No. 2, p. 33). The Honor Society of Phi Kappa Phi.

Hmelo-Silver, C.E. (2004). Problem-based learning: What and how do students learn? *Educational psychology review*, 16(3), 235-266.

Hmelo-Silver, C. E., Jordan, R., Eberbach, C., & Sinha, S. (2017). Systems learning with a conceptual representation: a quasi-experimental study. *Instructional Science*, 45(1), 53-72.

Louchart, S., & Aylett, R. (2003, September). Solving the narrative paradox in VEs–lessons from RPGs. In *International Workshop on Intelligent Virtual Agents* (pp. 244-248). Springer, Berlin, Heidelberg.

Ogle, D. M. (1986). KWL: A teaching model that develops active reading of expository text. *The Reading teacher*. 39(6), 564-570

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., ... & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the learning sciences*, 13(3), 337-386.