Exploring Affect and Inquiry in Open-Ended Game-based Learning Environments

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Abstract. Guided inquiry-based learning has been proposed as a promising approach for science education. However, students may not automatically follow effective problem-solving strategies in open-ended learning environments. Prior work has examined the relationships between students' inquiry behaviors, content learning gains, and problem-solving outcomes in an open-ended, game-based learning environment for middle school science. This paper reports on a follow-up investigation of student affect during problem solving in the same game environment. Results show that students who gathered more background information during the early stages of in-game problem solving experienced increased excitement, reduced confusion, and reduced frustration compared to their late information-gathering counterparts. Given games' implicit goal of fostering engagement, these findings highlight the importance of scaffolding student problem solving in open-ended game-based learning environments in order to promote positive affect.

1 Introduction

Inquiry-based learning has been the subject of recent attention in both traditional classrooms [1,2] and intelligent tutoring systems [3,4,5,6]. In this approach, students take on a more active role in learning than in direct instruction. Students are encouraged to "discover" knowledge through exploration, formulating questions and hypotheses, gathering and analyzing data, and interpreting their observations [5]. Inquiry-based learning environments are often open-ended, and scaffolding is necessary for students to learn and apply effective problem solving strategies. Without adequate guidance, students have been shown to learn less effectively in inquiry settings [1,2]. However, adequately scaffolding problem solving in inquiry-based learning environments can yield substantial learning benefits [2].

Game-based learning environments offer a promising platform for inquiry-based learning because of their capacity to foster engaging interactive experiences and diverse problem-solving scenarios [7]. However, open-ended games are also vulnerable to the risks of insufficient guidance. In an effort to foster motivation and engagement, these environments may be designed to promote player agency by increasing player

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freedom and autonomy. However, too much freedom and too little guidance may lead to decreased learning gains. With appropriate guidance and scaffolding, game-based learning environments are poised to be effective inquiry learning tools [2,7].

This paper expands upon recent work examining student inquiry and problem solving in an open-ended game-based learning environment. CRYSTAL ISLAND is a game-based learning environment for middle school science in which students engage in inquiry behaviors such as gathering evidence, forming and testing hypothesis, and reporting conclusions. Prior work suggested that students who performed more information-gathering actions prior to conducting experiments in a virtual laboratory also achieved improved problem-solving outcomes compared to students who gathered information later in the game [8]. The work reported in this paper follows up on that work by examining how students' inquiry strategies are related to their affective outcomes in the game. The investigation highlights the importance of scaffolding inquiry in open-ended game-based learning environments in order to promote positive affect and engagement.

2 Background

Inquiry-based learning seeks to promote active learning in which students explore the relationships between variables and form their own understanding of science content. However, there is considerable evidence that inquiry-based learning is most effective under specific conditions. For example, there is evidence that students need to have a reasonable level of background knowledge in order to learn new material in an inquiry-based setting [1, 2]. For students without sufficient prior knowledge, inquiry environments can require too many cognitive resources, resulting in weaker learning. The steps of effective inquiry should also be scaffolded in order to avoid student floundering [1,2,5]. There is evidence that initial guidance of appropriate inquiry behaviors can lead to students showing improved inquiry skills in the future [5]. The finding that inquiry-based instruction can improve inquiry skills is important for motivating this as an effective method of teaching [5,9].

There have been several efforts to incorporate intelligent tutors into inquiry-based learning environments. Woolf et al. developed the inquiry environment *Rashi*, which supports inquiry skills in a variety of different domains including biology and geology [4]. Students use tools such as the inquiry notebook and hypothesis editor to record their observations, reason about their findings and support or reject hypotheses. *SimQuest* is another inquiry-based learned environment designed for the physics domain [6]. Students control simulations in order to conduct experiments and test hypotheses. In the *Invention Lab*, students are encouraged to "invent" equations that explain the relationships between variables [3]. Students are presented with cases where one or more variables are modified, and they are encouraged to discover the equation which explains the differences between the cases. River City and CRYSTAL ISLAND both embed inquiry-based learning in science mystery scenarios [5,10]. Students are encouraged to gather information about patient symptoms and possible contaminants in open-ended virtual worlds.

River City and CRYSTAL ISLAND comprise a notable class of inquiry-based learning environments that leverage digital game technologies to create rich exploratory, virtual environments. Game-based learning environments have been the subject of growing attention due to their capacity to combine the engaging features of commercial games with educational content and intelligent tutors [7,10]. In addition to scientific inquiry, game-based learning environments have been used for teaching negotiation skills [11], foreign languages [12], policy argumentation [7] and critical reasoning [13]. While game designs vary widely, some game-based learning environments are designed to be intentionally open-ended in order to foster player agency, and thereby motivation. Open-ended game environments can provide a laboratory for investigating students' inquiry behaviors within highly configurable and observable settings [7, 8].

Prior work examining students' inquiry behaviors in a game-based learning environment suggested that good inquiry strategies (e.g. gathering background information prior to formulating and testing hypotheses in a virtual laboratory) were not necessarily associated with improved content learning gains [8]. However, good inquiry strategies were associated with improved problem-solving outcomes. Conversely, students who did not use good strategies (e.g., gathering background information *after* formulating and testing hypotheses) were less effective at solving the overall task. These observations led to the hypothesis that individual differences in inquiry strategies may also be associated with differences in affective outcomes. In particular, emotions such as frustration and curiosity were anticipated to correlate with different inquiry behaviors.

3 CRYSTAL ISLAND Learning Environment

For the past several years, the authors and their colleagues have been designing, implementing, and conducting empirical studies with CRYSTAL ISLAND. CRYSTAL ISLAND (Figure 1) is an open-ended game-based learning environment built on Valve Software's Source™ engine, the 3D game platform for Half-Life 2. CRYSTAL ISLAND features a science mystery set on a recently discovered volcanic island. The curriculum underlying CRYSTAL ISLAND's mystery is derived from the North Carolina state standard course of study for eighth-grade microbiology. CRYSTAL ISLAND's premise is that a mysterious illness is afflicting a research team stationed on a remote island. The student plays the role of a visitor who recently arrived on the island in order to see her sick father. However, the student gets drawn into a mission to save the entire research team from the spreading outbreak. The student explores the research camp from a first-person viewpoint and manipulates virtual objects, converses with characters, and uses lab equipment and other resources to solve the mystery. As the student investigates the mystery, she completes an in-game diagnosis worksheet in order to record findings, hypotheses, and a final diagnosis. This worksheet is designed to scaffold the student's problem-solving process, as well as provide a space for the student to offload any findings gathered about the illness. The mystery is solved when the student submits a complete, correct diagnosis and treatment plan to the camp nurse.

Fig. 1. CRYSTAL ISLAND environment

To illustrate the behavior of CRYSTAL ISLAND, consider the following scenario. Suppose a student has been interacting with the virtual characters in the story world and learning about infectious diseases. In the course of having members of the research team fall ill, she has learned that a pathogen is an agent that causes disease in its host and can be transmitted from one organism to another. As the student concludes her introduction to infectious diseases by reading related books and posters, she uncovers a clue while speaking with a sick patient that suggests the illness may be coming from food items the sick scientists recently ate. Some of the island's characters are able to help identify food items and symptoms that are relevant to the scenario, while others are able to provide helpful microbiology information. The student discovers through a series of tests that a container of unpasteurized milk in the dining hall is contaminated with a pathogen. After looking at the source of infection under a microscope she is able to use her knowledge about the structure of different pathogens to determine it is a bacterial infection. By combining this information with her knowledge about the characters' symptoms, the student deduces that the team is suffering from an *E. coli* outbreak. The student reports her findings back to the camp nurse, and they discuss a plan for treatment.

This scenario illustrates many of the data collection and problem solving tasks involved in the CRYSTAL ISLAND mystery. Specifically, there are many information-gathering behaviors that are encouraged for students. Students can converse with virtual subject matter experts to learn about microbiology content. Students can discuss symptoms and possible sources of the illness with sick characters. Students can read posters and books about different illnesses to help narrow down which illnesses match the patients' symptoms. As students work toward solving the problem, they have two primary means to test their hypotheses. The first method is through virtual laboratory equipment that enables students to test whether virtual objects have been contaminated with any infectious agents. The second method is a diagnosis worksheet, which is a graphical organizer that enables students to record a hypothesized source and identity of the illness. This worksheet can be checked by the camp nurse for correctness.

The current investigation focuses on two problem-solving milestones: running a laboratory test that comes out positive, and submitting a correct diagnosis worksheet to the camp nurse. These two tasks are critical for solving the mystery, but students can employ a range of inquiry strategies for accomplishing them. The following section describes the study and dataset we used to investigate how students' inquiry strategies and affective outcomes are related.

4 Procedure

A study was conducted with 450 eighth grade students from two North Carolina middle schools interacting with the CRYSTAL ISLAND environment. After removing instances of incomplete data, the final corpus included data from 400 students. Of these, there were 194 male and 206 female participants. The average age of the students was 13.5 years (SD = 0.62). At the time of the study, the students had not yet completed the microbiology curriculum in their classes.

Participants interacted with CRYSTAL ISLAND in their school classroom, although the study was not part of their regular classroom activities. During the week prior to interacting with CRYSTAL ISLAND, students completed several personality questionnaires and a researcher-generated curriculum test consisting of 19 questions created by an interdisciplinary team of researchers assessing microbiology concepts covered in CRYSTAL ISLAND. During the study, participants were given approximately 55 minutes to work on solving the mystery. Immediately after solving the mystery, or after 55 minutes of interaction, students moved to a different room in order to complete several post-study questionnaires including the curriculum post-test.

Students' affect data was collected during the learning interactions through regular self-report prompts. Students were prompted every seven minutes to self-report their current mood and status through an in-game smartphone device. Students selected one emotion from a set of seven options, which included the following: anxious, bored, confused, curious, excited, focused, and frustrated. After selecting an emotion, students were instructed to briefly type a few words about their current status in the game, similarly to how they might update their status in an online social network.

For this work we consider two major problem-solving milestones: running a positive test and submitting a correct diagnosis. To understand how students approach these milestones, we consider four important points in the problem solving process: first laboratory test, positive laboratory test, first diagnosis check, and correct diagnosis check. In particular, we are interested in students' affective experiences leading up to their first attempt to achieve a problem-solving milestone, as well as their subsequence experiences leading up to the moment that the milestone was accomplished.

For this investigation we grouped students into two groups: *early investigators* and *late investigators*. This division was based on a median split of the proportion of information-gathering behaviors that students undertook prior to their first test or diagnosis check. Information-gathering behaviors in the context of CRYSTAL ISLAND include talking with characters, viewing posters, reading books, and taking notes.

5 Results

Of the 400 students in the corpus, 320 students performed a positive test, and 124 students submitted a correct diagnosis to the camp nurse. Because we are interested in comparing behaviors prior to the first attempt at a problem-solving milestone and subsequent behaviors that occur prior to successfully completing the milestone, we limit our analysis to this subset of students.

During their interactions with CRYSTAL ISLAND, students were asked to self-report on their emotional state at regular intervals. We conducted a series of t-tests to identify differences in the proportions of affect reports among early and late investigators for each of the seven possible emotional states.

Positive Laboratory Test. At the time of the first test, early investigators reported both more excitement, $t(318) = 2.51$, $p = 0.01$, and curiosity $t(318) = 1.97$, $p = 0.05$ than late investigators. There are several possible explanations for this observation. Perhaps excitement and curiosity about CRYSTAL ISLAND led to more deliberate attempts to employ effective problem-solving strategies such as early information-gathering. Alternatively, early information gathering may have led to positive emotional states due to students achieving success in the problem-solving scenario.

By the time students performed a positive laboratory test, early investigators still reported more total excitement, $t(318) = 2.37$, $p = 0.02$ than late investigators. In contrast, late investigators reported higher levels of frustration at this stage, $t(318) = 2.83$, $p = 0.005$. This frustration may have stemmed from difficulties with problem solving associated with insufficient information gathering prior to hypothesis testing.

Correct Diagnosis Check. At the time of the first diagnosis check, early investigators reported less confusion than late investigators, $t(122) = 2.14$, $p = 0.03$. By the time students submitted a correct diagnosis, early investigators also reported less frustration than late investigators $t(122) = 2.09$, $p = 0.04$. These findings suggest that early investigators, armed with more background knowledge, may have experienced reduced cognitive disequilibrium.

Overall, students who performed more information gathering behaviors prior to first attempts to test hypotheses appeared to have better affective experiences. These early investigators reported more positive emotions, such as excitement and curiosity, and fewer negative cognitive-affective states, such as confusion and boredom.

6 Discussion

Prior investigations of problem solving in CRYSTAL ISLAND indicated that weaker inquiry strategies did not seem to harm content learning gains, but weak inquiry strategies were associated with reduced problem-solving outcomes. This work focused on extending those findings by examining the role of affect in inquiry and problem solving. Overall it was found that more effective inquiry behaviors corresponded with better affective experiences. Specifically, students who performed more information-gathering behaviors prior to hypothesis testing reported more positive emotions, such as curiosity and excitement, and fewer negative cognitive-affective states, like frustration and confusion.

These findings have implications for the design of inquiry-based learning environments and open-ended educational games. First, the results highlight the importance of scaffolding and guidance in inquiry-based learning environments. While CRYSTAL ISLAND does include inquiry scaffolding—including dialog branches and messages from virtual characters, as well as the graphical organization of the diagnosis worksheet—it was insufficient for students who employed weak inquiry strategies or did not complete the problem-solving milestones at all. If not carefully designed, increased scaffolding may negatively impact student perceptions of control and agency. Alternatively, the scaffolding may yield improved affective responses compared to versions that permit students to flounder.

One questions raised by these findings regards the role of curiosity and excitement in open-ended game-based learning environments. In the case of CRYSTAL ISLAND, it is unclear whether these positive affective states drove information-gathering behaviors or were a byproduct of successful information gathering. Examining the possible causality between inquiry and affect is an important next step in determining the roles of these emotions in problem solving.

There are many promising directions for future work. First, we intend to more closely examine the students who were unable to complete the problem solving milestones. The analysis presented in this paper focused on students who were able to arrive at correct conclusions within the timeframe. However, 20% of students were not able to perform a positive test, and 69% of students were not able to arrive at a correct diagnosis. An important next step will be distinguishing what features separate these students from those who were more successful at problem solving in the game. Another potential direction will be examining how personality features influence students' inquiry behaviors. It seems plausible that personality traits such as conscientiousness or openness may be associated with inquiry. Further examining these potential relationships may explain students' individual differences in inquiry behaviors.

The findings in this paper underline the importance of tailored scaffolding of inquiry behaviors in open-ended game-based learning environments such as CRYSTAL ISLAND. Student difficulties with inquiry may not merely be cognitive in nature, but affective as well. While some students are able to perform effective inquiry strategies and achieve positive learning and affective outcomes, other students were less successful. Identifying effective techniques for designing and tailoring inquiry scaffolding is a critical challenge for the game-based learning community.

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