The Role of Sub-Problems: Supporting Problem Solving in Narrative-Centered Learning Environments

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Abstract. Narrative-centered learning environments provide an excellent platform for both content-knowledge and problem-solving skill acquisition, as these experiences require students to apply learned material while solving real-world problems. Solving complex problems in an open-ended environment can be a challenging endeavor for elementary students given limitations in their cognitive skills. A promising potential solution is providing students with explicit *quests*, or proximal goals of a larger, more complex problem-solving activity. Quests have the potential to scaffold the process by breaking down the problem into cognitively manageable units, providing useful, frequent feedback, and maintaining motivation and the novelty of the experience. The aim of this research was to investigate the role of quests as a means for supporting situational interest and content-knowledge acquisition during interactions with a narrative-centered learning environment. Of the 299 5th grade students who interacted with CRYSTAL ISLAND, a narrative-centered learning environment for science, it was found that students who completed more quests exhibited significant increases in content learning and had higher levels of situational interest. These preliminary findings suggest potential educational and motivational advantages for integrating quest-like sub-problems into the design of narrative-centered learning environments.

Keywords: Narrative-Centered Learning Environments, Game-Based Learning, Problem Solving, Situational Interest.

1 Introduction

Leveraging affordances of technology for improving students' problem-solving skills is a long-term objective of the intelligent tutoring systems community. Kim and Hannafin [1] define problem solving as "situated, deliberate, learner-directed, activity-oriented efforts to seek divergent solutions to authentic problems through multiple interactions amongst problem solver, tools, and other resources." Students should be challenged with more open-ended problem-solving scenarios requiring domain knowledge, creativity, and high-level thinking skills [2], as it "affords them with opportunities to notice patterns, discover underlying causalities, and learn in ways that are seemingly more robust" [3]. Unfortunately, as students lacking sufficient problem-solving skills interact in such environments, they often suffer from cognitive overload [1,4] resulting in unfavorable learning outcomes [5,6].

However, narrative-centered learning environments—immersive spaces that engage users by juxtaposing domain knowledge and practical skill acquisition with

narrative and game elements—may mitigate this overload by providing adequate scaffolding or constraints [1,3,7,8]. Kim and Hannafin [1] suggest helping students reduce problems into reasonable units in order to maintain focus and interest. This approach has been used in several technology-enhanced, inquiry-based learning environments for science [1,9,10]. Narrative-centered learning environments allow for such scaffolding by casting sub-tasks of the overarching problem as sub-plot events, benefiting students four-fold. First, flexible problem solving is promoted by charging students with unique problem-solving scenarios each requiring different content knowledge and actions, yet emphasizing the generality of the basic problem-solving model [11]. Second, creating smaller, more defined activities reduces the amount of relevant information to be synthesized by the student thereby freeing up working memory resources [4]. Third, since multiple quests can be completed during one session, students are provided with frequent, informational feedback to regularly prompt reflection on efficiency and strategy use, an important component of skill development [11]. Finally, by breaking the problem down into manageable units, students are able to efficiently complete tasks, a triumph associated with maintaining situational interest [12,13], which has been shown to influence cognitive performance [14] and facilitate deeper learning [15]. Thus, the primary aim of this study was to examine the relationship between providing students with manageable sub-problems and student game performance and situational interest.

2 Current Investigation

Fifth-grade students from 4 large public elementary schools in Raleigh, North Carolina interacted with CRYSTAL ISLAND, a narrative-centered learning environment for fifth-grade science education (Figure 1). The curriculum underlying the CRYSTAL ISLAND mystery narrative is derived from the state of North Carolina's standard course of study for landforms and map skills and is also intended to support learning strategies such as problem solving, critical thinking, and metacognitive skill development in an applied setting.

Students played the role of a student-selected protagonist who is one of several ship-wrecked passengers stranded on a cluster of volcanic, fictional islands trying to establish a village community. This overall goal is decomposed into three distinct sub-problems, or *quests* as they are referred to within the game environment, each with two levels, totaling seven distinct tasks—the overall problem plus six quests. The three quests are self-contained adventures that challenge students to use their domain expertise in order to complete game-like activities, and each focuses on landform identification, map navigation, and modeling, respectively, and are leveled based on difficulty. For example, level two of the modeling quest challenges the student to create a virtual model of the village by correctly arranging the island's huts on a 2-D space. The students are free to complete the quests in any order they please; however, students must successfully complete the first level of all quests before engaging in any of the second level quests. To aid their problem solving, students can seek counsel from map and landform experts who happen to be among the ship-wrecked crew as well as the player's iPad-like device equipped with note-taking tools,

a camera, a log to monitor quest completion and progress, a glossary of key landform and map skill terminology, and a problem-solving app that details the steps to the problem-solving method. To succeed, students must complete all seven quests.

Fig 1. The CRYSTAL ISLAND narrative-centered learning environment.

After cleaning the data for incomplete and outliers, a total of 293 (134 male, 159 female) cases were used for the investigation. Approximately 6% of the participants were American Indian or Alaska Native, 4% were Asian, 22% were African American, 12% were Hispanic or Latino, 54% were European American, and 7% identified themselves as other. *Content knowledge* was measured with a researcher-constructed, 19-item multiple-choice test that was based on the North Carolina Standard Course of Study curriculum and was designed to measure domain-related material integrated within the learning environment. Specifically, the test utilized fact-level and application-level questions targeting problem-solving skills, map skills, and landform knowledge. *Situational interest* was measured using the Perceived Interest Questionnaire (PIQ), a 10-item measure on a 5-point Likert scale, which has been shown to be internally reliable [16]. Students were also asked a series of open-ended, reflection questions to identify and better understand their favorite aspects of the game. In particular, one question, "What did you like best about playing CRYSTAL ISLAND," was independently and reliably coded by two researchers ($r = .98$) and used for analysis. The experiment took place during three 60-minute sessions held on three consecutive days. Two weeks prior to data collection, students completed the content knowledge pre-test, and the post-test items were completed immediately following gameplay during the final session.

3 Results

In order to determine if content knowledge was affected as a result of interacting with the learning environment, a repeated measures analysis of variance was conducted comparing the pre- and post-content tests. Results showed a significant within-subjects effect ($F_{(1, 292)} = 25.79$, $p < .001$, $\eta^2 = .08$), indicating a significant mean difference in content test scores between pre-test and post-test. Furthermore, significant

correlations were found between content pre-test scores and total quests completed (r = .40, $p < .001$), content post-test scores and total quests completed ($r = .44$, $p < .001$), and situational interest and total quests completed ($r = .18, p < .001$).

To further investigate the relationship between quest completion and content knowledge acquisition, a hierarchical linear regression was conducted. Pre-content test scores (first block) and number of quests completed (second block) were used to predict post-content test scores. Both models were found to be significant (respectively, $F_{(1, 292)} = 440.35, p < .001$; $F_{(2, 291)} = 237.72, p < .001$; Table 3). The total number of quests completed was found to be a significant predictor in conjunction with pre-test scores with the entire model accounting for 61% of the variance. Interestingly, in order to determine whether the trend was simply due to high content knowledge students completing more quests, students were divided using a tertiary split on their pre-content-test scores, and the students in the lower third were isolated for analysis ($N = 83$). Both models in a similar hierarchical linear regression considering only those students also were found to be significant (respectively, $F_{(1, 82)}$ = 33.63, $p < .001$; $F_{(2, 83)} = 21.465, p < .001$). Again, both prior knowledge ($t = 4.84, p < .001$) and total quests completed ($t = 2.63$, $p = .01$) were found to be significant predictors accounting for 35% of the variance within this population.

Table 3. Hierarchical linear regression predicting post content test scores

Predictor	Model 1			Model 2		
	B	SE	β	B	SE	β
Pre Content Test	.79**	.04	.77**	.73**	.04	.70**
Total Quests Completed				.42**	.11	.16**

Notes: ** - $p < .01$

Finally, analyses were performed to determine the effect of quest completion on student situational interest levels. Again, a hierarchical linear regression was conducted to predict situational interest with pre content test entered into the first block, and post content test and total quests completed entered into the second block. Only the second model was found to be significant ($F_{(3, 290)} = 3.62, p < .05$; Table 4) and was responsible for 4% of the variance. The results found only total quests completed to be a significant predictor of situational interest.

Table 4. Hierarchical linear regression predicting situational interest

Predictor	Model 1			Model 2		
	B	SE	β	B	SE	β
Pre Content Test	.02	.01	.08	.01	.02	.06
Post Content Test				-.02	.02	-.07
Total Quests Completed				.12**	.04	.19**

Notes: ** - $p < .01$

Furthermore, students' responses to the reflection questions were coded for mentions of the quests, which divided students into two groups, those who mentioned the quests as their favorite part ($N = 132$) and those who mentioned other aspects of the game (e.g., choosing a player; $N = 167$). An analysis of variance (ANOVA) found students who mentioned quests as their favorite part of the CRYSTAL ISLAND

experience reported significantly higher ratings of situational interest than those who did not ($F_{(1, 298)}$ = 12.38, p < .001). Students stating that they enjoyed completing the quests made comments such as, "*The quests were the best...They kept you active and seeing what's behind the corner...*" and "*My favorite part was the quests you had to do because they teach you, but they are very fun!*" Positive reflections from the students further endorse the motivational advantages for implementing quests.

4 Conclusions

The findings of the study suggest that quests could be effectively utilized to scaffold problem solving in narrative-centered learning environments. Completing more quests during gameplay significantly predicted performance on the content post-test and indicated higher levels of situational interest. Interestingly, quest completion is a better predictor of situational interest than content knowledge. The current analysis has several implications. First, the use of quests appears to aid student learning and problem solving by decomposing problems into smaller, more manageable units. Secondly, quest completions enhance students' situational interest as completing more quests is highly predictive of situational interest and further evidenced by responses to open-ended reflections from the students following their interaction with the environment. Consequently, the data from this study supports this hypothesis, and suggests quests could be a beneficial design tool for scaffolding problem solving.

The limitations of the study should be noted. Most importantly, re-conducting the current analysis with a control condition is imperative for confirming our current findings and implications. Until this study occurs, we cannot make valid claims about the benefits of integrating quest-like activities in similar environments. In addition, it will be important to more closely analyze each quest and subsequently revise each in order to realize the quest's greatest potential as a learning device for the particular concept in on which it is focused. Nonetheless, the results suggest lines of future investigation. As quests in narrative-centered learning environments are focused on one particular aspect of the curriculum, they could potentially form the foundation for an adaptive system targeting learners at the individual level. Quests could be unlocked and presented to students in real-time as the system automatically senses a student's lack of understanding of a certain topic. Moreover, as more advanced students might not need scaffolding, quests could be used as a tool only for less accomplished problem solvers by promoting appropriate challenge at the individual level. Moreover, since students could be challenged to repeat quests as to beat their preceding score, investigating the role of quests for promoting mastery learning is another venue for future research.

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