Individual Differences in Gameplay and Learning: A Narrative-Centered Learning Perspective

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ABSTRACT

Narrative-centered learning environments are an important class of educational games that situate learning within rich story contexts. The work presented in this paper investigates individual differences in gameplay and learning during student interactions with a narrative-centered learning environment, CRYSTAL ISLAND. Findings reveal striking differences between high- and low-achieving science students in problem-solving effectiveness, attention to particular gameplay elements, learning gains and engagement ratings. High-achieving science students tended to demonstrate greater problem-solving efficiency, reported higher levels of interest and presence in the narrative environment, and demonstrated an increased focus on information gathering and information organization gameplay activities. Lower-achieving microbiology students gravitated toward novel gameplay elements, such as conversations with non-player characters and the use of laboratory testing equipment. The findings have implications for the design of broadly effective gameplay activities for narrative-centered learning environments, as well as investigations of scaffolding techniques to promote effective problem solving, improved learning outcomes and sustained engagement for *all* students.

Categories and Subject Descriptors

H5.1. Multimedia Information Systems: Artificial, augmented, and virtual realities; Evaluation/methodology.

General Terms

Measurement, Design, Experimentation, Human Factors.

Keywords

Narrative-centered learning environments, game-based learning, empirical evaluation, engagement.

1. INTRODUCTION

The past decade has seen a growing recognition of the potential for game-based learning environments to deliver rich, situated learning experiences that are effective and engaging [7, 19, 22]. Games exhibit several qualities that make them well suited to learning [7, 10, 23] and training [19, 22] applications. As described in a summative report from the National Summit on Educational Games, game-based learning environments provide students with opportunities to practice and refine key skills in strategic thinking, interpretative analysis, problem solving, plan formulation and execution, and adaptation to change [15]. An important category of educational games is *narrative-centered learning environments*, which center on story-centric problem-solving scenarios located in rich virtual settings, populated with believable characters, and embedded within compelling plots [1, 9, 11, 20]. Narrative-centered learning environments are naturally equipped to situate learning activities within meaningful contexts that afford multiple problem-solving paths and modes of inquiry [14]. By combining the motivational characteristics and interactivity of commercial games, the familiar structures of narrative, and the deep learning experiences promoted by guided inquiry, narrative-centered learning environments present novel opportunities for education.

While narrative-centered learning environments and other game-based technologies show significant promise, important questions remain about how students interact with these environments in practice, and how the environments should best be designed to support learning. A key motivation for the use of commercial game technologies in education is reaching students for whom traditional instructional methods have proven ineffective [11]. Efforts to reach these students should be informed by an understanding of the effects of prior knowledge, self-efficacy, game-playing experience, and other individual characteristics on students' gameplay behaviors, engagement, and learning [11]. Without first understanding how different types of students respond to game-based technologies, it can be challenging to devise narrative-centered learning environments that are accessible, engaging, and effective for all learners. This observation suggests a need to systematically investigate student interactions with narrative-centered learning environments and identify factors that influence students' gameplay behaviors, engagement, and learning outcomes. It is expected that this line of study will lead to effective designs and technologies for narrative-centered learning environments, as well as more effective tools for assessing student learning and engagement. Furthermore, by constructing an empirical account of how student and gameplay characteristics influence learning and problem solving in games, the education community will be better equipped to devise adaptive technologies that can tailor scaffolding and problem

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scenarios to the individual needs of learners, in a manner similar to those used by effective teachers and tutors [3].

This paper describes work that investigates the relationships between students' individual characteristics, gameplay behaviors, learning, and engagement during interactions with a narrative-centered learning environment. Findings are presented from a study with 153 eighth-grade students interacting with CRYSTAL ISLAND, a narrative-centered learning environment for middle school microbiology. In the game, students solve a science mystery by acquiring relevant microbiology knowledge and applying the scientific method to diagnose a mysterious spreading illness. Results from the study contrast students who achieved high scores in the game with students who earned low scores. The findings reveal notable differences between high and low scoring groups in prior knowledge and self-efficacy for science, gameplay behaviors, learning, and engagement. Perhaps surprisingly, prior game-playing experience and gender were not found to influence student performance in the game. The results suggest several implications for the design and application of narrative-centered learning environments, as well as additional hypotheses deserving further study.

The structure of the paper is as follows. Section 2 provides background and related work on narrative-centered learning. Section 3 provides a detailed description of the CRYSTAL ISLAND virtual environment. Following in Section 4 is a description of a study investigating the relationship between students' learning outcomes, individual differences, and gameplay experiences. Results are presented in Section 5, followed by discussion and implications for further research in Section 6. Section 7 offers concluding remarks and suggests directions for future work.

2. EDUCATIONAL GAMES AND NARRATIVE-CENTERED LEARNING

Within both the science and education communities, there have been growing calls to expand research on learning in digital games, the design of effective game-based learning environments, and educational practices that incorporate games and other interactive media [15, 23]. Recent years have seen a wide-ranging discussion about how digital games can best be used to help students meet the demands of a 21st century education. In James Gee's widely cited book on games and learning, he outlines thirty-six principles that modern games implement as part of fostering a literacy of video games [7]. He argues for a better implementation of these learning principles in schools and classrooms as a means of making learning more accessible, effective, and engaging. Shaffer extends this line of discussion by introducing *epistemic games*, which emphasize innovation and analytical thinking by centering game mechanics around the roleplay of real-world professions in virtual environments [22]. Shaffer argues that situated learning experiences afforded by epistemic games provide students with opportunities to learn how to think innovatively, and acquire transferrable skills that are vital for success in a range of domains [22]. Similarly, Marc Prensky suggests that game-based learning can be a powerful method for educating children as well as training young professionals, and offers several concrete examples for how to do so [19]. In addition to advocating the benefits of gameplay for learning, others have argued that students should be engaged in the creation of digital games, as a platform for constructivist learning [2, 8, 10].

Using key elements of commercial-quality games, narrative-centered learning environments aim to situate learning within virtual environments that feature rich plots, believable characters, and captivating discourse [14]. Stories provide contextual structure and meaning to knowledge, understanding, and experience. They are distinctive in providing the ability to draw audiences into plots and settings, and open perceptual, emotional, and motivational opportunities for learning. Establishing concrete connections between narrative contexts and pedagogical subject matter has been said to support the assimilation of new ideas in young learners [25]. Fantasy contexts have also been shown to provide motivational benefits in educational games [13]. By promoting cognitive activities such as suspension of disbelief and story involvement, narrative-centered learning environments aim to reinforce learning objectives, contextualize subject matter, and promote motivation and engagement.

Over the past several years, a number of narrative-centered learning environments have been developed that provide effective, engaging learning experiences situated within meaningful virtual contexts. Quest Atlantis is a multi-user virtual environment where students travel to different worlds and complete educational quests [1]. Many of the game's educational objectives incorporate social and ethical subtexts that provide additional gravity to learning. Quest Atlantis situates a range of learning activities across different domains within a global story arc about saving the struggling Atlantean civilization.

Whyville [16] is an educational, massively multi-user virtual environment aimed at young adolescents and pre-teens. Players spend time exploring the virtual world, chatting with other players, and visiting any of a variety of social and educational locations such as a virtual Getty Museum, a Center for Disease Control, and a City Hall. Many of the locations provide players with educational activities and links to outside websites that foster further exploration and learning. Whyville's dynamic, massively multiplayer environment allows for social narratives to emerge, with opportunities for connecting these emergent narratives to educational experiences (e.g., democratic elections, managing disease outbreaks).

The Tactical Language and Culture Training System (TLCTS) is a suite of story-centric, serious games designed for language and culture learning [9]. Many of the existing versions of TLCTS are tailored to the armed services and use a combination of interactive lessons and narrative scenarios to train students in spoken and non-verbal communication, as well relevant cultural knowledge. TLCTS also uses a range of artificial intelligence techniques for speech recognition, dialogue modeling, and virtual human behavior control to support gameplay.

River City [11] is a multi-user virtual environment aimed at strengthening middle school science content knowledge and problem solving skills. The game's narrative takes place during the late 1800s; River City's residents have fallen chronically ill, and the ailing town must depend on the player-students to diagnose the spreading epidemic. Students work in small collaborative teams as they synthesize information deriving from biology, history, sociology, and geography content in order to develop and test hypotheses about the disease's source. River City's complex, multi-stranded science mystery underscores the richness of the game's social, narrative and pedagogical environment. The River City research team is particularly interested in understanding the game's impact on traditionally low-performing students. Empirical studies found that students who reported lower levels of self-efficacy for science initially engaged in fewer inquiry-based tasks within the environment; however, after repeated visits to the environment over time, low self-efficacious students began to perform at the level of their high self-efficacious counterparts [11].

A key feature of several of these narrative-centered learning environments is their inherent support for situated learning. Situated learning theory views cognition as occurring within a particular activity, setting, or culture [5]. It contrasts with views that treat learning as abstracted away from the context in which it occurs. Situated learning generally implies authentic contexts and activities, as well as apprenticeship in 'communities of practice' [12]. Gee outlines several principles highlighting the role of situated learning in games [7]. These include what Gee refers to as the probing principle, multiple routes principle, situated meaning principle, and the multimodal principle. These situated learning principles are salient features of narrative-centered learning environments. For example, narrative-centered learning environments frequently present complex problem-solving scenarios that require students to iteratively generate, test, and revise hypotheses to progress through the story [11, 20], a process consistent with Gee's description of probing [7]. A number of narrative-centered learning environments provide open-ended virtual settings and story objectives, offering multiple routes for students to formulate goals, devise plans, and execute them. Narrative-centered learning environments inherently situate learning within the context of a virtual setting, populace, and plot. In fact, the narrative itself is often defined, at least in part, by the student's problem solving steps and discoveries. Finally, by leveraging the full gamut of experiences afforded by interactive, narrative settings—these include non-player character interactions, multimedia presentations through videos, posters, diagrams, texts, simulations, collaborative and cooperative spaces, and novel gameplay paradigms—narrative-centered learning environments take advantage of multimodal approaches to learning and instruction.

The next section describes a test bed narrative-centered learning environment currently under development in our laboratory, CRYSTAL ISLAND. CRYSTAL ISLAND provides a platform for investigating the relationships between student characteristics, gameplay behaviors, and learning outcomes.

3. CRYSTAL ISLAND

Now in its third major iteration, CRYSTAL ISLAND (Figure 1) is a narrative-centered learning environment built on Valve Software's Source™ engine, the 3D game platform for Half-Life 2. The curriculum underlying CRYSTAL ISLAND's mystery narrative is derived from the North Carolina state standard course of study for eighth-grade microbiology. Students play the role of the protagonist, Alyx, who is attempting to discover the identity and source of an infectious disease plaguing a research station. Several of the team members have fallen gravely ill, and it is the student's task to discover the nature and cause of the outbreak.

CRYSTAL ISLAND's narrative takes place in a small research camp situated on a recently discovered tropical island. As students explore the camp, they investigate the island's spreading illness by forming questions, generating hypotheses, collecting data, and testing hypotheses. Throughout their investigations, students interact with non-player characters offering clues and relevant microbiology facts via multimodal "dialogues" delivered by characters through student menu choices and characters' spoken

Figure 1. CRYSTAL ISLAND narrative-centered learning environment.

language. The dialogues' content is supplemented with virtual books, posters, and other resources encountered in several of the camp's locations. As students gather useful information, they have access to a personal digital assistant to take and review notes, consult a microbiology field manual, communicate with characters, and report progress in solving the mystery. To solve the mystery, students complete a *diagnosis worksheet* to manage their working hypotheses and record findings about patients' symptoms and medical history, as well as any findings from tests conducted in the camp's laboratory. Once a student enters a hypothesized diagnosis, cause of illness, and treatment plan into the diagnosis worksheet, the findings are submitted to the camp nurse for review and possible revision.

To illustrate the behavior of CRYSTAL ISLAND, consider the following scenario. Suppose a student has been interacting with non-player characters in the storyworld and learning about infectious diseases. In the course of having members of the research team become ill, she has learned that a pathogen is an illness that can be transmitted from one organism to another. As she concludes her introduction to infectious diseases, she learns from the camp nurse that the mystery illness seems to be coming from food items the sick members 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 provide helpful microbiology information. The student is careful to take notes recording information about bacteria and viruses in her personal digital assistant, and corroborates these notes with information contained in her microbiology field manual. After forming several hypotheses about which food items may be sickening the team members, the student discovers through a series of tests that a container of unpasteurized milk in the dining hall is contaminated with bacteria. By combining this information with her knowledge about the characters' symptoms and recent dining habits, the student infers that the cause of the outbreak is an *E. coli infection*, for which ample rest is the best immediate treatment plan. She records her findings in a diagnosis worksheet, and submits them to the camp nurse for review and implementation.

Table 1. Point values for calculation of in-game score.

Action	Points (pts)
Overall Mystery Solution	
Correct Solution	500 pts
Solution Efficiency	(7500 / elapsed time) pts
Incorrect Solution Attempt	-100 pts
In-game Quiz Questions	
First Attempt Correct	25 pts
Second Attempt Correct	10 pts
Second Attempt Incorrect	-10 pts
Object Contaminant Testing	
Test Milk for Pathogens	200 pts
Incorrect Object	-10 pts
Incorrect Contaminant	-25 pts
Character Interactions	
Talk to Kim	(25 / elapsed time) pts
Talk to Teresa	(50 / elapsed time) pts
Talk to Ford	(125 / elapsed time) pts
Talk to Robert	(125 / elapsed time) pts
Talk to Quentin	(125 / elapsed time) pts
Pathogen Labeling Activities	
Correct Answer	10 pts
Incorrect Answer	-10 pts
Total Maximum Points	**≈ 1665 pts**

4. STUDY

An experiment involving human participants was conducted with the entire eighth grade population of a North Carolina middle school. The primary goal of the experiment was to investigate the impact of different scaffolding techniques on learning and engagement in the CRYSTAL ISLAND narrative-centered learning environment. However, no condition effects were observed for either learning or engagement. This paper's findings are derived from a secondary analysis of the data, which considers the experiment's conditions as a whole.

4.1 Participants

A total of 153 eighth grade students ranging in age from 12 to 15 (M = 13.3, SD = 0.48) interacted with the CRYSTAL ISLAND environment during the study. Three of the participants were eliminated due to incomplete data. Among the remaining students, 80 were male and 70 were female. Approximately 3% of the participants were American Indian or Alaska Native, 2% were Asian, 32% were African American, 13% were Hispanic or Latino, and 50% were White. The study was conducted prior to students' exposure to the microbiology curriculum unit of the North Carolina state standard course of study in their regular classes.

4.2 Materials and Apparatus

Students completed an online demographic survey, game-playing experience questionnaire, impulsivity survey [17], self-efficacy for science survey [18], and CRYSTAL ISLAND curriculum test prior to the intervention. The game-playing experience questionnaire asked students to self-report about their game-playing habits and perceived game-playing skill. The self-efficacy for science learning scale is an 8-item self-report questionnaire measured on a 5-point Likert scale. It is adapted from Nietfeld et al. [17], which utilizes a portion of the measure presented in Britner & Pajares [4]. The impulsivity scale is included in accordance with Nietfeld & Bosma [18], which used a portion of the Eysneck Personality Inventory (EPI) [6] and consists of eight, 'yes' or 'no' self-report items. The impulsivity sub-scale is included in the extroversion factor of the EPI and is intended to measure students' tendency to be impulsive. The CRYSTAL ISLAND curriculum test consisted of 16 multiple-choice questions created by an interdisciplinary team of researchers. The test included eight factual and eight application questions assessing students' knowledge of pathogens, select diseases, and the scientific method.

Post-experiment materials were completed immediately following the CRYSTAL ISLAND intervention. Included in these materials were the same curriculum test used in the pre-experiment, a variation of the Perceived Interest Questionnaire [21], and the Presence Questionnaire [24]. The interest scale was adapted from measures used by Schraw [21], and examines situational interest in narrative-centered learning environments. The Presence Questionnaire is a validated measure containing several subscales, including involvement/control, naturalism of experience, and quality of interface [24]. The measure assesses a user's sense of being 'transported' into a virtual environment.

In addition to pre- and post-experiment subjective measures, the CRYSTAL ISLAND game environment calculated a numerical score to assess students' progress and efficiency in completing the science mystery. Students could view their scores in the upper left corner of their screens throughout their game interactions. The score consisted of a weighted sum of gameplay sub-scores, and incorporated time taken to accomplish important goals, students' ability to demonstrate microbiology content knowledge, and evidence of deliberate problem solving. Students were penalized for any attempt to "game the system" by repeatedly submitting incorrect diagnoses to the camp nurse or guessing on content knowledge quizzes. Details of the score's calculation are shown in Table 1. It should be noted that students began the game with a score of 0 points, and could earn up to 1665 points. However, their score was penalized for attempts to "game the system" by guessing at quiz questions or the mystery's solution. As an objective measure assessing students' understanding of the curricular content and effectiveness at completing the CRYSTAL ISLAND mystery, students' final scores are treated as an approximation of engagement in the problem-solving scenario, together with related concepts of presence and situational interest.

4.3 Participant Procedure

Participants entered the experiment room having completed the majority of pre-test materials one week prior to the intervention. Students were initially provided general details about the CRYSTAL ISLAND mystery and game controls during an introductory presentation by a member of the research team. After the presentation, students completed the remaining pre-test materials and were provided with several CRYSTAL ISLAND supplementary documents. These materials consisted of a CRYSTAL ISLAND backstory and task description, a character handout, a map of the island, and an explanation of the game's controls.

Participants were given sixty minutes to work on solving the mystery. Solving the mystery consisted of several objectives, including the following: learning about pathogens, viruses, and bacteria; compiling the symptoms and recent history of the sick researchers; recording details about diseases believed to be potentially afflicting the team members; testing a variety of

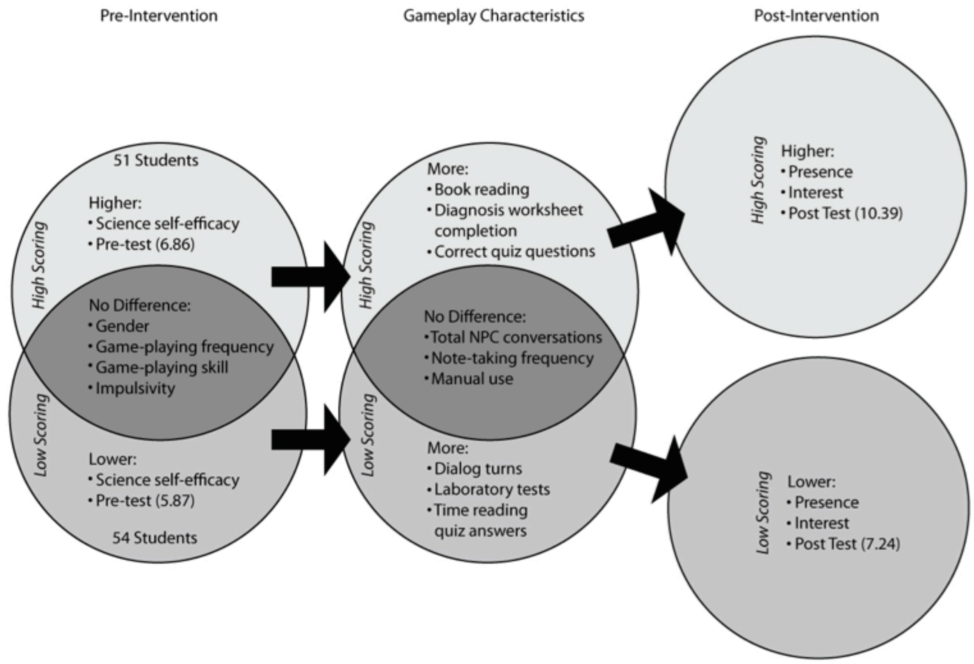

Figure 2. Individual differences prior to gameplay, in-game, and after gameplay.

possible sources for the disease; and reporting the solution—these include the cause, source, and treatment—to the camp nurse. Immediately after solving CRYSTAL ISLAND's science mystery, or sixty minutes of interaction, participants completed the post-experiment questionnaires. Completion of post-experiment materials took no longer than thirty minutes for participants. In total, sessions lasted up-to 120 minutes.

5. RESULTS

An investigation of learning found that on average, students answered 2.35 (SD = 2.75) more questions correctly on the post-test than they did on the pre-test. Matched pairs t-tests (comparing post-test to pre-test scores) indicated that students' learning gains were significant, $t(149) = 10.49$, $p < .001$.

Students' final in-game scores—a measure of success and engagement in the problem-solving scenario—averaged 318 points (SD = 509), and ranged from -1095 points to 1403 points. Interestingly, this analysis revealed a bimodal distribution over student scores; among the 123 participants that interacted with CRYSTAL ISLAND, 54 students scored in the lower range of -1095 to 100 points, 51 students scored in the upper range of 600 to 1403 points, and just 18 students scored in the intermediate range of 100 to 600 points. In other words, roughly half (44%) of the population clustered around the low end of the score range, and slightly less than half (41.5%) of the population was clustered near the high end. Further analysis was performed in order to investigate this polarization among gameplay scores. A summary of the findings is shown in Figure 2.

5.1 Individual Differences and Learning

The participant data was partitioned into high-scoring (600+ points) and low-scoring (100- points) groups. Several ANOVA tests were performed to investigate differences between the two clusters. The tests revealed that the high-scoring group was significantly more self-efficacious for science, $F(1, 100) = 20.71$, $p < .001$, and had greater microbiology background knowledge, $F(1, 103) = 7.27$, $p < .01$. Interestingly, no significant differences were found between the groups for either game-playing frequency or self-perceived game-playing skill. Furthermore, no differences were found for gender, or impulsivity.

A series of ANOVAs were performed to examine the differences between the low- and high-scoring groups on the post-game measures. Students in the high-scoring group answered significantly more questions correctly on the microbiology content test, $F(1, 103) = 38.66$, $p < .001$, and reported higher levels of situational interest, $F(1, 103) = 3.95$, $p < .05$, and presence, $F(1, 102) = 13.60$, $p < .001$. Because the high-scoring group demonstrated greater microbiology background knowledge prior to the CRYSTAL ISLAND intervention, an ANCOVA controlling for pre-test score was conducted. The analysis revealed that the high-scoring group still performed significantly better on the microbiology content post-test, $F(1, 102) = 29.25$, $p < .001$. This indicates that the high-scoring group demonstrated greater microbiology learning gains than the low-scoring group.

5.2 Gameplay Experiences

An analysis of the variance between the high- and low-scoring groups indicated significant differences in students' gameplay characteristics. The high-scoring group read virtual books more often than the low-scoring group, $F(1, 103) = 15.94$, $p < .001$, and spent more time reading books, $F(1, 103) = 6.03$, $p < .05$. High-scoring students also completed their diagnosis worksheets more accurately, $F(1, 103) = 151.93$, $p < .001$. This was true for all of the diagnosis worksheets' subsections: patient symptoms, $F(1, 103) = 17.46$, $p < .001$, laboratory test findings, $F(1, 103) = 14.05$,

$p < .001$, diagnosis hypotheses, $F(1, 103) = 42.53$, $p < .001$, and final diagnosis, $F(1, 103) = 235.89$, $p < .001$. Perhaps not surprisingly, high-scoring students also performed better on in-game quizzes. For the set of primary quiz questions that all students should have received during gameplay, high-scoring students answered more questions correctly on the first attempt, $F(1, 103) = 5.59$, $p < .05$), and answered more questions correctly in total, $F(1, 103) = 3.76$, $p = .05$.

In contrast, low-scoring students spent their time conducting more laboratory tests than the high-scoring group, $F(1, 103) = 20.73$, $p < .001$. Low-scoring students also conducted more erroneous tests, $F(1, 103) = 16.68$, $p < .001$, and when asked to explain their choice to conduct a particular test, more often replied with an erroneous justification, $F(1, 103) = 18.28$, $p < .001$. Low-scoring students were also more frequently involved in conversational interactions with non-player characters than high-scoring students. The low-scoring group spent more total time engaged in dialogue interactions, $F(1, 103) = 9.02$, $p < .01$, and also selected more dialogue branches during conversational interactions, $F(1, 103) = 5.16$, $p < .05$. Although high-scoring students performed better on quiz questions than low-scoring students, the low-scoring group spent more time reviewing quiz question answers than the high-scoring group, $F(1, 103) = 15.48$, $p < .001$.

No differences were found between the high- and low-scoring groups for number of initiated conversations ($M = 23.1$, $SD = 7.4$), microbiology field manual usage ($M = 2.2$, $SD = 1.7$), or note-taking frequency ($M = 3.1$, $SD = 3.65$).

6. DISCUSSION

The results of the analysis reveal several interesting differences regarding how eighth-grade students interact with CRYSTAL ISLAND (Figure 2). While interacting within the environment, students earned an in-game score as a function of their efficiency for achieving the goals associated with solving the science mystery. A striking contrast in scores, revealing two substantially different groups of students and game-play experiences, occurred. Remarkably, very few students received scores near the mean (mean = 378.8). Approximately half of the students earned less than 100 points, and the other half earned more than 600 points. Students who were likely to have a greater disposition for science (i.e., those with greater microbiology background knowledge and self-efficacy for learning science) tended to achieve higher scores during the game interaction, and experienced improved learning outcomes compared to students demonstrating a lesser disposition toward science. It should be noted that the score difference was not a factor of gender, perceived game-playing skill, or game-playing frequency.

Students' scores were closely tied to their efficiency in solving CRYSTAL ISLAND's mystery and their ability to demonstrate microbiology content knowledge at select points in the scenario. From the current analysis, it is difficult to determine whether the low-scoring students were off-task. However, the findings do suggest that low-scoring students focused on different activities than high-scoring students. Low-scoring students were less efficient in achieving important goals, and demonstrated less understanding of microbiology content during gameplay. Further, these students tended to converse more extensively with non-player characters and conducted larger numbers of laboratory tests. However, many of these tests were poorly chosen and unnecessary, and the students did not appear to always use the results effectively toward solving the overarching mystery. This may be symptomatic of student difficulties in forming and following effective problem-solving strategies.

In contrast, high-achieving students appear to have been more engaged in accumulating the microbiology knowledge necessary for solving the mystery, as evidenced by increased time reading virtual books and correctly answering curriculum quiz questions. High-scoring students were also more effective at using their diagnosis worksheets to organize findings and record hypotheses. Both high- and low-scoring students spent relatively equal amounts of time reading the microbiology manual and taking notes.

The findings raise a number of questions about students' individual differences in narrative-centered learning interactions. Clear relationships were found between student differences outside the game environment (disposition toward science, learning) and differences inside the game environment (gameplay characteristics, presence). Related findings were reported in Ketelhut [11], which studied student interactions in the River City narrative environment over the course of multiple gameplay sessions. Ketelhut's study found that students' self-efficacy influenced data-gathering behaviors in the virtual environment initially, but the differences gradually disappeared over repeated exposures [11]. The study described here found an influence of self-efficacy on in-game score, and similar relationships between score and microbiology information gathering behavior. However, because the version of CRYSTAL ISLAND used in the study reported here is designed to be completed in a single session, it does not support an analysis to determine whether these differences change over time as they did in the River City investigation.

The differences in in-game performance might be explained by students extrapolating classroom behaviors into the virtual environment. Activities such as reading textbooks and completing worksheets are typical classroom activities. However, educational games allow instructors to expose students to resources and facilities that may be rare or infeasible in real-world classrooms. Interestingly, during game play, students with higher incoming microbiology knowledge and science self-efficacy tended to engage in traditional classroom activities for which they were likely already familiar and successful, such as reading texts, answering quiz questions, and completing worksheets. Low-scoring students tended to interact with novel scientific resources such as non-player characters and laboratory testing equipment in order to approach solving the mystery. Although seemingly unsuccessful at utilizing the resources given in-game score and learning gains, low-achieving students were at least experimenting with tools for solving the mystery, rather than spending the entirety of their time off-task in the virtual environment [20]. It should be noted that low-scoring students still achieved significant learning gains, although lesser in magnitude than their high-scoring counterparts.

The observation that students' incoming differences in knowledge and self-efficacy may impact their learning, engagement, and in-game behaviors has important implications for the design of gameplay elements in narrative-centered learning environments. Despite the availability of information about microbiology concepts and problem solving through a range of modalities–including non-player character interactions, posters, and books–these gameplay elements were not sufficiently effective at reaching nearly half of the study's student population. This suggests the need to provide alternative methods for conveying important information in the game, incentives for students to spend more time attending to existing learning features, or scaffolds to direct students' attention toward important activities at relevant times in the narrative.

Furthermore, it seems possible that low-scoring students struggled because they were not familiar with effective problem-solving strategies. This suggests a need for adding gameplay mechanisms for guiding students toward effective problem-solving steps, and to tailor these scaffolds to individual students' needs. Low-scoring students still learned in the environment, and still appeared to make progress toward solving the mystery. However, they may simply need additional support to help them maximize the effectiveness of their narrative-centered learning experiences.

7. CONCLUSIONS AND FUTURE WORK

Narrative-centered learning environments offer the potential to be effective tools for promoting content and problem-solving learning gains by providing students with engaging, interactive learning experiences. Not only do these environments enhance the ability of high-achieving students, but they also aim to motivate lower-achieving students to become curious about the subject matter. As additional research is conducted regarding student individual differences while interacting with narrative-centered learning environments, further progress can be made on tailoring such systems to the student to encourage the most beneficial experience for that particular learner.

The study reported here revealed gameplay differences between high- and low-achieving science students in a narrative-centered learning environment for middle school microbiology, CRYSTAL ISLAND. During gameplay, high-achieving students tended to utilize more traditional science resources such as textbooks and worksheets while attempting to solve the presented mystery. In contrast, low-achieving students employed the help of expert non-player characters and virtual lab equipment to aid in their quest. While additional analysis is necessary to determine whether low-scoring students spent significant time off-task [20], their inability to effectively use the information allotted to them via in-game resources inhibited their progression through the mystery, as well as their learning outcomes.

An important hypothesis stemming from these findings is that low-achieving students tended to gravitate toward novel resources not often presented in the traditional classroom; however, it seems some guidance is necessary to promote the most effective use of narrative-centered learning environments. Leveraging narrative-centered learning enviroments to introduce students to learning resources that are impractical in real-world classrooms is a promising educational opportunity. However, given the novelty of these learning activities, scaffolding student interactions with these resources is essential. Future work in this area will involve revising current gameplay elements in CRYSTAL ISLAND to foster improved understanding of the processes involved in effective problem-solving, and also encourage the effective application of content knowledge encountered in the environment. This line of investigation will also require modifying and targeting current scaffolding techniques to address the needs of low-achieving students, and direct them toward effective problem-solving strategies. Means for encouraging student note-taking and other forms of cognitive off-loading should also be investigated.

Another important implication is related to the limited interaction time. The students were allotted roughly sixty minutes for playing CRYSTAL ISLAND. While both groups were engaged in productive activities for learning, it will be important to investigate whether the same result would occur in a similar environment with sufficient content and replayability to support repeated and extended gameplay sessions. A key open question is whether extended interactions with the environment would provide lower-achieving students an opportunity to hone their help-seeking skills. As we integrate more sophisticated resources into the environment, it will be important to investigate extended opportunities for gameplay and learning.

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