Chapter 14

Narrative-Centered Learning Environments: A Story-Centric Approach to Educational Games

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Abstract: Narrative-centered learning environments hold significant promise for K-12 STEM education. Much of the appeal of narrative-centered learning arises from the capability of narrative to provide a meaningful structure for integrating pedagogical objectives into a unifying, coherent form that serves as a powerful motivating force for students. This chapter explores the relationship between narrative-centered learning and student motivation. Connections are drawn between motivational factors and narrative context through an examination of the CRYSTAL ISLAND narrative-centered learning environment. Drawing on the results from studies of middle school students interacting with CRYSTAL ISLAND, we consider the hypothesis that narrative can simultaneously promote learning and increase students' motivation.

Keywords: Game-based learning, Narrative-centered learning environments, Intelligent tutoring systems, Interactive narrative, Motivation, Educational games, AI and education, Serious games, Inquiry-based learning, Problem-based learning, Science education.

The past decade has witnessed a growing recognition of the potential of digital games to deliver effective and engaging learning experiences. One particularly promising class of educational games is narrative-centered learning environments. *Narrative-centered learning environments* contextualize educational content and problem solving with interactive story scenarios. By embedding learning within narrative settings, they tap into students' innate facilities for crafting and understanding stories (Bruner, 1991; Graesser & Ottati, 1996; Polkinghorne, 1988). Narrative-centered learning environments provide meaningful contexts for

problem-solving activities, which illustrate connections between theories and applications (Jonassen & Hernandez-Serrano, 2002). They also exhibit a natural capacity to foster engagement by tightly integrating pedagogy and narrative elements.

Several narrative elements such as believable characters, dramatic plots, and fantasy settings are instrumental for yielding high quality stories (Egri, 1960; McKee, 1997). Incorporating these narrative elements into educational stories shows promise for enhancing student motivation and engagement during learning. However, effective authoring of narrative elements is difficult. The authoring challenges are heightened when working in a new medium, such as interactive digital games. In order to enhance the likelihood that a narrative-centered learning environment will positively impact student motivation for learning, it is valuable to consider how motivational factors bear on design decisions involved in authoring characters, plots, and settings, as well as gameplay mechanics. Moreover, explicit consideration of motivational factors can guide analyses of the extent and nature of these elements in narrative-centered learning environments.

This chapter describes design issues and empirical findings about motivation in narrative-centered learning environments. In the next section, we provide background on educational games and narrative-centered learning, as well as brief descriptions of extrinsic and intrinsic motivation. This background provides the foundation for our work on designing narrative-centered learning environments for K-12 classrooms. In the following section, we introduce a narrative-centered learning environment that has been iteratively refined in our laboratory over the past several years, CRYSTAL ISLAND. The CRYSTAL ISLAND learning environment supports middle grade science education, and it features an interactive science mystery. After describing CRYSTAL ISLAND, we consider design implications for creating narrative-centered learning

environments that promote intrinsic motivation. We also provide a short summary of recent empirical results about student learning and engagement that were found from observing student interactions with the CRYSTAL ISLAND environment. The chapter concludes with a description of next steps for the field. This final section is aimed at researchers and practitioners interested in creating narrative-centered learning environments, as well as incorporating them into classrooms.

BACKGROUND

As digital games have become ubiquitous sources of entertainment among children and adults alike, significant attention has been directed toward appropriating the best features of games and transferring them to educational settings (Gibson, Aldrich, & Prensky, 2007). Even the harshest critics acknowledge that games can be engaging, and there is mounting evidence that games offer significant potential for learning. It is widely believed that commercial games such as Civilization, SimCity, and Spore offer some educational value, and recent large-scale deployments of educational games have yielded promising findings (Barab, Gresalfi, & Ingram-Goble, 2010; Ketelhut, Dede, Clark, & Nelson, 2010). Efforts to design serious games, which harness commercial game technologies for training, have been the subject of increasing interest in the defense community and industry (Johnson, 2010; Prensky, 2001). In parallel, recent years have seen the emergence of theoretical and epistemological foundations for educational games (Aldrich, 2004; Gee, 2003).

A key feature of state-of-the-art digital games is rich, immersive stories. Stories lend meaning to activities undertaken by players in game worlds. Digital games' emphasis on interactive stories is indicative of narratives' pervasive presence throughout human communication and culture. Graesser and Ottati (1996) argue that "stories have a privileged status in the cognitive system" (p. 123), citing experimental findings that suggest readers process

narrative texts more quickly and recall narrative information more readily than expository forms. Although stories are often associated with entertainment, they also serve a critical role in enhancing learning and problem solving (Jonassen & Hernandez-Serrano, 2002). Stories are ubiquitous tools for sharing experiential knowledge, recounting prior problem solutions, and fostering vicarious experience. Additionally, stories are instrumental in assessment by virtue of their ability to present novel situations to test transfer of generalizable skills.

Interactive narrative is the cornerstone of narrative-centered learning environments. By incorporating advances from intelligent tutoring systems, intelligent virtual agents, and commercial games, narrative-centered learning environments present opportunities for creating adaptive, situated learning experiences that are highly motivating to learners (Aylett, Louchart, Dias, Paiva, & Vala, 2005; Johnson, 2010; Mott & Lester, 2006; Thomas & Young, 2010). Narrative-centered learning environments have integrated a diverse range of educational objectives within interactive stories, such as teaching negotiation skills (Kim et al., 2009; Traum, et al. 2008) and foreign languages (Johnson, 2010), through story-driven interactions with virtual characters. Also, scientific inquiry has been realized in interactive mysteries where students play the roles of detectives (Ketelhut et al., 2010).

Interactions with narrative-centered learning environments can take several forms. Students may directly influence a narrative by completing actions in order to solve a problem, or they may indirectly influence events by providing guidance to autonomous virtual characters. Narrative-centered learning environments have been developed to support both single and multiple players, they have been realized using realistic 3D graphics engines as well as abstract cartoon-like representations, and they have structured problem-solving activities within overarching narratives, as well as sequences of related vignettes. Across these variations, the key

unifying characteristic among narrative-centered learning environments is their tight integration between interactive narrative, educational content, and pedagogy.

Case Studies of Narrative-Centered Learning Environments

Two successful examples of deployed narrative-centered learning environments are River City and Quest Atlantis. River City is a multi-user virtual environment aimed at improving middle school students' deep inquiry skills and science content knowledge (Ketelhut, 2007; Ketelhut et al., 2010). River City's narrative takes place in a late nineteenth century city, where the city's residents have mysteriously fallen ill. Students control in-game avatars and work in teams to explore the virtual city, collect clues and evidence concerning the mysterious illness, formulate and test hypotheses, and compare research findings. Science content is integrated with historical, social, and geographical content.

Over the past decade, the River City software has been used with tens of thousands of students throughout the U.S.. In a series of studies involving more than 2,000 students, the research team observed positive learning gains among students interacting with River City (Ketelhut et al., 2010). The observed learning gains exceeded gains achieved by students in a paper-based control condition with the same pedagogy. However, this finding was not replicated in two subsequent implementations, suggesting the need for further investigation. In related studies, the research team observed promising trends in that students' inquiry behaviors increase in quantity and diversity over multiple exposures to the software (Ketelhut et al., 2010). Furthermore, Ketelhut (2007) obtained preliminary evidence that interacting with River City might help undo initial differences in in-game inquiry behaviors among high and low self-efficacy students. These findings point toward narrative-centered learning environments'

promise for fostering motivation and scientific inquiry, although additional work remains to investigate their potential for promoting content learning.

As a second example, Quest Atlantis is a narrative-centered, multi-user virtual environment that has been used by over fifty thousand students internationally (Barab et al., 2010; Hickey, Ingram-Goble, & Jameson, 2009). The virtual learning environment features a complex storyline about the fictional world of Atlantis. The Atlantians' planet is in rapid decline, and students must help to restore lost Atlantian knowledge that has precipitated the world's social and environmental decay. Gameplay activities are distributed across several virtual worlds. The virtual worlds feature distinct problem-solving scenarios that connect to national and local academic standards. For example, the Taiga Park world focuses on a riverside community with a declining fish population (Hickey et al., 2009). In Taiga Park, students complete a series of quests that incorporate socioscientific inquiry and ecological science concepts, incrementally addressing the community's looming ecological and economic dilemma. Students interact with virtual characters, collect and analyze data, and write and submit reports in order to improve the quality of the river.

Quest Atlantis's educational effectiveness has been investigated for several academic subjects, including middle school science (Hickey et al., 2009) and language arts (Barab et al., 2010; Warren, Dondlinger, & Barab, 2008). Empirical studies with a range of elementary student populations found that interactions with Quest Atlantis yielded significant learning gains on both proximal and distal test items, although the learning gains were statistically no different than traditional, text-based comparison treatments (Hickey et al., 2009). In another study, the research team observed substantial motivational benefits of Quest Atlantis compared to a comparison condition. The study examined a writing-focused version of the software, and the results

suggested that students who played Quest Atlantis completed significantly more voluntary writing exercises than students in a face-to-face instruction comparison condition (Warren et al., 2008). While these findings are promising, it should be noted that neither of the studies were randomized controlled experiments.

The narrative-centered learning environment that is the focus of the current chapter, CRYSTAL ISLAND, was explicitly designed to foster content learning gains and intrinsic motivation for a curriculum that is aligned with state educational standards. Intrinsic motivation has previously been shown to positively impact student learning outcomes (Cordova & Lepper, 1996). Identifying factors that contribute to intrinsic motivation provides a foundation for formulating design guidelines for creating effective and engaging narrative-centered learning environments, as well as a theoretical framework for assessing the environments empirically.

Motivation

Motivation is a powerful force: it drives humans to act (Schunk, Pintrich, & Meese, 2007). Two types of motivation have been studied extensively: Extrinsic and intrinsic motivation. *Extrinsic motivation* refers to engaging in a behavior because of external influences, such as tangible rewards or pressures (Ryan & Deci, 2000). Extrinsic motivation does not stem from one's internal interests. Instead, extrinsically motivated behavior can often be attributed to acting for the reward of pleasure or security manifested by something other than the task itself. Intrinsic *motivation* refers to engaging in a behavior because it is inherently interesting (Malone, 1981; Malone & Lepper, 1987; Ryan & Deci, 2000). The behavior is undertaken solely for the challenge it poses, the enjoyment it yields, or the curiosity it satisfies; the act has some internal utility. Intrinsic motivation is favored because it has been associated with quality learning and creativity (Ryan & Deci, 2000). Further, it is believed that pedagogy that cultivates interest in a

subject matter is more likely to lead to self-initiated learning beyond instructional experiences (Bandura, 1997).

Malone and Lepper (1987) outline a taxonomy of intrinsic motivations that consists of both individual and interpersonal factors. We focus on the four individual intrinsic motivators: challenge, control, curiosity, and fantasy.

- *Challenge:* Tasks that are too easy or impossibly difficult will foster little or no intrinsic interest and may lead to student boredom or frustration, respectively. Designing optimally challenging tasks will enhance student motivation.
- *Curiosity:* Student interest can be maintained by controlling for an optimal level of discrepancy between the student's current knowledge and skills and the expected knowledge and skills following engagement in particular activities.
- *Control:* Humans have a basic tendency to desire a hand in their own fate. Providing mechanisms that allow students to manipulate the learning experience results in a sense of power and choice.
- *Fantasy*: Playing to students' abilities to develop mental models of situations that are not present contributes to motivation. Fantasies can evoke each of the other intrinsic motivators in ways that otherwise are unavailable to the student in reality.

These four intrinsic motivators can be realized in a number of forms within narrative-centered learning environments. In the next section, we describe a narrative-centered learning environment that was designed with the four intrinsic motivators in mind. We summarize several design decisions about how the motivators were implemented in the narrative environment, as well as empirical findings about the environment's instructional and motivational effectiveness.

[Insert Figure 14.1]

EXEMPLAR: CRYSTAL ISLAND

For the past several years, the authors and their colleagues have been designing, implementing, and conducting empirical studies with CRYSTAL ISLAND (McQuiggan, Rowe, & Lester, 2008; Mott & Lester, 2006; Rowe, Shores, Mott, & Lester, in press). CRYSTAL ISLAND (see Figure 14.1) is a narrative-centered 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 science 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.

To illustrate the behavior of CRYSTAL ISLAND, consider the following situation. 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 become 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, 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 bacteria. 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.

Motivational Design Issues for Narrative-Centered Learning

The design of narrative-centered learning environments demands careful consideration of the factors promoting student motivation. Exploiting various motivational features during a narrative learning experience can influence factors, such as student focus and depth-of-involvement (Parker & Lepper, 1992). As noted above, challenge, curiosity, control, and fantasy are key factors affecting intrinsic motivation (Malone & Lepper, 1987). We consider how narrative-centered learning environments can address each factor and illustrate the discussion with examples from CRYSTAL ISLAND.

Challenge

Theories of intrinsic motivation suggest that humans often equate objectives that are challenging with those that are meaningful. Overcoming a challenging task provides a student with a personal sense of achievement and a test of her abilities. Challenge depends on student characteristics such as efficacy, prior knowledge, and skills, as well as inherent task difficulty. Maintaining optimal levels of challenge throughout a learning experience is important.

Excessively low-challenge periods may cause the student to feel bored, but high-challenge periods may bring about frustration and feelings of hopelessness. Incorporating intelligent tutoring system and interactive narrative models provides a promising technological route for dynamically tailoring challenge levels to individual students. Investigating intelligent tutoring systems and interactive narrative models is a key element of the research agenda that we are undertaking with the CRYSTAL ISLAND learning environment (Mott & Lester, 2006).

Pedagogical and narrative goals serve as natural embodiments of challenge in narrative-centered learning environments. While pedagogical goals generally surface as tasks that reveal information to be learned or provide problem-solving experience, narrative goals involve interactions that advance the plot. The exploratory learning structure of CRYSTAL ISLAND is goal-based, unifying pedagogical and narrative goals into singular objectives that drive the experience. The learning environment utilizes fixed goals and emergent goals, as well as short- and long-term goals, in defining the interaction. Fixed goals are specific, system-dictated objectives that may be assigned by a virtual character or appear on screen through a heads-up display. Examples of fixed goals include "Speak to the camp nurse" or "Run a laboratory test on the milk container." These are short-term goals for the student, and they can be accomplished by performing a well-defined sequence of actions. In contrast, emergent goals are student-defined tasks that arise as a function of the narrative path chosen. Interactive narrative environments, such as CRYSTAL ISLAND, permit several paths to progress through the story, each of which may be supported by different plot points and realizations of pedagogical objectives. One interaction may compel the student to find and test a banana for contamination, whereas a separate interaction may not involve bananas at all. These goals emerge from the student's chosen path through the story. Finally, long-term goals in CRYSTAL ISLAND arise through complex multi-step

objectives posed to the student, such as “Solve the mystery” or “Cure the sick patients.” Long-term goals provide a driving force behind the story, and serve as a baseline motivator.

Uncertainty is useful in conceptualizing optimal goal challenge. At a given time, the student should be unsure about whether she will accomplish a goal or fail. This unpredictability provides an incentive to attempt a goal, coinciding with an innate student desire to test one’s own abilities (Malone & Lepper, 1987). The mystery-based plot of CRYSTAL ISLAND provides a deliberate embodiment of goal uncertainty, incorporating variable goal locations and difficulty levels. The interaction also begins with the student having no knowledge of the epidemic’s cause, nor any sense of whether the mystery can be solved. Gradually revealing secrets underlying the mystery drives the entire experience.

Performance feedback and student self-esteem also influence a student’s perceived challenge. The characters of CRYSTAL ISLAND manipulate student perceptions of challenge through dialogue in which characters demonstrate or hint at the level of difficulty for a particular task. Capitalizing on the task-oriented nature of CRYSTAL ISLAND, models of affect (Lee, McQuiggan, & Lester, 2007) are likely to aid in understanding the affective responses to student appraisal of goal progression. For example, affect models can detect student frustration indicating that the challenge level may be too difficult. The student’s experience can then be adapted, perhaps through character acknowledgement of the task’s difficulty or comments on the student’s expended effort. Further, models of student efficacy (McQuiggan, Mott, & Lester, 2008) may provide useful insight to a student’s perceived challenge level through recognition of self-beliefs about the ability to manage the task at hand.

Curiosity

Curiosity is inherently motivating. It is typified by an individual's drive to explore and discover some unknown subject, a desire that exemplifies motivation. Narrative introduces additional sources for evoking curiosity beyond the core subject matter. However, narrative-centered learning environments must be carefully designed so that story-centric curiosity does not detract from learning objectives. A balance must be struck between narrative elements that contribute to the richness of a story world and elements that introduce seductive details. In CRYSTAL ISLAND, we have observed the best results with a streamlined mystery narrative that incorporates enough elements to create a coherent and believable story scenario, but does not introduce extraneous plot twists or characters that have no bearing on the overall problem-solving task. For example, previous versions of CRYSTAL ISLAND included a poisoning scenario that was intended to heighten drama and enrich characters' personalities. While preliminary findings suggested that these additions contributed to engagement in the narrative, they did not appear to contribute to engagement in the game's educational objectives (McQuiggan, Rowe, Lee, & Lester, 2008). We observed that the extraneous narrative elements were associated with diminished student learning gains, perhaps as a result of the additional time that the elements occupied or cognitive load they imposed. As a consequence of this investigation, we typically adhere to the following design heuristic: narrative elements are only included if they directly contribute to the immersive quality of the story world or invoke curiosity or meaning making for an explicit educational objective.

Curiosity involves both sensory and cognitive influences (Malone & Lepper, 1987). Sensory curiosity is triggered through appeals to students' senses such as aesthetic visual design, dramatic lighting, and enticing sounds. CRYSTAL ISLAND promotes sensory curiosity through its use of rich graphics, physics, and behaviors for the surrounding world. Non-player characters are

realistically rendered with high-polygon models and realistic animations. The surrounding world is realized with authentic-looking lighting, detailed landscapes and atmospheric sound effects. This high-fidelity experience provides strong sensory stimuli.

In contrast, cognitive curiosity centers on the desired modification of cognitive forms into well-formed structures like narrative completeness, consistency, and parsimony (Malone & Lepper, 1987). A student will pursue a subject in hopes of removing incompleteness and inconsistency from her understanding. Again, this is concretized in CRYSTAL ISLAND's science mystery, where students have an incomplete understanding of the elements responsible for the research team's illness. The spreading disease is inconsistent with a student's desire that the team members should be healthy, instigating a desire to solve the mystery.

Control

Control is one of the major tenets of interactive narratives, such as CRYSTAL ISLAND. Interactive narratives are explicitly intended to produce story experiences that react to a student's decisions and actions. The student's influence on the developing story reinforces feelings of competence and self-determination, both of which contribute to intrinsic motivation (Deci & Ryan, 1985). Similarly, perception of control, in contrast to actual control, is an integral motivational factor (Malone & Lepper, 1987).

Responsiveness, choice, and power contribute to the student's sense of control in narrative-centered learning environments. Nearly all events in CRYSTAL ISLAND are contingent upon student actions; when a student approaches a door and presses the 'Use' key, the door perceivably opens; when a student approaches a non-player character (NPC) and engages in a multimodal conversation, the character will respond appropriately with speech and gesture. The environment responds to student actions in clear and observable ways. This seemingly simple

behavior is imperative for fostering a sense of responsiveness and power. Furthermore, students are free to choose how to navigate the world, interact with the environment, and solve the mystery. This flexibility is intended to provide students with a strong sense of choice, similarly advancing feelings of empowerment and motivation.

Fantasy

Narrative-centered learning environments use virtual settings and characters, which makes them an ideal platform for incorporating fantasy elements into learning. Fantasy has previously been shown to significantly influence motivation in elementary school students (Parker & Lepper, 1992). However, designing environments without considering both audience interests and fantasy themes can actually be detrimental to intrinsic motivation (Malone & Lepper, 1987). In designing CRYSTAL ISLAND, we have aimed to develop a fantasy setting that is sufficiently exotic to evoke broad interest, but recognizable enough to avoid confusion or distraction from the educational task.

Endogenous, emotional, and cognitive factors contribute to fantasy as an intrinsic motivator (Malone & Lepper, 1987). Endogenous fantasy refers to a bi-conditional relationship between the skills being learned and the fantasy supporting learning. Such environments tolerate neither the variation of pedagogical components without modification of the fantasy nor alteration of the fantasy without variation of pedagogical components. This contrasts with exogenous fantasy, where the context depends on the skills being learned, but the skills do not depend upon the fantasy. The fantasy inherent in CRYSTAL ISLAND is endogenous. One of the primary objectives for the environment is learning through exploration and the scientific method, which is central to the actions necessary for solving the mystery. Removing either the mystery

elements or the exploratory elements of CRYSTAL ISLAND would change both the pedagogical and narrative content of the experience.

Fantasy can elicit emotional reactions in students that support enhanced intrinsic motivation. Narrative context introduces opportunities for vicarious, affective experiences such as fame, adventure, and intrigue. Story worlds may also introduce non-player characters with which the student may identify and potentially develop empathetic relationships. CRYSTAL ISLAND's remote island environment, its empathetic characters, and the mysterious, spreading illness were designed to elicit emotional reactions, thereby influencing intrinsic motivation. Models of student affect (Lee et al., 2007) might also be used to influence narrative and pedagogical planning, ideally enhancing student motivation in real-time.

Impact on Motivation and Learning

Over the past five years, more than 1,500 students have interacted with CRYSTAL ISLAND through a series of studies that have been used to iteratively refine the learning environment. For example, a recent study (Rowe et al., in press) investigated the relationship between learning and engagement in game-based learning environments. The investigation explored questions in the science education community about whether learning effectiveness and engagement are synergistic or conflicting in game-based learning. The study related to concerns that, on the one hand, students interacting with a game-based learning environment may be engaged but unlikely to learn, while on the other hand, traditional learning technologies may promote learning but provide limited engagement.

The investigation used data from a study involving over 150 middle school students interacting with CRYSTAL ISLAND. For the study, students entered the study room having completed a majority of pre-study test materials one week prior to the intervention. The pre-

study materials included a content test comprised of 16 multiple-choice questions about relevant microbiology concepts. Upon entering the study room, students were provided with general details about CRYSTAL ISLAND and the game's controls through an introductory presentation. After the presentation, students completed the remaining pre-study materials and received 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 learning environment's controls.

Students were given 60 minutes to work on solving the mystery. Immediately after solving CRYSTAL ISLAND's science mystery, or after 60 minutes of interaction, participants completed a post-study content test and several post-study questionnaires. The content test was identical to the pre-study content test. The post-study questionnaires included a Perceived Interest Questionnaire (Schraw, 1997) and Presence Questionnaire (Witmer & Singer, 1998). The Perceived Interest Questionnaire consists of 10 Likert items that measure students' situational interest. The scale was adapted from a previous version (Schraw, 1997) that assessed interest in literary texts. The Presence Questionnaire consists of 32 Likert items that measure user perceptions of presence, which refers to the subjective experience of feeling transported into a virtual environment (Witmer & Singer, 1998). The Presence Questionnaire is widely regarded as a standard questionnaire for post-hoc subjective assessments of presence in virtual environments.

In addition to the post-study materials, the CRYSTAL ISLAND environment recorded an in-game score that provided a quantitative assessment of students' progress and efficiency in completing the science mystery. In-game score served as a loose proxy for in-game engagement. Details about the in-game score's calculation have been previously described by Rowe et al. (in

press). The number of in-game sub-goals that students completed was also logged, and it served as a measure of problem solving. Post-study materials took no longer than 30 minutes for participants to complete. In total, sessions lasted up to 120 minutes.

An investigation of learning gains found that students answered 2.35 (*SD*=2.75) more questions correctly on the post-test than the pre-test. The effect was observed to be statistically significant. The relationship between learning and engagement was investigated by analyzing students' learning gains, problem-solving performance, and several engagement-related factors. The engagement-related factors included presence, situational interest, and in-game score. Rather than finding an oppositional relationship between learning and engagement, the study found a strong positive relationship between learning outcomes, in-game problem solving, and increased engagement. Partial correlations controlling for pre-test score found significant relationships between microbiology post-test scores and two engagement-related measures, presence ($r = .25$, $p < .01$), and final game score ($r = .38$, $p < .01$). A subsequent linear regression analysis indicated that microbiology background knowledge, presence, and final game score were all significant predictors of microbiology post-test score ($R^2 = .33$, $F(3, 143) = 23.5$, $p < .001$). Similarly, a partial correlation analysis controlling for content pre-test score found significant relationships between sub-goals completed and microbiology post-test performance ($r = .40$, $p < .01$) and presence ($r = .24$, $p < .01$).

NEXT STEPS

Narrative-centered learning environments show significant promise for fostering positive learning gains while simultaneously promoting student motivation. Strong connections between narratives, educational games, and intrinsic motivation ground arguments that narrative-centered learning environments promote learning and engagement through the constructs of challenge,

control, curiosity, and fantasy. These motivational factors underlie key design issues in creating narrative-centered learning environments that synergistically integrate learning and engagement. Over the past several years, we have actualized these designs through an iterative development process in creating CRYSTAL ISLAND, a narrative-centered learning environment for middle school microbiology. Empirical results from a study involving middle school students have shown that CRYSTAL ISLAND effectively integrates student learning and engagement. In the future, we will be expanding the scope and length of CRYSTAL ISLAND's curriculum and narrative, as well as enhancing the existing interactive narrative features that foster intrinsic motivation for scientific problem solving. To further understand the effects of narrative on motivation, we plan to investigate real-time diagnosis of student motivation and devise an expanded array of techniques to create adaptive narratives tailored to learning episodes of individual students.

Research on narrative-centered learning environments is still in its nascent stages, and fundamental questions about their design, effectiveness, and deployment will likely drive the field for the next several years. Identifying a set of design principles to guide the creation of effective narrative-centered learning environments will be especially critical; in the same sense that some digital games are more compelling than others, well-designed narrative-centered learning environments may yield superior learning and motivational outcomes than poorly designed systems. Systematically investigating narrative-centered learning environments for a broad range of subjects and contexts will also be essential for properly assessing the pedagogical potential of this novel class of educational tools.

Compared to paper-based methods and non-immersive computer software, narrative-centered learning environments are relatively expensive to develop. Fortunately, these costs are

rapidly dropping with advances in computing power, as well as improvements in development tools. Similarly, deployment costs are rapidly dropping with the emergence of web-based distribution technologies. As these costs continue to fall, it will be essential to devise an extensive empirical account of the effectiveness of narrative-centered learning environments, as well as how students interact with these systems. These investigations should combine randomized controlled experiments as well as design-based field studies. Along these lines, it will be essential to devise frameworks for effectively incorporating narrative-centered learning environments in a range of educational contexts, including both classrooms and informal education settings.

As narrative-centered learning environments move out of the laboratory and into schools, professional development resources will become increasingly valuable for teachers to be able to readily determine how to successfully implement narrative-centered learning environments in their classrooms. Teachers trained in the most effective use of narrative-centered learning environments will likely yield maximum pedagogical and motivational benefits for students. Further, it will be important to develop supplementary classroom materials that complement the core story experiences presented by narrative-centered learning environments, extending the motivational impacts of these systems in a cost-effective manner.

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REFERENCES

Aldrich, C. (2004). *Simulations and the future of learning: An innovative (and perhaps revolutionary) approach to e-learning*. San Francisco, CA: John Wiley & Sons.

Aylett, R., Louchart, S., Dias, J., Paiva, A., & Vala, M. (2005). FearNot! An experiment in emergent narrative. In T. Panayiotopoulos, T. Gratch, R. Aylett, D. Ballin, P. Oliver, & T. Rist (Eds.), *Proceedings of the 5th International Conference on Intelligent Virtual Agents* (pp. 305-316). Berlin, Heidelberg: Springer-Verlag.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York, NY: Freeman.

Barab, S. A., Gresalfi, M., & Ingram-Goble, A. A. (2010). Transformational play: Using games to position person, content, and context. *Educational Researcher*, *39*, 525-536. doi: 10.3102/0013189X10386593

Bruner, J. (1991). The narrative construction of reality. *Critical inquiry*, *18*, 1-21.

Cordova, D. I., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of Educational Psychology*, *88*, 715-730. doi: 10.1037/0022-0663.88.4.715

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York, NY: Springer.

Egri, L. (1960). *The art of dramatic writing: Its basis in the creative interpretation of human motives*. New York, NY: Simon and Schuster.

Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. New York, NY: Palgrave Macmillan.

Gibson, D., Aldrich, C., & Prensky, M. (2007). *Games and simulations in online learning: Research and development frameworks*. Hershey, PA: Information Science Publishing.

Graesser, A. C., & Ottati, V. (1996). Why stories? Some evidence, questions, and challenges. In R. S. Wyer (Ed.), *Knowledge and memory: The real story* (pp. 121-132). Hillsdale, NJ: Erlbaum.

Hickey, D. T., Ingram-Goble, A. A., & Jameson, E. M. (2009). Designing assessments and assessing designs in virtual educational environments. *Journal of Science Education and Technology*, *18*, 187-208. doi: 10.1007/s10956-008-9143-1

Johnson, W. L. (2010). Serious use of a serious game for language learning. *International Journal of Artificial Intelligence in Education*, *20*, 175-195. doi: 10.3233/JAI-2010-0006

Jonassen, D. H., & Hernandez-Serrano, J. (2002). Case-based reasoning and instructional design: Using stories to support problem solving. *Educational Technology Research and Development*, *50*(2), 65-77. doi: 10.1007/BF02504994

Ketelhut, D. J. (2007). The impact of student self-efficacy on scientific inquiry skills: An exploratory investigation in River City, a multi-user virtual environment. *Journal of Science Education and Technology*, *16*, 99-111. doi: 10.1007/s10956-006-9038-y

Ketelhut, D. J., Dede, C., Clarke, J., & Nelson, B. C. (2010). A multi-user virtual environment for building higher order inquiry skills in science. *British Journal of Educational Technology*, *41*, 56-68. doi: 10.1111/j.1467-8535.2009.01036.x

Kim, J., Hill, R. W., Durlach, P. J., Lane, H. C., Forbell, E., Core, M., Marsella, S. C., Pynadath, D., & Hart, J. (2009). BiLAT: A game-based environment for practicing negotiation in a cultural context. *International Journal of Artificial Intelligence in Education*, *19*, 289-308.

Lee, S., McQuiggan, S. W., & Lester, J. C. (2007). Inducing user affect recognition models for task-oriented environments. In C. Conati, K. McCoy, & G. Paliouras (Eds.), *Proceedings of the Eleventh International Conference on User Modeling* (pp. 380-384). Berlin, Heidelberg: Springer.

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science*, *5*, 333-369.

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomic model of intrinsic motivations for learning. In R. E. Snow & M. J. Farr (Eds.), *Aptitude, learning, and instruction: III. Conative and affective process analysis* (pp. 223-253). Hillsdale, NJ: Erlbaum.

McKee, R. (1997). *Story: Substance, structure, style and the principles of screenwriting*. New York, NY: HarperCollins.

McQuiggan, S. W., Mott, B. W., & Lester, J. C. (2008). Modeling self-efficacy in intelligent tutoring systems: An inductive approach. *User Modeling and User-Adapted Interaction*, *18*, 81–123.

McQuiggan, S. W., Rowe, J. P., Lee, S., & Lester, J. C. (2008). Story-based learning: The impact of narrative on learning experiences and outcomes. In B. Woolf, E. Aimeur, R. Nkambou, & S. Lajoie (Eds.), *Proceedings of the Ninth International Conference on Intelligent Tutoring Systems* (pp. 530–539). Berlin, Heidelberg: Springer.

McQuiggan, S. W., Rowe, J. P., & Lester, J. C. (2008). The effects of empathetic virtual characters on presence in narrative-centered learning environments. In M. Burnett, M. F. Costabile, T. Catarci, B. de Ruyter, D. Tan, M. Czerwinski, & A. Lund (Eds.), *Proceedings of the 26th Annual SIGCHI Conference on Human Factors in Computing Systems* (pp. 1511-1520). New York, NY: ACM Press.

Mott, B. W., & Lester, J. C. (2006). Narrative-centered tutorial planning for inquiry-based learning environments. In M. Ikeda, K. D. Ashley, & T. W. Chan (Eds.), *Proceedings of the Eighth International Conference on Intelligent Tutoring Systems* (pp. 675–684). New York, NY: Springer.

Parker, L. E., & Lepper, M. R. (1992). Effects of fantasy contexts on children's learning and motivation: Making learning more fun. *Journal of Personality and Social Psychology*, *62*, 625-633. doi: 10.1037/0022-3514.62.4.625

Polkinghorne, D. (1988). *Narrative knowing and the human sciences*. Albany, NY: State University of New York Press.

Prensky, M. (2001). *Digital game-based learning*. New York, NY: McGraw-Hill.

Rowe, J. P., Shores, L. R., Mott, B. W., & Lester, J. C. (in press). Integrating learning, problem solving, and engagement in narrative-centered learning environments. *International Journal of Artificial Intelligence in Education*.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, *25*, 54-67. doi:10.1006/ceps.1999.1020

Schraw, G. (1997). Situational interest in literary text. *Contemporary Educational Psychology*, *22*, 436-456. doi: 10.1006/ceps.1997.0944

Schunk, D., Pintrich, P., & Meese, J. (2007). *Motivation in education: Theory, research and application* (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Thomas, J. M., & Young, R. M. (2010). Annie: Automated generation of adaptive learner guidance for fun serious games. *IEEE Transactions on Learning Technologies*, *3*, 329–343. doi: 10.1109/TLT.2010.32

Traum, D., Marsella, S. C., Gratch, J., Lee, J., & Hartholt, A. (2008). Multi-party, multi-issue, multi-strategy negotiation for multi-modal virtual agents. In H. Prendinger, J. Lester, & M. Ishizaka (Eds.), *Proceedings of the 8th International Conference on Intelligent Virtual Agents* (pp. 117-130). Berlin, Heidelberg: Springer.

Warren, S. J., Dondlinger, M. J., & Barab, S. A. (2008). A MUVE towards PBL writing: Effects of a digital learning environment designed to improve elementary student writing. *Journal of Research on Technology in Education*, *41*, 113-140.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*, *7*, 225-240. doi: 10.1162/105474698565686

FIGURE LIST