

# CRYSTAL ISLAND: A Narrative-Centered Learning Environment for Eighth Grade Microbiology

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**Abstract.** Narrative-centered learning environments offer significant promise for promoting interactive learning experiences that are both effective and engaging. Models of narrative generation and reasoning can balance the motivational and pedagogical aspects of narrative-centered learning interactions. Affect recognition and affect expression models are useful for shaping students' affective trajectories during narrative-centered learning. Conducting empirical evaluations are critical for determining what factors contribute to the potential pedagogical and motivational benefits of narrative-centered learning environments. This paper presents an overview of progress in these areas by summarizing work on CRYSTAL ISLAND, a narrative-centered learning environment for eighth grade microbiology.

**Keywords.** Narrative-centered learning environments, game-based learning environments, affect recognition, affect expression, evaluation.

## 1. Introduction

Narrative-centered learning environments (NLEs) afford significant opportunities for students to participate in motivating story-based educational experiences. By combining commercial game technologies, intelligent tutoring systems, and rich narrative structures, NLEs seek to provide effective, engaging learning experiences that are tailored to individual students. NLEs show promise for encouraging problem solving, strategic and analytical thinking, decision-making, and other 21<sup>st</sup> century skills [1]. They also serve as a natural platform for adapting learning experiences to individual students. Recent work on narrative-centered learning environments has investigated pedagogical agents with rich models of dialogue [2, 3], affect [4, 5, 6] and social behavior [7], director agents that can manipulate the pedagogical and narrative directions of learning experiences [8], models for detecting students' emotional and motivational states [9], and predictive models of students' goals [10] and other in-game behaviors. NLEs are currently under investigation in a range of domains, including language learning [2, 11], anti-bullying education [5], and science learning [12].

This paper presents work on several experimental versions of CRYSTAL ISLAND, a narrative-centered learning environment developed for middle school students in the

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domain of eighth-grade microbiology. Specifically, it summarizes several lines of investigation that have explored how computational models of narrative and affect can be leveraged in NLEs to create effective, engaging learning experiences. The structure of the paper is as follows. Section 2 provides background and related work on narrative-centered learning environments. Section 3 provides a detailed description of the CRYSTAL ISLAND virtual environment. Following in Section 4 is a summary of work on narrative generation and reasoning, affective recognition and expression, and evaluation in CRYSTAL ISLAND. Section 5 provides concluding remarks and a brief discussion of future work.

## **2. Background and Related Work**

Narrative-centered learning environments offer significant potential for enhancing students' learning experiences. Stories draw audiences into plots and settings, thereby opening perceptual, emotional, and motivational opportunities for learning. Establishing concrete connections between narrative context and pedagogical subject matter has been said to support the assimilation of new ideas in young learners [13]. Narratives can also facilitate students' semantic encoding of new information and making commitments to long-term memory in the form of episodic memories [14]. Furthermore, fantasy contexts in educational games have been shown to provide motivational benefits for learning [15]. Although it is important to remain mindful of potential disadvantages such as seductive details [16], a dynamically generated narrative that draws students into the evolving plot has the potential to be pedagogically compelling.

Narrative-centered learning environments leverage a range of techniques for providing effective, engaging learning experiences. Multi-user virtual environments such as Quest Atlantis [17] and River City [18] use rich narrative settings to contextualize inquiry-based science learning scenarios with strong social and ethical dimensions. Although the systems do not use artificial intelligence to provide tailored narrative or learning experiences, several classroom studies have yielded promising learning results. Other work on narrative-centered learning environments has applied a range of techniques to generating engaging interactive narrative experiences that are pedagogically effective and tailored to individual students. FearNot! uses affectively-driven autonomous agents to generate dramatic, educational vignettes about bullying [5]. In between the non-interactive vignettes, the virtual agent consults the student for advice about prior bullying scenarios, and then uses this feedback to inform its behavior in subsequent vignettes. The Thespian architecture takes a decision-theoretic, multi-agent approach to controlling virtual characters in the Tactical Language and Culture Training System's narrative scenarios [11, 2]. The agents' goal-driven behaviors are trained using a corpus of linear, pre-authored scripts, providing the agents with believable behavior models for conversing with students during language and culture training scenarios [2]. The SASO (Stability and Support Operations) narrative-centered learning environment uses robust, socially intelligent virtual humans as actors in military training scenarios. SASO's virtual humans implement models of multimodal conversational behavior [19, 3], affective reasoning [4], and social behavior [7].

Computational models of affect recognition and affect expression are also important for effective narrative-centered learning environments. The AI in Education

community has seen the emergence of work on affective student modeling [20], detecting frustration and stress [21, 22, 23], modeling agents' emotional states [24, 4], devising affectively informed models of social interaction [25, 26, 27], detecting student motivation [28], and diagnosing and adapting to student self-efficacy [29]. All of this work seeks to increase the fidelity with which affective and motivational processes are understood and utilized in intelligent tutoring systems in an effort to increase the effectiveness of tutorial interactions and, ultimately, learning. Recent work has also sought to characterize the affective experiences of learners interacting with intelligent learning environments by considering student affective trajectories during learning [30, 31, 32].



**Figure 1.** The CRYSTAL ISLAND narrative-centered learning environment.

### 3. Crystal Island

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. 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. Students play the role of the protagonist, Alyx, who is attempting to discover the identity and source of an infectious disease plaguing a newly established research station. The story opens by introducing the student to the island and members of the research team for which the protagonist's father serves as the lead scientist. Several of the team's members have fallen gravely ill, including Alyx's father. Tensions have run high on the island, and prior to Alyx's arrival various team members began to accuse one another of having poisoned the sick researchers. It is the student's task to discover the outbreak's cause and source, and determine whether one of the team members is guilty of poisoning.

CRYSTAL ISLAND's setting includes a beach area with docks, an outdoor field laboratory, underground caves, and a research camp. Throughout the mystery, the student is free to explore the world and interact with other characters while forming questions, generating hypotheses, collecting data, and testing hypotheses. The student can pick up and manipulate objects, take notes, view posters, operate lab equipment, and talk with non-player characters to gather clues about the source of the disease. During the course of solving the mystery, the student is minimally guided through a five problem curriculum. The first two problems focus on pathogens, including viruses,

bacteria, fungi, and parasites. The student gathers information by interacting with in-game pathogen “experts” and viewing books and posters in the environment. In the third problem, the student is asked to compare and contrast her knowledge of four types of pathogens. In the fourth problem, the student is guided through an inquiry-based hypothesis-test-and-retest problem. In this problem she must complete a “fact sheet” with information pertaining to the disease afflicting members of the research team. Once the “fact sheet” is completed and verified by the camp nurse, the student completes the final problem concerning an appropriate treatment plan for the sickened CRYSTAL ISLAND researchers.

To illustrate the behavior of CRYSTAL ISLAND, consider the following situation. Suppose a student has been interacting with virtual agents in the storyworld and learning about infectious diseases. In the course of having members of the research team become ill, she has learned that an infectious disease 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 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 disease is *E. coli*. The student reports her findings back to the camp nurse, and they discuss a plan for treatment. The *E. coli* diagnosis ultimately exonerates the members accused of poisoning, and the sick researchers make a speedy recovery.

#### **4. Current Progress**

Narrative-centered learning environments are inherently complex systems, and multiple lines of investigation are necessary to develop suites of technologies that can produce adaptive, engaging learning experiences. To date three principal areas of research have been conducted with the CRYSTAL ISLAND virtual environment: narrative generation and reasoning, affect recognition and expression, and empirical evaluation of NLEs.

##### *4.1. Narrative Generation and Reasoning*

Because of their interactive nature, narrative-centered learning environments must cope with a wide range of student actions that can be performed in a virtual environment. Providing students with a strong sense of control and agency is important for supporting motivation [33], but agency also introduces opportunities for students to violate or ignore important aspects of an intended narrative experience. This presents a major challenge for narrative-centered learning environments: to simultaneously maintain the coherence and pedagogical effectiveness of a learning experience, but permit significant user agency in the environment. Developing computational models that can reason about students’ actions within the narrative, adapt and re-plan narrative events in response to student actions, and promote robust, believable interactions with virtual characters is critical.

Models of narrative generation for CRYSTAL ISLAND have taken a dual planning space approach, with one planning space allocated to tutorial planning and a second

allocated to narrative planning [34]. A tutorial planner supports the requirements of inquiry-based learning by formulating tutorial strategies that encourage question formation, hypothesis generation, data collection, and hypothesis testing. A narrative planner is responsible for generating plot elements, sequencing plot elements into coherent and engaging stories, and directing characters' actions and storyworld events to achieve tutorial and narrative goals. However, for the two planners to work in concert, they must effectively coordinate their actions, resulting in a single stream of events occurring in the virtual storyworld. To this end, the tutorial planner posts goals in the tutorial planning space that are achieved by operators in the narrative planning space. This tutorial-driven model seeks to balance plot advancement and tutorial goal achievement seamlessly by the built-in coordination of the two planning spaces via lower-level tutorial constraints and the upper-level narrative goals [34].

The resulting plans are incorporated into a decision-theoretic director agent architecture that manages the narrative-centered learning experience [8]. Decision-theoretic narrative planning offers a unified approach to dynamically guiding narratives in a storytelling environment. The director agent has access to three principal knowledge sources: narrative objectives, storyworld state, and student state. To cope with the uncertainty in narrative planning, the three sets of knowledge sources are integrated into a dynamic decision network (DDN) that the director agent evaluates regularly to select the next narrative action. Once the director agent has fully updated the decision network, it selects the director action that maximizes the expected narrative utility, waits to see what action the student takes (if any) and updates its beliefs as necessary [8].

Student goal recognition is also important for narrative generation in game-based learning environments. Providing narrative planners with the ability to recognize students' goals could enable planners to monitor students to determine if their goals were consistent with the plot, and determine whether sufficient plot progress has been made. Two families of goal recognition models have been investigated in CRYSTAL ISLAND:  $n$ -gram models (unigrams and bigrams) and Bayesian network models [10]. The models, which exploit knowledge of narrative structure as well as locational information about students' activities in the world, are induced from training data acquired from traces of students' actions in the story environment. Experimental results suggest that probabilistic models can accurately predict students' goals, and that they converge on correct interpretations as observations of a student's activities become available over time [10].

An additional feature of narrative-centered learning environments is their natural support for encouraging rich, believable interactions with embodied pedagogical agents. Character dialogue behavior is crucial for defining and advancing plots, as well as scaffolding learning experiences. Character dialogue generators for interactive narrative environments must meet several requirements. They must generate dialogues that are appropriate for characters' traits, such as personalities, motivations, and preferences; they must consider narrative context and history as they formulate dialogue; and they must be able to robustly handle the large number of possible character-character and character-player interactions that may result in dialogue. CRYSTAL ISLAND takes advantage of a probabilistic unification-based dialogue generation architecture that considers multiple sources of information (character archetypes, narrative context, and communicative goals) to dynamically generate character- and situation-appropriate dialogue [35]. The generated dialogues use preference information encoded within character archetype representations and yield

character-specific variations in the dialogue that satisfy the major objectives for conversational interactions during narrative-centered learning.

#### 4.2. *Affect Recognition and Expression*

Emotion is critical for both narrative and learning. Creating narrative-centered learning environments that are in tune with students' affective experiences can provide support for guiding pedagogical scaffolding and engaging students in virtual story worlds. Affective interactions proceed through a three-stage process termed the *affective loop*: affect recognition, affect understanding, and affect expression (adapted from [36]). Affect recognition is the task of inferring a user's affective state from a sequence of observations of behavior. Affect expression is the task of determining how a system should communicate emotion. Affect understanding is the process of interpreting recognized user emotions, determining what it means for the user to feel the recognized emotion, and then formulating adaptation strategies based on how the user feels. Collectively, affect recognition, expression, and understanding have been the subject of growing attention in the AI in Education community. Work on CRYSTAL ISLAND has primarily focused on data-driven approaches to affect recognition and affect expression, and has yielded promising initial results.

Data-driven models of affect recognition are trained and validated using a rich corpus of student actions, locations, goals, physiological information, and temporal information collected during student interactions with the CRYSTAL ISLAND environment. After students' problem-solving traces have been recorded, affect recognition models are induced using supervised machine learning techniques such as naïve Bayes, decision trees, and support vector machines. This methodology has yielded affect recognition models that are both accurate and efficient, with some models capable of correctly predicting over 95% of students' emotion self-reports [9]. The same methodology has also been successfully applied to induce models of student self-efficacy in the CRYSTAL ISLAND environment [37]. Related work has investigated students' affective transitions in the CRYSTAL ISLAND environment, differentiating typical affective transitions and those stemming from pedagogical agents' empathetic responses to student affect [38]. Also important is the ability to make "early" predictions of student affect. Early detection allows systems adequate time to prepare for particular affective states, opening a window of opportunity for the learning environment to take corrective action. Inductive approaches using a combination of  $n$ -gram models and decision trees have yielded results with accuracy, precision, and recall exceeding 88%, which was significantly better than baseline comparisons [23].

Computational models of agents' empathetic behavior are an important area of investigation in affect expression. Defined as "the cognitive awareness of another person's internal states, that is, his thoughts, feelings, perceptions, and intentions" [39], empathy enables people to vicariously respond to one another via "psychological processes that make a person have feelings that are more congruent with another's situation than with his own situation" [40]. Initial work on constructing empathetic virtual agents for CRYSTAL ISLAND explored learning empirically grounded models of empathy from observations of human-human social interactions [6]. In this approach, training data is first generated as a by-product of trainers' interactions in a virtual environment, and models of empathy are induced from the resulting datasets. Critically, the training data include only features that can be directly observed in the environment, so that at runtime, the same features can be used by the empathy models to drive the

behavior of virtual agents interacting with students. Two complementary lines of evaluation, one investigating predictive accuracy and one investigating perceived accuracy, were conducted on an implemented empathy modeler, and yielded promising results. Follow-up work investigated more detailed models of empathetic agent behavior, namely the use of parallel vs. reactive empathy [41]. In the parallel case, the empathizer mimics the affective state of the target. In the reactive case, empathizers exhibit a higher cognitive awareness of the situation and react with empathetic behaviors that do not necessarily match those of the target's affective state. The results indicated that models of empathy induced from knowledge of the student's situation and the student's affective state can effectively determine which type of empathy is most appropriate for interactions requiring empathetic expression.

### *4.3. Empirical Evaluation*

The third principal line of investigation in CRYSTAL ISLAND has been empirical evaluation of narrative-centered learning environments. NLEs offer myriad opportunities for enhancing learning experiences and motivating students. However, determining appropriate metrics, criteria, and methodologies that can be used to assess NLEs poses a number of challenges. Determining the impact of individual elements of narrative-centered learning environments (setting, plot, game play activities, empathetic pedagogical agents) also introduces a wide range of practical and theoretical challenges. Further, because many narrative-centered learning environments permit activities that are not strictly pedagogical, assessment of players' action traces and problem-solving paths can have implications for environment design as well as models of adaptive scaffolding. The complexity inherent in intelligent narrative-centered learning environments calls for a sophisticated, multi-faceted approach to evaluation. Empirical evaluations of CRYSTAL ISLAND have sought to take initial steps toward this objective.

A controlled, human participant experiment with middle school students investigated the impact of narrative on learning [12]. The study compared two versions of CRYSTAL ISLAND against a more traditional instructional approach, a narrated slideshow that conveyed the same curricular material. The two CRYSTAL ISLAND conditions featured varying levels of narrative content supplementing the curriculum. The results showed that students in the NLE conditions did exhibit learning gains, but that those gains were less than those produced by traditional instructional approaches. However, the motivational benefits of narrative-centered learning, particularly with regard to self-efficacy, presence, interest, and perception of control, were substantial. Students reported the highest levels of presence in the full-narrative condition, a finding that bears important implications for motivation. A recently completed follow-up study with an updated version of the CRYSTAL ISLAND learning environment again found that students in the NLE condition exhibited learning gains, and further, with the updated version, the gains were on par with those of the slideshow condition. Numerically, the learning gains in the CRYSTAL ISLAND condition exceeded those in the slideshow condition, and analyses are underway to investigate these findings.

A different series of studies examined the impact of virtual characters' empathetic behavior on student presence in narrative-centered learning environments [42]. In a study with middle school students comparing non-empathetic and empathetic characters, it was found that empathetic characters in narrative-centered learning environments had a significant effect on measurements of students' overall presence

(total PQ), involvement and control, naturalism of the experience, and resolution. When the study was replicated with high school students, the same effects were found. In short, it appears that empathetic interactions with characters in narrative-centered learning environments can contribute to increased student presence. The results are encouraging for the motivational potential of narrative-centered learning environments, and they extend other results illustrating the relationship between narrative and presence. The work points to a need for continued examination of the impact of narrative content in virtual environments, as well as social and emotional interactions that take place during those experiences [42].

Empirical evaluations of CRYSTAL ISLAND have also focused on the nature of student behavior in narrative-centered learning environments. Work examining students' note-taking is one example. CRYSTAL ISLAND provides students with a note-taking feature so that students can document useful information encountered during learning interactions. A corpus of student notes was collected from a study involving 116 middle school students [43]. A team of judges annotated the corpus by classifying individual notes into one of several categories including narrative, curricular, and hypothesis notes. An analysis of the tagged corpus revealed that students who took hypothesis notes performed better on posttests, confirming inquiry-based learning findings suggesting the importance of scaffolding students' hypothesis generation activities. Individual differences were also able to suggest which students are likely to take notes. Results illustrated significant gender effects on note-taking, where females took significantly more notes than males. Goal orientation and efficacy for self-regulated learning also exhibited significant correlations with note-taking behavior in narrative-centered learning environments.

## **5. Conclusions and Future Work**

Narrative is the subject of increasing attention in the AI in Education community as a powerful medium for contextualizing learning. Narrative-centered learning environments present a range of opportunities for investigating how different computational models can be leveraged to create effective, engaging learning experiences. Work on the CRYSTAL ISLAND environment has begun to illustrate how models of narrative generation and reasoning, as well as affect recognition and expression, can bear on game-based learning environments. A series of empirical evaluations has begun to demonstrate the motivational and pedagogical potential of narrative-centered learning.

Results to date suggest several promising directions for future work on narrative generation and reasoning, affect recognition and expression, and empirical evaluation in narrative-centered learning environments. Currently under investigation are adaptive models for scaffolding students' narrative and pedagogical progress through a learning environment. Devising models that can integrate knowledge about the state of a virtual environment, sets of intended narrative objectives, and individual student qualities, poses serious challenges. Additionally, exploring computational models of affect understanding will become increasingly important for closing the "affective loop" that exists in interactive learning environments. Finally, a critical step in this research agenda will be conducting extensive empirical investigations to explore the relationships between narrative, affect, character behavior, and their collective impact on learning gains, self-regulated learning, and motivation.

## Acknowledgements

The authors wish to thank members of the IntelliMedia lab for their assistance, Omer Sturlovich and Pavel Turzo for use of their 3D model libraries, and Valve Software for access to the Source™ engine and SDK. This research was supported by the National Science Foundation under Grants REC-0632450, IIS-0757535, DRL-0822200 and IIS-0812291. Portions of this material are based upon work supported under a National Science Foundation Graduate Research Fellowship. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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