Narrative-Centered Environments for Guided Exploratory Learning

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ABSTRACT
Narrative-centered learning environments offer significant potential for supporting guided exploratory learning. By taking advantage of the inherent structure of narrative, narrative-centered environments provide students with engaging worlds in which they actively participate in motivating story-based problem-solving activities. Two key challenges posed by narrative-centered environments for guided exploratory learning are (1) supporting the hypothesis-generation-testing cycles that form the basis for exploratory learning, and (2) orchestrating all of the events in the unfolding story to support appropriate levels of student motivation, engagement, and self-efficacy for effective learning.

In this paper we propose a narrative-centered architecture for guided exploratory learning environments. The architecture continually constructs and updates narrative plans to support exploratory learning while monitoring the student's progress, observing her behaviors in the interactive environment, and guiding the behaviors of believable agents serving as characters in the stories. The architecture is being used to implement CRYSTAL ISLAND, a prototype narrative-centered guided exploratory learning environment under development in our lab. CRYSTAL ISLAND is a guided exploratory learning environment for the domain of microbiology in which students play the role of a detective solving a science mystery.

Categories and Subject Descriptors
H.5.1 [**Multimedia Information Systems**]: Artificial, augmented, and virtual realities

K.3.1 [**Computer Uses in Education**]: Computer-assisted instruction.

General Terms
Algorithms, Design

Keywords
Interactive Narrative, Synthetic Agents, Exploratory Learning Environments

1. INTRODUCTION
Narrative is central to human cognition. Because of the motivational force of narrative, it has long been believed that story-based learning can be both engaging and effective. Many educational software packages have been devised for story-based learning. These systems include both research prototypes and a long line of commercially available software. However, these systems have primarily relied on scripted forms of narrative: they have employed either predefined linear plot structures or simple branching storylines. In contrast, one can imagine a much richer form of narrative learning environment that dynamically crafts customized stories for individual students at runtime. Recent years have seen the emergence of a growing body of work on dynamic narrative generation [10, 31, 36], and narrative has begun to play an increasingly important role in intelligent tutoring systems [17, 21, 30]. For example, it has been shown that narrative-centered learning environments can facilitate story creation [22], second language learning [15], social behavior education [3], and problem solving for health education [21].

Narrative could play an important role in discovery learning [8], an approach to learning that emphasizes students' active exploration of a subject matter. In stark contrast to didactic pedagogies that emphasize students' memorization of facts from lectures and reading, discovery learning encourages students to learn by trial-and-error: they pose questions and answer them by conducting experiments, manipulating artifacts in physical or simulated environments, analyzing information, and systematically generating and testing their hypotheses [8, 37]. It is widely believed that discovery learning offers much promise because students actively participate in problem-solving activities [26]. However, it has been demonstrated that "pure" discovery learning in which students receive no guidance in the form of coaching and hints from a teacher or learning environment is ineffective [24]. Thus, guided discovery learning [33] and guided discovery learning environments [16] have been the subject of increasing attention in recent years.

This paper proposes a narrative-centered architecture for guided exploratory learning environments that provides students with intriguing 3D storyworlds. By dynamically creating stories that feature the student as the protagonist in engaging plots revolving around problem-solving activities, the architecture creates customized narrative experiences that scaffold exploratory learning. The architecture addresses two important challenges in exploratory learning: (1) it supports the hypothesis-generation-testing cycles that form the basis for exploratory learning, and (2) it plans all of the events in the unfolding stories to support appropriate levels of student motivation, engagement, and self-efficacy for effective learning. The architecture monitors students' progress, observes their behaviors in the storyworld, and directs the behaviors of the believable agents that act as characters in the stories. The architecture is being investigated in CRYSTAL ISLAND, a learning environment being developed for the domain of microbiology in which students solve science mysteries.

The paper is structured as follows. Section 2 discusses the challenges of guided exploratory learning environments and the role that narrative can play in their creation. Section 3 proposes a narrative-centered architecture for guided exploratory learning. Section 4 introduces the CRYSTAL ISLAND narrative-centered guided exploratory learning environment and illustrates its behavior in a learning scenario. Concluding remarks and directions for future work follow in Section 5.

2. GUIDED EXPLORATORY LEARNING AND NARRATIVE

It has long been recognized that exploration and discovery are key elements of the scientific enterprise, and recent years have seen a growing focus on their role in education. For more than a decade, science education reform efforts by organizations such as the US National Research Council and the National Academy of Sciences have set forth standards promoting a greater emphasis on discovery learning [2, 26]. In discovery learning, students approach a new topic via learning-by-doing. Instead of being presented problems and solutions in an expository fashion, students are given problems to solve, a rich environment in which to explore the problems, and a set of tools and techniques for constructing solutions. While early accounts of discovery learning focused on concept discovery [8], contemporary work views discovery learning as scientific investigation. Thus, the process of discovery learning is analogous to the scientific method: students design and perform experiments, collect data, and evaluate hypotheses [16]. First and foremost, discovery learning is *active* learning. As stated in the National Science Education Standards [26], discovery learning is "something that students do, not something that is done to them."

Discovery learning offers several advantages over more didactic approaches. It tends to increase students' ability to remember what they have learned, to apply their new knowledge, and to transfer it to new tasks more effectively than with more passive approaches that might emphasize activities such as reading textbooks [6, 16]. In addition to the cognitive benefits of discovery learning, it also offers potential motivational benefits. It enables students to become more active science learners (rather than passive consumers of information), it increases students' beliefs that scientific theories change as new evidence becomes available (rather than being seen as unchangeable entities), and perhaps most importantly, it makes science more concretely meaningful (rather than seeming too abstract) [37].

Despite the potential benefits of discovery learning, in the absence of appropriate scaffolding, discovery learning can be ineffective. Early findings suggested that discovery learning augmented with guidance can be more effective than pure discovery learning in enabling students to apply their knowledge to new problems [33]. Furthermore, students may sometimes learn incorrect concepts through discovery learning, and discovery learning may be inefficient [13]. A recent analysis of thirty years of studies on discovery learning suggests that discovery learning accompanied by guidance in the form of feedback and coaching is more effective than unguided discovery learning [24]. Thus, *guided exploratory learning* appears to be a promising alternative to didactic instruction and to pure discovery learning.

Narrative could serve as the foundation for guided exploratory learning. It is becoming apparent that narrative can be used as an effective tool for exploring the structure and process of "meaning making." Narrative analysis is being adopted by those seeking to extend the foundations of psychology [9], and one can imagine narrative-centered curricula that leverage students' innate metacognitive apparatus for understanding and crafting stories. This insight has led educators to recognize the potential of contextualizing all learning within narrative [35].

Narrative-centered environments for learning may also offer motivational benefits. Motivation is critical in learning environments, for it is clear that from a practical perspective, educational software that fails to engage students will go unused. Game playing experiences and educational experiences that are extrinsically motivating can be distinguished from those that are intrinsically motivating [19]. In contrast to extrinsic motivation, intrinsic motivation stems from the desire to undertake activities sheerly for the prospective reward. Narrative-centered exploratory learning could provide the four key intrinsic motivators identified in the classic work on motivation in computer games and educational software [20]:

- **Challenge**: Narrative-centered learning can feature challenging tasks of intermediate levels of difficulty, i.e., tasks that are not too easy and not too difficult. Dynamically created narratives can feature problem-solving episodes whose level of difficulty is customized for individual students.
- **Curiosity**: Narrative-centered learning can stimulate students' curiosity by presenting students with quests that require them to explore intriguing storyworlds and interact with engaging characters.
- **Control**: Narrative-centered environments can empower students to take control of their learning experiences; they can choose their own paths, both figuratively (through the solution space) and literally (through the storyworld), while being afforded significant guidance crafted specifically for them.
- **Fantasy**: Narrative-centered learning is inherently fantasy-based. All narrative elements ranging from plot and characters to suspense and pacing can contribute to vivid imaginative experiences.

In short, narrative can provide the guidance essential for effective exploratory learning and the "affective scaffolding" for achieving high levels of motivation and engagement.

3. AN ARCHITECTURE FOR NARRATIVE-CENTERED GUIDED EXPLORATORY LEARNING

Narrative-centered learning environments for guided exploratory learning should address two important challenges. First, they must support the hypothesis-generation-testing cycles that form the basis for exploratory learning. Plots driven by students' problem-solving activities should be tightly coupled to hypothesis-generation-testing cycles to create the best possible

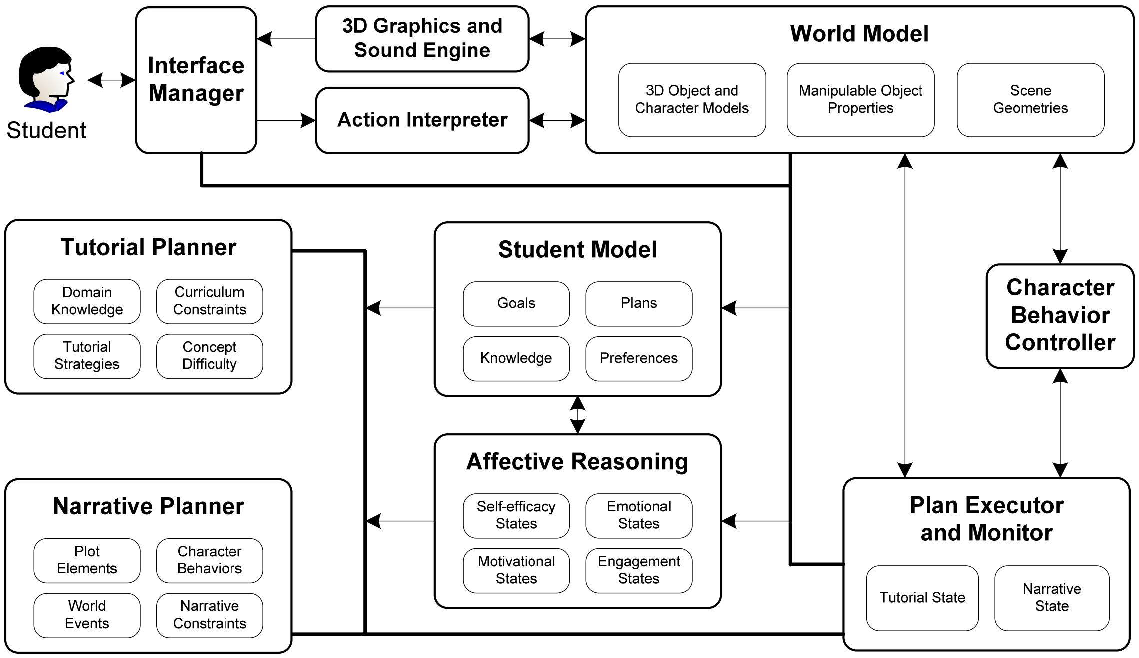

Figure 1: Narrative-Centered Guided Exploratory Learning Architecture

learning outcomes. Second, narrative-centered learning environments must plan all of the events in the unfolding stories to support appropriate levels of student motivation, engagement, and self-efficacy for effective learning. These environments must strike a delicate balance between advancing the plot and achieving tutorial goals. The former cannot be ignored without making the narrative less engaging and coherent; the latter cannot be ignored without reducing pedagogical effectiveness.

In our laboratory we are designing and implementing a narrative-centered guided exploratory learning architecture (Figure 1). Some components are fully designed and implemented, e.g., the narrative planner [25], while others are in the early stages of design. The narrative-centered architecture directs all of the core activities of its associated learning environment. All student activities are mediated through the interface manager for the virtual environment. The interface manager interacts with the world model, which houses the 3D object and character models, the properties of manipulable objects, and the scene geometries. The world model drives both the rendering and sound engines. The tutorial planner operates in a tutorial planning space. It utilizes domain knowledge, curriculum constraints, tutorial strategies, and concept difficulty annotations to make its decisions. The narrative planner operates in a narrative planning space. It utilizes a library of plot elements, a library of character behaviors, a set of world event categories, and narrative constraints on possible stories to make its decisions. The student model informs the tutorial and narrative planners as well as the affective reasoning module about the student's current objectives and progress from both a tutorial and narrative perspective. The affective reasoning module provides detailed knowledge about the student's affective state as well as information for synthesizing affective behaviors for believable characters in the storyworld. The plan executor and monitor interact with both the tutorial and narrative planners and updates the tutorial and narrative states. It sends directives to the character behavior controller and the world model.

3.1 Narrative-Centered Tutorial Planning for Guided Exploratory Learning

A dynamically constructed story featuring the student as a protagonist should propel the student through problem-solving activities directly in the service of the plot. Storyworlds should provide the "narrative backbone" for the key functionalities of guided exploratory learning. They should situate students in environments that compel them to pose scientific questions, design experiments, make predictions, and generate and test hypotheses, all in the rich context of unfolding stories. For example, a narrative-centered exploratory learning environment for microbiology, the domain of our prototype learning environment, could foster an in-depth understanding of how real-world microbiologists solve problems by featuring the student as the protagonist in a science mystery whose plot requires them to solve infectious disease problems afflicting a community.

Early interactive narrative systems were either partially or entirely scripted. The stories utilized by these systems consisted of a completely linear or simple pre-determined branching structure [7]. However, the simplicity of the tree-like representations severely limited the level of interactivity that users could experience, and the combinatorics of highly interactive storyworlds could not be accommodated. Dynamic interactive narrative planning, in which stories are created on the fly, offers a promising alternative to pre-defined branching structures. Narrative planning for interactive storytelling environments has been the subject of increasing interest [10, 17, 21, 23, 31, 36]. Recent work on narrative planning has investigated a broad range of issues for interactive story environments. The narrative community has devised techniques for tightly-coupled plot creation and character behavior in dialogue-oriented interactive stories [23], search paradigms for encoding author aesthetics with an evaluation function [36], and monitoring users' actions to determine if they are threatening the plot and, if so, either accommodating the new development or intervening [31]. Work on emergent narratives, in which highly believable synthetic agents are given initial goals in a simulated world, has been particularly active [3, 10].

The narrative and tutorial planning components of the architecture provide all of the functionalities that classic tutorial planners provide, as well as the functionalities that narrative planners provide. With regard to tutorial planning, they select and present problems, sequence content from the curriculum, provide timely and context-specific advice and explanations, manage the initiative, and select and execute tutorial strategies [28, 34, 38]. To address the requirements of exploratory learning, their tutorial strategies support question formation, hypothesis generation, data collection, and hypothesis testing. With regard to narrative planning [10, 31, 36], they generate all plot elements, sequence plot elements into coherent and engaging stories, and direct characters' actions and storyworld events to achieve tutorial and narrative goals.

It is critical that tutorial planning and narrative planning support one another: they cannot be permitted to diverge. All (or most) tutorial goals should be realized through plot elements, and all (or most) plot elements should be generated in support of tutorial goals. Although some learning might occur through non-narrative means, e.g., providing textual and animated explanations external to the story, the overarching narrative objective of "suspension of disbelief" [5] dictates that the student should remain immersed in the story to the greatest possible extent. Moreover, although engaging story events could be created that served no tutorial purpose, the interests of pedagogy must drive the student's experience.

The architecture integrates narrative planning and tutorial control via a hierarchical task network (HTN) planner [12] that operates in two coordinated planning spaces. In this approach, one planning space is allocated to tutorial planning and a second is allocated to narrative planning. This approach offers the advantage of modularity: narrative planning issues can be considered separately from tutorial planning issues. However, for the two planners to work in concert, they must effectively coordinate their actions, which will result in a single stream of events occurring in the virtual storyworld.

The tutorial planning space houses all concepts, goals, methods, and operators for reasoning about the student's learning experience, as well as the tutorial state. These encode domain knowledge, curriculum sequencing constraints represented as a partial order on concepts, the student model, and difficulty annotations on concepts. They also encode inquiry-based learning strategies that guide hypothesis-generation-testing cycles. HTN methods represent decompositions of higher level tutorial goals to lower level tutorial goals. All HTNs eventually bottom out in tutorial constraints, which collectively guide narrative planning and focus it on the most relevant regions of the narrative planning space that are consistent with the current tutorial plan.

The narrative planning space houses all goals, methods, and operators for reasoning about the storyworld. These encode plot construction knowledge, character behaviors, storyworld event categories, and narrative constraints, including coherence and flow constraints. All narrative HTNs eventually bottom out in primitive narrative events, which play out in the storyworld. These primitive events are directives that will be physically interpreted in the virtual environment.

3.2 Student Modeling for Guided Exploratory Learning

In exploratory learning, students have great freedom to explore the physical environment and the problem-solving space. However, it is precisely this freedom that poses a significant challenge to student modeling. Particularly challenging and important tasks in student modeling for exploratory learning environments are plan and goal recognition. Plan and goal recognition are the tasks of inferring the student's goals and her plans for achieving the goals in the current context. Goal and plan tracking are especially difficult when students have access to multiple techniques for solving a problem and when solution steps can have multiple (correct) orderings. When multiple goals and plans come into play, the student model must determine which is most likely given the current context.

We are currently exploring probabilistic approaches to plan recognition. Recent years have seen the successful introduction of probabilistic and statistical inference frameworks into a broad range of computational tasks. One such framework is Bayesian networks. Bayesian user modeling offers much promise because of its ability to deal with the uncertainty inherent in human-computer interaction. There appears to be great potential for Bayesian network frameworks to deal with plan recognition [1, 11] and misconception detection. In CRYSTAL ISLAND, to recognize students' plans, Bayesian student models should capture dependencies in students' actions, plans, and goals.

To provide support for guidance (advice and hint giving), Bayesian student models need to be able to determine appropriate times for intervening and providing advice. Hints can be given when students request assistance explicitly. However, in exploratory learning environments, students may not always recognize their own misconceptions and need for assistance. One approach to determining whether to provide advice is to consider what tasks have drawn the attention of the student. This approach is similar to early work in Bayesian user modeling [14]. Bayesian student models will need to interact with several components in the narrative-centered architecture, including the affective reasoning component (see below) and the tutorial and narrative planners, to address these issues. Moreover, the affective reasoning component should be able to assist the student model in recognizing students' plans, goals, and misconceptions. Knowledge of recognized affective states may lead to better and earlier detection of student misconceptions. Tutorial and narrative planners can take advantage of student model recognized goals, knowledge assessment, and mastery status of concepts to formulate appropriate tutorial and narrative strategy selection.

3.3 Affect in Guided Exploratory Learning

Because self-efficacious students are effective learners, it is important to incorporate mechanisms for diagnosing student affect (self-efficacy [4], emotional state [29], and motivation [20]) to effectively inform pedagogical decision-making. *Self-efficacy* refers to "one's beliefs in their capabilities to organize and execute the courses of action required to manage prospective situations" [4]. It influences students' reasoning, their level of effort, their persistence, and how they likely feel; it shapes how they make choices, how much resilience they exhibit when confronted with failure, and what level of success they are likely to achieve [4, 32, 39]. Emotional state is often an indication of

Figure 2: CRYSTAL ISLAND Learning Environment

how a student feels she is performing on a given task. For example, students often take pleasure in successfully completing tasks, while negative emotions, such as frustration, often accompany learning impasses. Motivation is an internal state that influences the activities students' engage in and their persistence in such activities. It can also increase activity levels in students and guide students in the direction of particular goals [18]. Adapting tutorial strategies that foster positive affective states affords a broad range of potential learning benefits, such as effectiveness, efficiency and transfer, since students tend to persist longer and put forth more effort in problem-solving activities when they enjoy what they are learning and believe in their abilities to succeed [39]. For these reasons, it is essential to coordinate affective reasoning with student modeling as well as with the tutorial and narrative planners.

We are currently considering a variety of information channels for reasoning about affect. For example, monitoring physical changes (such as physiological response) in the student, observing her behaviors and relevant events occurring in the virtual world, tracking both narrative and tutorial planning actions, and considering internal models of believable characters in the virtual world are a few of the potential sources of information available. However, recognizing student affective states is a challenging task and many approaches to date have required the use of invasive and disruptive technologies. For practical purposes, deployable systems will call for affective reasoning techniques that limit or eliminate learning disruption. The ability to reason about student affect could provide potentially useful information about how the student feels about her learning experience. This would allow the narrative and tutorial planners to consider refinements that may increase student interest, engagement, and self-efficacy by selecting specific tasks and providing directed guidance given the student's situation. Using a variety of machine learning techniques, we plan to investigate predictive modeling of affect for recognizing student levels of self-efficacy, their emotional states, and their levels of motivation. Further, reasoning about such affect predictions can inform tutorial and narrative planning, thus potentially making learning episodes even more effective.

4. A PROTOTYPE NARRATIVE-CENTERED LEARNING ENVIRONMENT

In our laboratory we are using the narrative-centered guided exploratory learning architecture to implement a prototype exploratory learning environment. Some components are fully designed and implemented while others are in the early stages of design. The prototype exploratory learning environment, CRYSTAL ISLAND, is being created in the domain of microbiology for middle school students (Figure 2). After introducing CRYSTAL ISLAND, we describe the implementation and present an example scenario.

4.1 Crystal Island Storyworld

CRYSTAL ISLAND features a science mystery set on a recently discovered volcanic island where a research station has been established to study the unique flora and fauna. The user plays the protagonist attempting to discover the origins of an unidentified infectious disease at the research station. The story opens by introducing her to the island and the members of the research team for which her father serves as the lead scientist. As members of the research team fall ill, it is her task to discover the cause of the outbreak. She is free to explore the world and interact with other characters while forming questions, generating hypotheses, collecting data, and testing her hypotheses. Through the course of her adventure she must gather enough evidence to correctly choose among candidate diagnoses including botulism, cholera, giardiasis, paralytic shellfish poisoning, salmonellosis, and tick paralysis as well as identify the source of the disease.

4.2 Implementation

The narrative-centered tutorial planner is implemented with an HTN planner that is based on the SHOP2 planner [27] and was constructed in our laboratory to meet the specific needs of narrative and tutorial planning. For efficiency, it was designed as an embeddable C++ library to facilitate its integration into high-performance 3D gaming engines. The virtual world of CRYSTAL ISLAND, the semi-autonomous characters that inhabit it, and the user interface were implemented with Valve Software's Source™ engine, the 3D game platform for Half-Life 2. The Source engine also provides much of the low-level (reactive) character behavior control. The character behaviors and artifacts in the storyworld are the subject of continued work. The tutorial and narrative planners are fully implemented, a decision-theoretic "director" agent based on dynamic decision networks has been implemented to guide the narrative in the face of uncertain student actions [25], and the method and operator libraries for the microbiology domain are currently being built out.

4.3 Guided Exploratory Learning in the Crystal Island Environment

To illustrate the behavior of the CRYSTAL ISLAND learning environment, consider the following situation. Consider a student who has been interacting within the storyworld and learning about infectious diseases and related topics. In the course of having members of her 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 salmonellosis and that the source of the disease must be identified. The narrative planner has decided to have her pursue satisfying the tutorial constraints associated with the *Spread-of-Infectious-Diseases* topic by constructing a plan which has the unfolding story involve the spread of a disease by means of contaminated food. Specifically, it chooses salmonellosis as the illness and contaminated eggs as the source of the bacterial infection.

At one point in the story, although the student has made steady progress while learning about infectious diseases, the task of identifying the source of the illness has left her wandering aimlessly around the storyworld to locate the source. As the execution and monitoring components of the system assess the story, it determines that the student's progress towards identifying the origins of the illness is lagging. To address this, the narrative planner updates the narrative plan to include a hint action realized in the camp nurse revealing that she believes the source of the disease is something that the victims ate. The story continues with the student collecting data, running experiments, and ruling out hypotheses until she eventually definitively identifies salmonella as the disease, locates its source, and gets the research team on the road to recovery.

5. CONCLUSION AND FUTURE WORK

Narrative offers much promise for exploratory learning. Given the importance of exploration and experimentation in exploratory learning, creating story-based exploratory learning environments for science education has significant potential. By creating dynamically constructed narratives featuring students as protagonists solving science mysteries, narrative-centered learning environments could create vivid, motivating interactive problem-solving experiences with stimulating plots and captivating characters. The narrative-centered architecture for guided exploratory learning introduced in this paper represents an initial step towards this goal, and we are currently building out the architecture in an iterative refinement fashion using CRYSTAL ISLAND as a testbed.

Narrative-centered exploratory learning poses interesting challenges. These include balancing tutorial and narrative objectives in planning, recognizing students' plans and goals in the open environments that characterize exploratory learning, and accurately recognizing students' affective states. Of particular interest is the exploration of learning environment component synergies, e.g., between affect recognition and plan recognition in guided exploratory learning.

Narrative-centered exploratory learning also raises fundamental education questions that call for empirical evaluation. First, how effective can story-based science education be? Investigating issues of effectiveness entails using measures as simple as recall and as challenging as near and far transfer. Second, how efficient can story-based science education be? Efficiency is an important concern, for exploratory learning is known to suffer from efficiency issues: exploratory learning, even guided exploratory learning, often is more time consuming than more didactic approaches. One expects to find a trade-off between effectiveness (especially motivational effectiveness) and efficiency, and it will be interesting to see how the trade-off plays out in practice. Third, how motivating is narrative-based learning for students? To what degree is narrative-based science education engaging to students over short term and longer term interactions? Finally, how can narrative-centered exploratory learning be seamlessly integrated into the science curriculum? The content of CRYSTAL ISLAND is being targeted to specific objectives set forth in the middle school science curriculum, and one of the key goals of this line of work is to offer students core subject matter presented in engaging stories that draw them into becoming active participants in the scientific enterprise.

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