A Framework for Narrative Adaptation in Interactive Story-Based Learning Environments

Jonathan P. Rowe, Lucy R. Shores, Bradford W. Mott, James C. Lester
Department of Computer Science
North Carolina State University
Raleigh, NC 27695
{jprowe, lrshores, bwmott, lester}@ncsu.edu

ABSTRACT
A key functionality provided by interactive narrative systems is narrative adaptation: augmenting story experiences in response to users' actions, and tailoring story elements to individual users' preferences and needs. However, the task of interactive narrative adaptation is not yet well defined. There is little consensus about the key features of a general model for narrative adaptation, which results in a limited ability to draw comparisons between alternate solutions. This paper aims to synthesize a diverse range of approaches to narrative adaptation, as well as related experience management techniques from intelligent tutoring systems, in order to devise a framework for more clearly conceptualizing the general task of interactive narrative adaptation. The framework has three components: plot adaptation, discourse adaptation, and user tailoring. The conceptual framework is illustrated with examples from CRYSTAL ISLAND, an interactive narrative-centered learning environment for middle school microbiology. The framework is being used to inform preliminary development efforts on an interactive narrative director agent for the CRYSTAL ISLAND learning environment, and aims to provide a first step toward establishing a general model of interactive narrative.

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

General Terms
Design

Keywords
Interactive Narrative, Narrative Adaptation, Narrative-Centered Learning, Drama Management.

1. INTRODUCTION
Interactive narratives provide opportunities for users to actively participate in rich, engaging story experiences. One of the key features of interactive narratives is the ability to adapt story experiences in response to users' actions, as well as tailor story elements to individual users' preferences and needs. To implement these capabilities, interactive narratives utilize a range of artificial intelligence techniques for narrative planning [9][15] and autonomous agent behavior [2][3][19]. The capacity to dynamically augment and revise narrative plans has shown promise for several application areas, including art [9], entertainment [3][15], and education [2][7][12][19]. In particular, learning applications stand to benefit from the unique affordances of interactive narratives. The ability to customize learning experiences—similar to one-on-one human tutoring—has been shown to provide considerable learning benefits [20]. To realize the potential of narrative adaptation for learning, interactive narrative learning environments have been created to serve a variety of educational purposes, such as language and culture learning [19], social behavior education [2], combat medical training [7], and microbiology education [12].

Over the past several years, the intelligent narrative technologies community has devised a diverse collection of techniques for adapting interactive narratives, and more generally, manage interactive experiences [16]. As a result, progress has been made toward achieving the technical vision of interactive narrative. However, the general task of interactive narrative adaptation is not yet well defined. It continues to be difficult to draw comparisons among systems that differ in their conceptual approaches to narrative adaptation. For example, planning-based systems such as Mimesis [15] and Façade [9] approach narrative adaptation by accommodating user actions into existing plots when possible, and otherwise replanning or sequencing narrative units (plot points, beats) in response to user actions. The approaches of I-Storytelling [3] and THESPIAN [19] indirectly influence plots by modifying the goals of autonomous virtual characters, allowing new story directions to arise emergently. Other systems have operated primarily at the discourse level, making dynamic adjustments to cinematography [4][6] or the presentational order of events [11]. In related work, the artificial intelligence in education community has spent nearly forty years devising experience managers, also known as intelligent tutoring systems, that manage learning experiences by delivering tailored problems, hints and feedback to address students' cognitive, affective, and meta-cognitive needs [16][20]. Without a shared notion of the key features and functionalities associated with a general model for interactive narrative adaptation, it grows increasingly difficult to assess individual solutions, draw meaningful comparisons across systems, or determine how to best take advantage of conceptual and technological advances made by others.

To address these challenges, this paper aims to synthesize multiple approaches into a general framework for conceptualizing interactive narrative adaptation. Three categories of narrative

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adaptations are described: plot adaptation, discourse adaptation, and user tailoring. Examples are drawn from the intelligent narrative technologies literature, as well as related fields such as intelligent tutoring systems. Connections are also made to the application domain of story-based learning. To illustrate the framework's potential to facilitate interactive narrative design and critical analysis, each of the framework's categories are discussed within the context of CRYSTAL ISLAND, an interactive narrative-centered learning environment for middle school microbiology.

The framework is currently being used to inform development efforts to create an interactive narrative director agent for CRYSTAL ISLAND. There are also a number of potential benefits to be realized by the intelligent narrative technologies community in establishing such a framework. First, it facilitates comparisons between different interactive narrative systems and their primary components. It does so by providing a model against which a single interactive narrative's adaptation facilities can be compared. Second, by synthesizing approaches from a range of interactive narrative systems and related experience managers, a narrative adaptation framework provides future system designers the opportunity to consider methods or functionalities from other domains and applications. Third, in order to establish a general model of interactive narrative—a critical step for progress on robust authoring systems or evaluation methodologies—it is necessary to identify and characterize interactive narrative's primary computational tasks. Narrative adaptation is an important example of such a computational task.

2. BACKGROUND AND RELATED WORK

A key challenge posed by interactive narratives is balancing user agency and narrative coherence [15]. Dynamic narrative adaptation is the principal method available for implementing this balance. By adapting a narrative in response to user actions and individual characteristics, a narrative system permits users to exert meaningful influence over the direction of a narrative while remaining within a space of narratives specified by the author and that is most appropriate for the user [15].

Technical approaches to the design of interactive narrative systems are often characterized in terms of two families: character-based systems and plot-based systems [3]. *Character-based* systems [3][19] feature plots that emerge through interactions between believable, autonomous characters. *Plot-based* approaches typically implement a director agent or drama manager to create, monitor, and adjust narrative event sequences and produce compelling, coherent plots [9][15][21]. Both approaches to interactive narrative prominently feature narrative adaption; character-based systems distribute narrative adaptation decisions across many individual autonomous characters, whereas plot-based systems centralize narrative adaptation decision-making in a single, omnipotent agent. Hybrid interactive narrative systems integrate features from both character-based and plot-based approaches [2][16], but the basic calculus of narrative adaptation remains the same.

Interactive narrative systems have adopted a range of computational approaches for directly adapting plots, including adversarial search [21], planning [3][15], and decision-theoretic techniques [12][13][19]. For example, Moe implemented a search-based drama manager that could cause, deny, temporarily deny, re-enable, or hint about specific plot points [21]. Moe's conceptual approach to narrative adaptation was adopted a number of years later by the declarative optimization-based drama management (DODM) family of systems [13]. Mimesis also took a narrative adaptation approach that directly augmented plots and narrative events [15]. In order to cope with user actions that threatened the author's intended narrative experience, Mimesis accommodated user actions by re-sequencing subsequent story plans, or directly intervened in the execution of user actions to prevent story conflicts [15]. Façade implemented a beat-based approach to structuring narrative content, and performed narrative adaptations through strategic sequencing of beats to optimize the dramatic arc of the user's narrative experience [9].

Others have taken alternate approaches to narrative adaptation by avoiding direct plot manipulations. OPIATE used a case-based planning approach to adaptively assign goals to autonomous virtual characters, thereby indirectly influencing the emerging narrative [5]. I-Storytelling and Thespian took goal-directed approaches to influencing autonomous character behaviors, adapting character goals in response to user actions [3] [19].

Other work has pursued narrative adaptations at the discourse level. Discourse occupies the "expression plane" of a narrative, or alternatively, "how" a story is told as opposed to "what" is told or the medium used for telling [14]. Jhala and Young describe a discourse-based approach to camera control for virtual environments, which selects camera positions and angles to convey affective information to the viewer, as well as maintain rhetorical coherence [6]. El Nasr presents ELE (Expressive Lighting Engine), an intelligent lighting system for virtual environments that adjusts lights for aesthetic and communicative purposes [4]. Montfort discusses an approach to event ordering that featured non-chronological sequences for interactive fictions [11].

Interactive narratives are not the only class of systems that use dynamic adaptation techniques to manage user experiences [16]. Using one-on-one human tutoring as a model, intelligent tutoring systems have sought to tailor learning experiences to individual students [20]. Intelligent tutoring systems are sometimes characterized in terms of two loops: an outer loop and an inner loop [20]. The outer loop iterates over learning tasks, such as practice problems, making coarse-grained adjustments to the trajectory of the overall learning experience. The inner loop is responsible for delivering tailored feedback and hints during student's individual problem-solving processes. Inner loop adaptations are inherently local, because they address only a single problem, and are tailored to individual student's needs. These outer and inner loops are analogous to global and local plot adaptations in intelligent narrative technologies. While most intelligent tutoring systems do not face the same structural constraints—coherence, dramatic tension, character roles—as narrative systems, symmetries between the two fields suggest that work on intelligent tutoring systems may offer useful insights into the core problems of interactive narrative, including narrative adaption.

3. CRYSTAL ISLAND

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

CRYSTAL ISLAND's narrative takes place in a small research camp situated on a recently discovered tropical island. As students explore the camp, they investigate the island's spreading illness by forming questions, generating hypotheses, collecting data, and testing hypotheses. Throughout their investigations, students interact with non-player characters offering clues and relevant microbiology facts via multimodal "dialogues" delivered by characters through student menu choices and characters' spoken language. The dialogues' content is supplemented with virtual books, posters, and other resources encountered in several of the camp's locations. As students gather useful information, they have access to a personal digital assistant to take and review notes, consult a microbiology field manual, communicate with characters, and report progress in solving the mystery. To solve the mystery, students complete a *diagnosis worksheet* to manage their working hypotheses and record findings about patients' symptoms and medical history, as well as any findings from tests conducted in the camp's laboratory. Once a student enters a hypothesized diagnosis, cause of illness, and treatment plan into the diagnosis worksheet, the findings are submitted to the camp nurse for review and possible revision.

4. NARRATIVE ADAPTATION FRAMEWORK

A range of approaches have been devised for dynamically adapting interactive narrative experiences. In order to synthesize these different approaches, and to develop a clearer understanding of the key features and functionalities inherent in a general model of interactive narrative adaptation, a framework for dynamic narrative adaptation is proposed.[1] The framework has three components: plot adaptation, discourse adaptation, and user tailoring.

4.1 Plot Adaptation

Plot is the sequence of events and situations that characterize the content and structure of a narrative [14]. Interactive narrative systems frequently make use of plot graphs, which provide a means for defining a space of possible plot sequences. Plot adaptations are structural manipulations to a fully or partially ordered sequence of plot events that have been targeted for an interactive narrative experience. Plot adaptations typically occur because of two possible reasons: the user has performed an action that interferes with the author's intended narrative goals, or the system aims to tailor the narrative to the individual user's preferences or needs. Plot adaptations are analogous to the outer loop in an intelligent tutoring system; the outer loop selects and sequences problems that are tailored to a student's knowledge and abilities, just as plot adaptations select and sequence events in ways that are tailored to a student's preferences and needs.

Plot adaptation raises the issue of local versus global plot changes. Global plot changes are coarse-grained plot modifications that affect the structure, and potentially the overall path, of an intended narrative experience. Local plot changes are modifications of fine-grained narrative features that may impact the user but do not affect the overall structure of a narrative experience. Computationally, a global plot change can be viewed as transforming the plot graph characterizing an interactive narrative experience, whereas a local plot change would not affect the plot graph. Local plot changes are analogous to the inner loop of intelligent tutoring systems [20]; they are addressed by the framework's third component, User Tailoring.

4.1.1 Direct Plot Adaptation

A direct plot adaptation refers to an explicit modification of the plot trajectory for an interactive narrative experience. Direct plot adaptations occur by adding, removing, modifying, or re-sequencing major plot events in the targeted narrative. In considering direct plot adaptations, it is important to note the potential for conflicts between plot adaptations and an existing narrative history. For example, if a plot adaptation causes a non-player character to behave in a manner that is inconsistent with an established archetype, or if an event occurs that conflicts with some prior plot event, the believability of the character and the narrative's coherence may suffer, ultimately undermining the user's sense of transportation into the narrative. Therefore, the choice to execute direct plot adaptations should be realized by narrative facilities that reason about positive or negative impacts on the user's narrative experience.

- **Modifying the targeted sequence of plot events**. A director agent or drama manager may directly cause or prevent the occurrence of a narrative event. Examples include directing a virtual character to take some concrete action, triggering some event that modifies the virtual setting, or reordering a sequence of events scheduled to take place in the narrative. Mimesis and Façade provide clear examples of this type of direct plot adaptation via intervention, replanning and beat sequencing behaviors [9][15]. In learning applications, a plot may require direct adjustment if a student appears to be incapable of solving a problem. By making direct plot adjustments, a system seeks to maintain narrative coherence while providing the student with new opportunities to remediate weaknesses in their domain knowledge or skills [16]. In CRYSTAL ISLAND, students are expected to gather background information on pathogens before conducting tests in the camp's laboratory. A student who chooses to conduct her tests before acquiring the necessary background knowledge may discover an important clue about the mystery disease, but lack the necessary knowledge to successfully apply it. In this case, a narrative director agent might choose to insert a narrative event (e.g., the student is directly approached by one of the camp's pathogen expert characters) in order to satisfy the narrative goal that the student investigates pathogen concepts before solving the mystery.
- **Manipulation of player goals**. A director agent or drama manager can alternatively adapt a plot sequence by adding or removing goals for the player to accomplish. In this case, the interactive narrative system does not need to manipulate

[1] It should be noted that this exercise is not motivated by the belief that a single, unified approach should be taken to interactive narrative adaptation; rather, it is driven by the expectation that identifying the key features of a broad range of known narrative adaptation techniques will inform the design of more effective models of interactive narrative.

a story event independent of the user's intervention. Instead, it assigns the user a quest or goal whose achievement (or failure) will constitute an important plot point. Manipulating student goals is particularly useful for story-based learning because it provides students with additional opportunities to learn important skills and concepts, and it streamlines narratives to eliminate activities that may be redundant. Alternatively, introducing assessment-focused quests can be used to provide an interactive narrative system additional insight into the students' knowledge and motivational states. To illustrate the benefits of manipulating students' narrative goals, consider the following CRYSTAL ISLAND scenario. After gathering clues and researching pathogen concepts, a student mistakenly indicates in his diagnosis worksheet that a batch of oranges is responsible for spreading the mysterious disease. To address the student's misconception, a director agent could provide the student with a goal to test the orange in the laboratory, revealing that it is not contaminated with pathogens, and encouraging consideration of other explanations for the mystery's solution.

4.1.2 Indirect Plot Adaptation

Similar to direct plot adaptation, indirect plot adaptation seeks to amend the state or direction of a narrative's plot. However, rather than directly augment plot points, indirect plot adaptations manipulate key narrative features, such as autonomous character states or player abilities, to foster plot adaptations that occur emergently. If carefully executed, indirect plot adaptations may avoid some of the sense of "manipulation" often associated with direct plot adaptations. Indirect plot adaptation is a common technique in character-based interactive narrative systems [3][19].

- **Modifying virtual character states**. Autonomous virtual characters commonly have goals, emotional states, roles, and personalities that guide their behaviors during interactive narratives. Because many narratives are fundamentally character-driven, manipulations of autonomous character traits can indirectly shape an interactive narrative's emerging path. Character-state modifications can be used by story-based learning systems in a number of ways. Characters' empathetic behaviors can be dynamically adjusted to manage students' emotional states during learning, such as excitement, confusion, boredom, and frustration [17]. In CRYSTAL ISLAND, virtual characters' goals could hypothetically be adjusted to provide more or less problem-solving guidance during students' investigations.
- **Introducing and removing virtual characters.** The introduction and removal of autonomous virtual characters manipulates the set of character roles available for composing a narrative experience. These techniques are used by FearNot! during the generation of educational vignettes about bullying [2]. An interactive narrative system may elect to expand (or reduce) a cast of characters to serve a plot purpose without negatively impacting the narrative's coherence and clarity by appending additional roles to existing characters. However, character introductions should be performed prudently in order to avoid the problems associated with the presence of redundant characters. Virtual character introductions could benefit a story-based learning environment such as CRYSTAL ISLAND by introducing additional virtual "experts" to the camp to enhance the presentation of key microbiology and problem-solving concepts, or including new patients to provide supplemental details about the problem-solving scenario.
- **Rewards and incentives**. The purpose of rewards is to provide extrinsic motivation [18]. In interactive narratives, rewards and incentives can be used to discreetly guide players toward a targeted narrative path. In contrast to manipulations of player goals, rewards and incentives do not mandate a particular course of action; they motivate players to take narrative actions that promote a desired plot progression. A hypothetical director agent could dynamically offer rewards and incentives to influence students to stay within a desired space of narrative paths. Within the CRYSTAL ISLAND narrative-centered learning environment, students are awarded points during efficient completion of plot events and deliberative problem solving.
- **Modifying player abilities**. Interactive narrative plots can also be indirectly adapted by manipulating the capabilities of a user. Users are typically afforded a finite set of actions that they can perform in an interactive narrative environment. This choice of actions shapes the user's degree of agency and participation in the interactive narrative. However, player capabilities can also be dynamically expanded or constrained for narrative effect. Within CRYSTAL ISLAND, the student can pose questions to virtual characters, gather relevant information in books and posters, conduct laboratory tests on food objects, and record her findings in a diagnosis worksheet. However, these capabilities could be expanded by allowing the student to examine food items using an electronic microscope, gather clues by inspecting the virtual team members' recent emails, or swab patients for bacterial samples. By modifying the set of capabilities afforded to the student, the learning experience's problem-solving process and narrative trajectory can be augmented.

4.2 Discourse Adaptation

Discourse adaptations are orthogonal to plot adaptations; manipulations of a narrative's discourse can be performed without impacting the narrative's underlying plot structure. However, dynamic adaptations of discourse can have important rhetorical and affective impacts on a user. By augmenting the presentation of a particular story experience, interactive narratives can dynamically define particular moods, hide or reveal facets of the narrative environment, and take advantage of dramatic idioms to highlight important story elements. The effective use of discourse mechanisms to present a narrative can also be powerfully engaging, and serve as a motivational factor in story-based learning. Discourse should not be confused with medium [14]. Distinct media (e.g., text, static image, film, interactive environment) each have their own discourse forms and vernacular. Discourse adaptations focus on presentational manipulations that are situated within a particular medium.

4.2.1 Perspective Adaptation

A majority of recent interactive narrative systems portray narrative events with 3D graphical environments. A key discourse feature in graphical presentations of narrative is the user's perspective or point-of-view. Perspective dictates the type, quantity, and quality of narrative information that is provided to the user, and can be manipulated to draw or divert a user's attention for narrative effect. Two key cinematographic tools that define discourse in 3D graphical environments are camera use and lighting.

- **Camera adjustments**. Camera position, angle, framing, and pacing serve an important communicative function in visual narratives. Several cinematic idioms have been established by the film community to portray affective and rhetorical information in narratives. Computational representations of these idioms have also been developed for use in virtual environments [6]. In story-based learning, camera adjustments can effectively portray important events or processes to be learned, draw student attention toward narrative elements that may be conducive to learning, and create an engaging atmosphere that fosters flow and other affective states conducive to learning. In CRYSTAL ISLAND, different groups of students frequently have variable success at critically analyzing and identifying information sources to aid in problem solving. Dynamic camera adjustments can be used to emphasize features of the setting (e.g., useful books, posters, and equipment) that are important for particular plot events. Camera adjustments can also be used to dynamically reveal important actions taken by virtual characters that may be outside of the student's default point-of-view.
- **Lighting adjustments**. Similar to camera adjustments, changes in cinematic lighting can significantly impact a user's perception of a virtual environment. Lighting provides an additional means for conveying information regarding the state of a narrative, and can influence a user's overall perception of the presentation of a story experience. El Nasr [4] developed a computational model of dynamic lighting to achieve specific authorial goals, such as emotion evocation and direction of a user's visual attention. Building on this work, narrative-centered learning environments can implement strategic manipulations of light features such as placement, brightness, and color in order to dynamically adjust the atmosphere of a setting or to manipulate the visibility of environmental features, thereby shaping student interpretations of learning events. In CRYSTAL ISLAND, strategic lighting can be used to dynamically adjust the atmosphere of different locations as a form of problem-solving feedback: the infirmary building that houses the camp's sick patients may be dimly lit and foreboding at the onset of the mystery. However, as the student progresses toward a correct solution, the infirmary's atmospheric lighting may brighten to discreetly reinforce the student's effective problem solving processes.

4.2.2 Event-Presentation Sequence Adaptation

Prince identifies a key difference between plot and discourse by distinguishing between "the order in which events (are said to) occur and the order in which they are recounted" [14]. In other words, the presentational order of events in a narrative need not mirror the chronological order of the narrative's events. Similar to the role of perspective, event ordering can have a significant impact on an audience's perception of a narrative. Event ordering can be utilized to deliberately hide or reveal information about a narrative through non-chronological orderings. Manipulating presentational order enables an author to increase suspense and drama by concealing key narrative information, or alternatively evoke curiosity and interest by prematurely revealing information without supporting elaboration. Montfort presents a seven-category taxonomy for event ordering in text-based interactive narratives: chronicle, retrograde, zigzag, analepsis, prolepsis, syllepsis, and achrony [11]. Two related categories, analepsis and foreshadowing, are particularly important in perspective adaptation.

- **Analepsis.** Informally known as flashback, analepsis is a presentation of events situated in a current plot moment's chronological past [14]. Analepsis can serve as a narrative device for revealing the backstory of a narrative setting or key character, as well as a tool for repeating and reinforcing prior narrative events. It is often used in mysteries, which typically feature a protagonist tasked with uncovering facts about past events in pursuit of an explanation for the narrative's current state of affairs. In interactive story-based learning environments, analepsis can be used to redemonstrate past problem-solving successes or recount earlier investigations into important concepts and scenario details. For example, in CRYSTAL ISLAND, the diagnosis worksheet provides a direct mechanism for gauging students' beliefs and problem-solving progress. If the student has previously interviewed one of the sick team members to learn her symptoms and recent diet, but later inserts a contradictory entry into the diagnosis worksheet, a dynamically generated flashback could be used to review the details of the original interview and encourage revision. In this case, the author's intended plot is not amended, but the student is facilitated to stay on track by utilizing a familiar narrative device.
- **Foreshadowing.** In contrast to analepsis, foreshadowing does not involve the explicit presentation of events from a different chronological period from the current plot moment. Foreshadowing is a narrative device that simply *hints* about a future event in advance of its occurrence [14]. While foreshadowing, or advance mention, does not directly resequence events, it does foster increased awareness of future events in a non-chronological fashion. In interactive narrative-centered learning applications, advanced hinting about the consequences of a narrative action has the potential to encourage a student to critically examine, and potentially revise, her problem-solving decisions before a commitment. Foreshadowing could be used in CRYSTAL ISLAND during occasions when a student attempts to conduct a laboratory test with an ill-advised object. The nearby lab technician could be directed to make a dismissive remark about the object under consideration, hinting that the student should reconsider the test attempt before squandering valuable time and laboratory resources.

4.3 User Tailoring

User tailoring utilizes local plot changes and both diegetic and non-diegetic presentations (i.e., information proffered inside and outside of the fictional setting, respectively) to deliver customized guidance, support, and feedback to a user. Users' incoming individual differences can significantly impact their abilities to successfully navigate an interactive narrative environment. When interactive narratives tailor their behavior to users' cognitive, affective, and meta-cognitive characteristics, they accommodate users' individual differences in hopes of fostering enhanced user engagement and an increased likelihood of quality narrative experiences. User tailoring does not explicitly aim to augment the plot structure or discourse of an interactive narrative. Instead, it seeks to deliver the support necessary to facilitate a user's following the interactive narrative's intended plot progression. It should be noted that user tailoring is one of the key functionalities associated with intelligent tutoring systems [20].

4.3.1 Narrative Scaffolding

Narrative scaffolding is the provision of tailored support to guide users toward actions that are consistent with an interactive narrative's intended plot progression, rather than diverging from the expected narrative path. In educational applications, scaffolding is typically faded over time to increase student independence. Currently, it is unclear whether narrative scaffolding should be faded over time, what types of scaffolding are best suited for different user populations, and what the tradeoffs are between diegetic and non-diegetic delivery mechanisms.

- **Cognitive support.** During interactive narratives, not all users may be cognitively prepared to take actions that proceed toward a rewarding plot progression. At a given moment, a user may be distracted from meaningful narrative elements, or the user may be unsure about which action is best to take next. Tailored cognitive support encompasses discreet and overt techniques for prompting students toward taking desirable narrative actions. Cognitive supports are likely to be most useful for users who are off-task, confused, or have low self-efficacy with regard to their ability to successfully progress through the interactive narrative. Cognitive supports can be delivered in several ways, such as through conversational interactions with virtual characters, targeted camera or lighting adjustments, or non-diegetic means (e.g., text overlayed on the interactive narrative interface). The U-Director system used a decision-theoretic approach to select cognitive supports in an earlier version of the CRYSTAL ISLAND environment [12]. The system triggered subtle narrative events (flickering lights, moaning patients) to guide students toward important parts of the narrative environment.
- **Affective support.** Emotion is key to narrative experiences. Interactive narrative systems should therefore be capable of recognizing, understanding, and influencing users' affective experiences. Investigations into empathetic behavior in CRYSTAL ISLAND's virtual characters have shown that empathetic feedback has significant effects on users' emotional states [17], as well as an increased sense of presence in the virtual narrative [10]. Dynamic affective supports can be used to enrich the emotional impacts of interactive narrative experiences; dramatic moments of tension can be enhanced through parallel emotional expressions by virtual characters, and moments of frustration or confusion can be mitigated through targeted, empathetic feedback. In story-based learning environments, affective feedback should be used to guide students toward emotional states that are conducive to learning and promote motivation.
- **Tailored challenge.** Theories of intrinsic motivation suggest that humans often equate objectives that are challenging with objectives that are meaningful [8]. Overcoming a challenging task provides a test of abilities and a personal sense of achievement. Challenge depends on user characteristics, such as self-efficacy and prior knowledge, as well as inherent task difficulty. Dynamically maintaining optimal levels of challenge throughout story-based learning experiences is important for effective interactive narratives. Excessively low-challenge periods may cause a student to feel bored, where high-challenge periods may bring about frustration and feelings of hopelessness. Performance feedback and student self-esteem also influence a student's perceived challenge [8].

4.3.2 Information Revelation

Dynamic revelations of plot and domain information are tools for tailoring interactive narrative experiences to individual users' knowledge and learning characteristics. A user who is struggling with an interactive narrative because of insufficient prior or acquired knowledge might benefit from explicit, targeted dissemination of information. In contrast, an easily bored, high-achieving user might be stimulated through the presentation of new plot information that complicates the scenario and demands additional critical thought.

- **Tailored presentation of narrative and domain information.** Interactive narrative plots generally encompass a backstory and the sequence of events that unfold during a user's actual narrative interaction. During narrative interactions, users are typically treated as having perfect recall of all narrative events and backstory details once the information has been presented. However, perfect recall is unlikely, and lack-of-recall is particularly common during story-based learning assessments. Unfortunately, users may be expected to have a complete mastery of prior narrative events, or robust understanding of a particular domain topic, in order to successfully progress or appreciate subsequent narrative events. To address this incongruence, interactive narratives can dynamically present and reinforce information, concepts, and previous events to remediate shortcomings in user knowledge. For story-based learning environments, tailoring the presentation of key learning concepts is a means of directly addressing weaknesses in students' domain understanding. Customized concept presentations are particularly important in CRYSTAL ISLAND, where incomplete understanding of microbiology concepts is a common factor associated with student difficulties in solving the mystery.
- **Addressing misconceptions.** Misconceptions often stem from circumstances in which a user has developed a flawed mental model for a particular process or observation. Detecting and dynamically correcting misconceptions is important, particularly for complex learning scenarios. Misconceptions about microbiology concepts can be problematic for students interacting with CRYSTAL ISLAND. Without tools available to remediate students' misconceptions, it may be difficult for a student to progress along CRYSTAL ISLAND's intended narrative trajectory.

4.3.3 Meta-Narrative Feedback

In certain circumstances, it may be beneficial for an interactive narrative to deliver feedback at the meta-narrative level. In particular, it may be helpful to guide users to reflect on the interactive narrative experience itself, as opposed to the content of the particular narrative in which they are participating. If a user is having difficulty successfully progressing through an interactive narrative, she may need to evaluate her overall approach to the interaction. In non-interactive narrative media, meta-narrative feedback is often characterized as "breaking the fourth wall;" it is a violation of the invisible boundary between the audience and the narrative world. The notion of the fourth wall in interactive narrative, which is an inherently participatory medium, is a topic that has gone relatively unexplored by the intelligent narrative technologies community. An investigation into interactive narrative's fourth wall is beyond the scope of this paper, but the issue raises important questions about the types of adaptations that are possible, and most suitable, for different narrative experiences.

Meta-narrative feedback is analogous to meta-cognitive support in intelligent tutoring systems. Meta-cognitive hints and scaffolding are used to help shape students' general problem-solving and help-seeking strategies through guided tutoring interactions [1]. Meta-narrative feedback is intended to serve a similar purpose, aiding users in more effectively navigating interactive narratives and participating in quality story interactions.

- **Encouraging reflection**. Interactive narrative environments generally allow users to explore and make decisions autonomously. As a user makes decisions, reflecting on the utility of the decisions in relation to the user's goals and alternative choices is essential for developing strategies that result in narrative interactions yielding engaging story experiences. Interactive narratives can facilitate the reflection process by prompting users to consider their narrative actions critically. This approach is especially effective in narrative-centered learning environments such as CRYSTAL ISLAND, which feature complex interactive narratives centered on problem-solving activities. Similar to narrative scaffolding, inducements for student reflection can be delivered through diegetic and non-diegetic means.
- **Guiding explicit action monitoring**. Monitoring performance is an important component of effective problem solving [22], as well as effective participation in interactive narratives. Self-awareness of accomplishments can help to inform user strategies for goal achievement in both interactive narrative and learning settings. Monitoring can pose serious challenges for some types of users [22] and should be scaffolded. Although the idea of scaffolding monitoring processes may appear intrusive, it need not necessarily disrupt the narrative or be delivered via non-diegetic means. For example, CRYSTAL ISLAND's camp nurse serves as a mentor agent who periodically contacts the student by using a virtual communicator. During these brief conversational interactions, the nurse can prompt the student to monitor her actions by requesting obligatory status reports. The reports discreetly serve as a narrative tool for the employee to explicitly outline her accomplishments.

5. DISCUSSION AND CONCLUSIONS

The proposed framework represents an initial step toward a general model for conceptualizing narrative adaptation in interactive narrative environments. By considering plot adaptations, discourse adaptations, and user tailoring as key mechanisms for dynamically adjusting interactive narrative experiences, we can progress toward a systematic characterization of interactive narrative behavior across the range of systems, domains, and applications that have been developed by the intelligent narrative technologies community. Currently, the framework is being used to guide preliminary development efforts on an interactive narrative director agent for the CRYSTAL ISLAND learning environment. The framework's categories comprise a "toolbox" of possible adaptations to be considered by the hypothetical director agent, which will aim to optimize student engagement and learning during narrative-centered learning interactions. By considering the categories outlined in this paper, we aim to devise an interactive narrative system that is broadly expressive in terms of its narrative adaptation capabilities.

The current work offers the beginnings of a comprehensive narrative adaptation framework, but it has several notable limitations. First, narratives inherently involve the intimate interplay between plot events and narrative components such as characters, setting, and discourse. The lines distinguishing the proposed framework's three categories of narrative adaptations are not intended to serve as hard boundaries; rather, the framework's components are simply collections of related adaptation techniques, and it is likely that some types of narrative adaptations may fall into multiple categories. Second, the framework is not intended to be comprehensive. There are likely known narrative adaptation techniques that do not fall into any of the categories outlined here, and there is little doubt that novel types of narrative adaptations have yet to be devised that will not be easily accommodated by the categories of the framework. The categories outlined here should not be taken to discourage diversity in approaches to interactive narrative adaptation, but rather are an attempt to broadly encompass the diverse set of approaches that have already been developed by the intelligent narrative technologies community. Despite these limitations, it is our hope that this work will serve as a springboard for concerted efforts to create the next generation of computational models of interactive narrative adaptation, as well as inform progress on the key problems of intelligent narrative technologies, including authoring and evaluation.

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