

Serious Games with GIFT: Instructional Strategies, Game Design, and Natural Language in the Generalized Intelligent Framework for Tutoring

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INTRODUCTION

Recent years have seen significant progress on game-based learning. These advances include theoretical developments (Gee, 2007; Linderoth, 2012), the creation of game-based learning environments for a broad range of curricula (Johnson, 2010; Habgood & Ainsworth, 2011; Forsyth et al., 2013; Lester et al., 2014), and the emergence of immersive game-based learning technologies for both education (Hickey, Ingram-Goble, & Jameson, 2009; Ketelhut, Dede, Clarke, & Nelson, 2010) and training (Johnson, 2010). Recent empirical studies demonstrate that game-based learning environments can enable students to achieve learning gains in laboratory settings (Fiorella & Mayer, 2012) as well as in classroom settings (Hickey et al., 2009; Ketelhut et al., 2010; Lester et al., 2014). A pair of recent meta-analyses independently concluded that digital game technologies are often found to be more effective than traditional instructional methods in terms of cognitive outcomes, such as learning and retention (Clark, Tanner-Smith, Killingsworth, & Bellamy, 2013; Wouters, Van Nimwegen, Van Oostendorp, & Van der Spek, 2013). Expanding on this conclusion, Wouters et al. suggest that, “the next step is more value-added research on specific game features that determine ... effectiveness” (p. 262).

A key challenge for the education community is determining how to effectively integrate established instructional strategies with successful game design principles. Over the past decade, several reports have provided clear recommendations about scientifically grounded instructional strategies that can be utilized by teachers or implemented in computer-based learning environments (Graesser, Halpern, & Hakel, 2007; Pashler et al., 2007). These instructional strategies are derived from rigorous research conducted in multiple disciplines, they have been supported by empirical studies, and they are aligned with cognitive theories about how people learn. Despite this wealth of knowledge, recommendations for how specific instructional strategies should be implemented in specific contexts, or how they should be used in combination, remain unclear.

In the case of game-based learning, there remains a dearth of theoretical and empirical work at the intersection of instructional design and game design (Isbister, Flanagan, & Hash, 2010; Linehan, Kirman, Lawson, & Chan, 2011). Many questions about the implementation and effectiveness of instructional strategies in game-based learning environments have not yet even been articulated, let alone answered. These questions are especially salient in the case of intelligent game-based learning environments, which are game environments that combine the adaptive pedagogical functionality of intelligent tutoring systems with the engaging environments of digital games. Intelligent game-based learning environments derive their effectiveness from the ability to deploy context-appropriate instructional tactics during game-based learning interactions. Game-based learning environments have grown as an educational medium over the past several years, and the need for general design principles that align instructional strategies with game design is clear. In addition, emerging architectures for intelligent tutoring systems, such as the Generalized Intelligent Framework for Tutoring (GIFT) (Sottolare, Goldberg, Brawner, & Holden, 2012), stand to benefit from an enriched understanding of how instructional strategies can be most effectively utilized across game-based learning environments.

Along with the need for expanded theories and empirical evidence to guide implementations of instructional strategies in game-based learning environments, fundamental advances in artificial intelligence will be necessary to realize the medium's full educational potential. In particular, natural language processing (NLP) stands poised to serve a critical role in the implementation of instructional strategies in game-based learning environments. NLP encompasses a broad range of computational linguistics technologies, including speech synthesis and recognition, dialogue management, natural language understanding and generation, summarization, and computational models of narrative (Jurafsky & Martin, 2009). Natural language plays a central role in human instruction. For example, linguistic phenomena such as dialogue, speech understanding, and question generation are critical elements of human-to-human educational interactions (Graesser, Person, Magliano, 1995). As the research community investigates computational models of instructional strategies, NLP is also likely to play a central role. NLP holds a particularly privileged status in game-based learning environments because the rich learning interactions afforded by digital games demand sophisticated, multi-level communication capabilities only made possible by NLP. Natural language is central to many interactions with game-based learning environments, including language-based input (e.g., text, speech), human-agent dialogue, dynamically generated narratives, and believable speech by virtual agents. However, implementing robust and accurate natural language processing capabilities that meet the real-time performance requirements of digital games raises significant challenges to be addressed by the research community.

In this chapter, we explore the question of how theoretically and empirically grounded instructional strategies can be effectively implemented in game-based learning environments, with a focus on how NLP can play a key role in their implementation. We review recent research from the educational games literature, and discuss examples of how NLP is currently being used by educational games and intelligent tutoring systems. To illustrate the potential synergies between game design, instructional design, and NLP, we examine several instructional strategies in CRYSTAL ISLAND, a game-based learning environment for middle school science and literacy. We outline prospective opportunities for the implementation of game-based instructional strategies in CRYSTAL ISLAND through integration with NLP functionalities. To conclude, we discuss directions for devising generalizable models of natural language-driven instructional strategies for game-based learning environments, and we identify design recommendations and research directions for game-based instructional strategy models in GIFT.

RELATED RESEARCH

Over the past few years, the game-based learning community has expanded efforts to conduct empirical game-based learning studies, including studies in laboratory settings (Adams, Mayer, MacNamara, Koenig, & Wainess, 2012) as well as classrooms (Hickey et al., 2009; Ketelhut et al., 2010). While this has produced a wealth of evidence on the overall effectiveness of educational games, the research literature on educational game *design* remains relatively sparse. In one of the few exceptions, Isbister, Flanagan, and Hash (2010) conducted semi-structured interviews with experienced game developers to identify key design practices and themes used by professionals in their work. The interviewees described themes such as emphasizing fun as a central design value, requiring high levels of polish and well-tuned end experiences, emphasizing deep learning content rather than 'bolted on' learning materials, supporting collaboration and specialization, designing for role-playing and emotional engagement, and including affordances for exploring complex systems. In other work, Linehan and colleagues (2011) describe methods for educational game design rooted in applied behavior analysis. Still, empirical and theoretical studies on the design of specific educational game features remain few and far between.

Notably, several intelligent game-based learning environments have begun to leverage NLP to drive core aspects of learning interactions. For example, the Tactical Language and Culture Training System (TLCTS) is a suite of story-centric, serious games designed for language and culture learning (Johnson,

2010). TLCTS uses a combination of interactive lessons and narrative scenarios to train culturally embedded spoken and non-verbal communication skills. In another example, Operation ARIES! is a dialogue-centric intelligent tutoring system about scientific reasoning that leverages game-like features to foster student engagement and learning (Forsyth et al., 2013). Operation ARIES! combines a fantasy storyline, multimedia presentations, and three-way conversational interactions with pedagogical agents to teach students about critically evaluating research claims and understanding scientific methods. Multi-agent conversational interactions are driven by tutorial dialog and language-understanding models from AutoTutor, an intelligent tutoring system that has also been used for multiple domains, including computer literacy and physics (Forsyth et al., 2013).

Complementary to intelligent game-based learning environments, virtual humans draw on intelligent tutoring systems, game engine technologies, and NLP in order to simulate naturalistic interactions with humans within software. Over the past ten years, virtual humans have been devised for a range of education and non-education applications (Swartout et al., 2013). Virtual humans typically interact with learners through combinations of verbal and non-verbal behavior, providing advice and explanations through integrated modules for speech recognition and synthesis, natural language understanding, dialogue management, and non-verbal behavior.

Many advances in educational applications of NLP have occurred outside of digital games. Automated essay grading has been the subject of considerable interest for decades, particularly given its role in assessment and standardized testing (Valenti, Neri, & Cucchiarelli, 2003). Recently, computational models of tutorial dialogue have garnered increasing interest (Boyer et al., 2011; Chi, VanLehn, & Litman, 2010). Computational models of dialogue have targeted a broad range of dialogue phenomena, from low-level micro-tactics (Chi, VanLehn, & Litman, 2010) to high-level tutorial strategies (Boyer et al., 2011). Moreover, dialogue models have made strides by leveraging data-driven computational frameworks such as hidden Markov models (Boyer et al. 2011) and reinforcement learning (Chi, VanLehn, & Litman, 2010). Intelligent tutoring systems for writing have begun to emerge, such as Writing Pal, which combines strategy instruction, educational games, writing practice, and formative feedback components to automatically support students' writing processes (Roscoe et al., in press). Writing Pal employs several NLP modules—including a lemmatizer, syntactic parsers, lexical databases, rhetorical analyzers, and Latent Semantic Analysis—to assess students' essays and implement formative feedback functionality. In related work, intelligent tutoring systems have begun to leverage fine-grained linguistic indices—including measures of lexical, syntactic, and cohesion metrics—to devise models for assessing the quality of students' written self-explanations during learning (Jackson & McNamara, 2012; McNamara et al., 2012).

Although research on NLP in game-based learning environments and intelligent tutoring systems shows great promise, a major gap remains in the literature concerning what role NLP should play in implementing instructional strategies in game-based learning environments. As games continue to establish themselves as an important medium for education and training, resolving this question will become critical for the success of generalizable models of intelligent tutoring such as GIFT.

DISCUSSION

In order to begin exploring the role of NLP-driven instructional strategies in game-based learning environments, we examine the implementation and effectiveness of five categories of instructional strategies in CRYSTAL ISLAND, a game-based learning environment for middle grade science. The instructional strategies are drawn from *Lifelong Learning at Work and at Home* (Graesser, Halpern, & Hakel, 2007), a report that enumerates 25 evidence-based principles of human learning that correspond to actionable instructional strategies. For the purpose of discussion, we describe instructional strategies that

are currently, or planned to be, implemented in CRYSTAL ISLAND. For each instructional strategy, we discuss how NLP should drive its implementation, what form it could take in game-based learning environments, and likely computational challenges that will arise.

CRYSTAL ISLAND Game-Based Learning Environment

Over the past several years, our lab has been developing CRYSTAL ISLAND (Figure 1), a game-based learning environment for middle school microbiology and literacy (Rowe, Shores, Mott & Lester, 2011). Designed as a supplement to classroom science instruction, CRYSTAL ISLAND's curricular focus is aligned with North Carolina Essential Standards for 8th Grade Science, as well as Common Core State Standards for reading informational texts. CRYSTAL ISLAND has served as a platform for investigating a range of intelligent tutoring functionalities, including narrative-centered tutorial planning (Lee, Rowe, Mott, & Lester, in press), student goal recognition (Ha, et al. 2011), and affect recognition (Sabourin, Mott & Lester 2011). The environment has also been the subject of extensive empirical investigations of student learning and engagement (Rowe, et al. 2011). Studies have indicated that students achieve significant learning gains from using CRYSTAL ISLAND, and these findings have been replicated across multiple student populations (Rowe, 2013). The latest edition of CRYSTAL ISLAND was developed with the Unity game engine, which provides 3D rendering, audio, and input device capabilities, and enables deployments in schools through web browsers.



Figure 1. CRYSTAL ISLAND narrative-centered learning environment.

CRYSTAL ISLAND features a science mystery in which students attempt to discover the identity and source of an infectious disease that is plaguing a research team stationed on a remote island. Students adopt the role of a medical field agent who has been assigned to investigate the illness and save the research team from the outbreak. Students explore the research camp from a first-person viewpoint, gather information about patient symptoms and relevant diseases, form and test hypotheses about the infection, and record their findings in a diagnosis worksheet. The mystery is solved by uncovering details about the spreading infection, testing potential transmission sources of the disease in a virtual laboratory, recording a diagnosis and treatment plan, and presenting the findings to the camp nurse.

Implementing Game-Based Instructional Strategies with Natural Language Processing

To illustrate how evidence-based instructional strategies and game design principles can be aligned, we examine five cognitive principles of learning from the perspective of CRYSTAL ISLAND: 1) stories and example cases, 2) dual code and multimedia effects, 3) organization effects, 4) explanation effects, and 5) feedback effects. We discuss instructional strategies that are built upon these learning principles, and explore how NLP can serve a critical role in realizing the strategies' full pedagogical potential in CRYSTAL ISLAND, as well as game-based learning environments in general.

Stories and Example Cases. Stories provide a natural structure for encoding experiential knowledge, and they are an integral component in meaning making (Bruner, 1991). Graesser and Ottati (1996) argue that “stories have a privileged status in the cognitive system,” citing experimental findings that suggest readers process narrative texts more quickly and recall narrative information more readily than expository forms. In narrative-centered learning environments—which are a class of educational games that tightly integrate gameplay, stories, and educational subject matter—students have the opportunity to serve as active participants in dynamically generated interactive narratives (Rowe et al., 2011). Narrative-centered learning environments demand use of computational models of narrative generation, which automatically reason about plots and discourse to dynamically construct coherent and engaging plots that unfold in either text-based or 3D virtual environments (Zook et al., 2012; Lee et al., in press). Recent years have witnessed growing interest in computational models of narrative for a range of education and training applications (Si, Marsella, & Pynadath, 2005; Lee et al., in press). In CRYSTAL ISLAND, data-driven models of narrative-centered tutorial planning, which integrate tutorial planning and interactive narrative generation functionalities, have yielded promising results for enhancing students' learning outcomes and problem-solving processes (Lee et al., in press; Rowe, 2013). Care must be exercised in designing interactive narratives in order to avoid harmful effects of seductive details (Rowe et al., 2009), but there are also reasons to believe that interactive narratives create opportunities for supporting emotion self-regulation processes, at least for some students (Sabourin et al., 2013). Research in this area is still in its nascent stages; a majority of computational models of narrative are investigated in only a single narrative domain and educational context. Continued research on generalizable models of real-time narrative generation will be important for leveraging the instructional promise of stories and example cases in game-based learning environments, so that they can be dynamically tailored to individual learners.

Dual Code and Multimedia Effects. Dual code and multimedia effects suggest that rich representations of educational content that leverage multiple channels in a principled manner, including both verbal and visual forms, are more effective than presentations involving only a single medium (Mayer, 2009). Game-based learning environments make wide use of multi-channel interfaces, both for input and feedback. For example, TLCTS uses simultaneous text and speech in culturally-situated conversational interactions with virtual agents (Johnson, 2010). Operation ARIES! leverages models of tutorial dialogue to teach scientific reasoning skills through the medium of conversational trialogs (Forsyth et al., 2013). In CRYSTAL ISLAND, science concepts are presented in three primary formats: 1) dialogue-based interactions with virtual characters that combine text and speech, 2) graphical posters that combine high-resolution images and text-based summaries of microbiology concepts, and 3) complex informational texts that appear as books and research articles in the virtual environment. These examples include both language that is procedurally generated, as well as language that is hand-authored. In order to create generalizable instructional models that adaptively tailor multimedia presentations to individual learners, devising NLP models for speech understanding and synthesis, dialogue management, text summarization, discourse understanding, and natural language generation will be essential.

Organization Effects. Organization effects suggest that outlining, integrating, and synthesizing information can enhance students' learning outcomes (Graesser, Halpern, & Hakel, 2007). A number of game-based learning environments, including CRYSTAL ISLAND, scaffold organization processes using

embedded *graphic organizers*. Graphic organizers provide visual representations of how concepts are related and text is structured (Bromley, Irwin-DeVitis, & Modlo, 1995). In CRYSTAL ISLAND, graphic organizers are used to scaffold students' reading comprehension processes as they read complex informational texts about microbiology concepts. Specifically, students fill out concept matrices to record key pieces of information encountered in the informational texts (Rowe, Lobene, Mott & Lester, 2013). Completing a concept matrix involves clicking on blank cells within a matrix (i.e., table) and selecting responses from drop-down menus. After a student has filled out a concept matrix, she can press an on-screen "Submit" button to receive immediate feedback on her responses.

In the current version of CRYSTAL ISLAND, completing a concept matrix is menu-driven; students do not generate the concept matrices themselves or construct their own responses. However, increasing the role of generative processing—such as students creating their own concept matrices—is an important direction for future work. Generative learning processes have been demonstrated to be effective for enhancing reading comprehension (Linden & Wittrock, 1981), but automatically assessing student-generated concept matrices raises significant computational challenges. Providing context-sensitive feedback on student-generated content in concept matrices requires robust natural language understanding capabilities to interpret and model students' responses, as well as understand the content of associated complex informational texts. Furthermore, natural language generation would be necessary to deliver tailored feedback about students' self-generated content. In CRYSTAL ISLAND, feedback on students' concept matrices arrives in the form of virtual text messages shown on an in-game smartphone; generating brief text messages that specifically respond to the strengths and weaknesses of students' completed concept matrices would likely require automated natural language generation facilities. While intermediate solutions are possible (Rowe et al., 2013), computational challenges in providing tailored feedback on student-generated graphic organizers will shape the extent to which educational game designers can leverage generative organization effects in game-based learning environments.

Explanation Effects. Explanation effects indicate that students benefit more from generating self-explanations of mental models than memorization of shallow facts (Fonseca & Chi, 2011). While self-explanation is highly effective for learning, care should be taken in deploying self-explanation activities during game-based learning, due to the potential risks of disrupting flow during gameplay. In CRYSTAL ISLAND, self-explanation is encouraged by a diagnosis worksheet where students record their findings and conclusions as they investigate the mystery. The diagnosis worksheet is itself a graphic organizer for students' explanations of their diagnostic problem-solving processes. It includes sections for recording patients' symptoms, laboratory test results, hypotheses, and final conclusions. Prior empirical work investigating how students complete CRYSTAL ISLAND's diagnosis worksheet indicated that maintaining a thorough, accurate worksheet is significantly predictive of learning outcomes ($p < .001$), particularly for students with low prior domain-knowledge (Shores, 2010).

Although these findings are promising, several directions remain for enhancing the diagnosis worksheet's efficacy. Currently, the diagnosis worksheet is menu-based, but in future work we plan to implement a version where students will write their own conclusions using free-form text; students will use a *diagnosis argumentation interface* to report their conclusions. Using the interface, students will write scientific arguments to support their diagnoses, cite supporting evidence for their claims, and describe chains of deductive reasoning. With this implementation, computational models for argumentation mining—which aim to automatically detect, classify, and structure arguments in text—are likely to serve an important role in assessing the quality and correctness of students' diagnoses (Mochales & Moens, 2011).

Feedback Effects. Providing feedback on students' task performance is an important instructional strategy, and it is also a major tenet of effective game design (Schell, 2008). In game-based learning environments, feedback comprises one half of the *loop of interaction*, which refers to the continuous cycle of information flowing between the student and the game during gameplay. Feedback has two

primary roles in game-based learning. First, feedback enables students to understand the effects of their actions on the game's virtual environment. Second, feedback informs students of the correctness, or success, of their problem-solving actions during learning. Feedback can be immediate or delayed, formative or summative. Game-based learning environments such as CRYSTAL ISLAND make extensive use of feedback.

In CRYSTAL ISLAND, students receive feedback on the effects of their actions in the virtual world, the outcomes of laboratory tests they run on scientific equipment, and the correctness of their proposed diagnosis and treatment plan when they attempt to solve the mystery. However, most of this feedback is pre-specified (i.e., canned), and it is tightly coupled to the particular action the student just performed. In contrast, feedback can be adaptively tailored based on the context in which it is delivered (Serge, Priest, Durlach, & Johnson, 2013). In games, feedback is often presented from virtual characters. Automatically generating context-sensitive feedback about students' problem solving demands computational models of natural language generation to drive characters' responses. Without flexible natural language generation facilities, feedback from virtual characters is likely to be limited in its context-sensitivity, as well as limited in usefulness to learners. Furthermore, it is important that natural language generation facilities utilize knowledge about affective and social dimensions of feedback—such as the politeness effect (Wang, et al., 2008)—in order to achieve optimal learning outcomes. By acting politely and empathetically while engaging students in natural language dialogues, virtual characters are better positioned to enrich affective dimensions of learning alongside cognitive dimensions.

RECOMMENDATIONS AND FUTURE RESEARCH

In this chapter, we have examined the alignment of empirically based principles of instructional strategies with game design principles. While recent research has indicated game-based learning environments hold considerable promise for a broad range of education and training settings, important questions remain about how educational games should be designed and what features are most responsible for learning effectiveness. Using the CRYSTAL ISLAND game-based learning environment as an example, we have argued that evidence-based instructional strategies can be synergistically aligned with game designs, but in order to realize their full potential, advances in natural language processing technologies are critical. Recent work has begun to investigate natural language processing in intelligent game-based learning environments, and significantly expanding this line of research is an important and promising future direction.

To address these questions, we envision a three-pronged research agenda focused on the design and implementation of instructional strategies in game-based learning environments. First, we propose systematically investigating how instructional strategies can be aligned with game design principles across a range of educational subjects, learning environments, and game genres. In some cases, games and instructional design align naturally, but in others they come into conflict. For example, there are many open questions about how to most effectively incorporate narratives into game-based learning environments for different populations, educational subjects, and settings; although narrative can enhance student interest, narratives also risk introducing seductive details. Identifying the right degrees of narrative for different types of game-based learning environment is an important question for the field. As another example, it is widely recognized that self-explanation processes are effective for learning. However, it is unclear how self-explanation should be embedded in games, particularly due to the risk of disrupting players' flow. Self-explanation often requires students to write, a skill that is rarely called for in entertainment-focused games. Identifying the role of self-explanation in game-based learning environments, and how to effectively embed self-explanation processes in games, is an important question.

Second, we recommend increased efforts toward identifying algorithmic advances in NLP that enable computational models of instructional strategies in game-based learning environments to better emulate human-level implementations of these strategies. For example, fundamental advances in computational models of dialogue will enhance the opportunities available for speech-based interfaces with games, as well as opportunities for tutorial dialogue-based interactions with virtual characters. Similarly, advances in natural language understanding will enhance intelligent game-based learning environments' capacity to assess, and provide feedback on, students' writing and explanations. Without continued progress in NLP, we are unlikely to witness intelligent game-based learning environments capable of implementing instructional strategies on par with human tutors.

Third, we propose an empirically-based research program on NLP-driven instructional strategies in game-based learning environments to identify the relative effectiveness of competing techniques, and pave the way for generalized intelligent tutoring models that are highly effective, transferrable, and broadly useful. This type of research program will require deploying intelligent game-based learning environments in a broad range of settings, both inside and outside the laboratory. Furthermore, this research agenda suggests a demand for tools to implement a wide range of research study designs, as well as streamline data analysis.

While it should be noted that the specific instructional strategies discussed in this paper focus on cognitive aspects of learning—thereby omitting important affective, motivational, and metacognitive facets—we make no claim that the specific strategies or examples cited here are comprehensive. Rather, we intend for this chapter to outline one promising path forward for enhancing the effectiveness of game-based learning environments across a broad range of subjects and educational settings.

Given these recommendations, GIFT shows particular promise as a research platform for systematic investigations of NLP-driven instructional strategy models in game-based learning environments. To further align GIFT's software infrastructure with the proposed research agenda on NLP-driven instructional strategy models for games, we suggest three potential directions. First, identifying NLP-centric requirements for inter-module messaging standards and pedagogical module designs would offer a promising first step toward implementing the necessary infrastructure for supporting the proposals laid out in this chapter. Second, providing recommendations and examples for how adaptive modules for interactive narrative generation, dialogue generation, and other NLP capabilities should be integrated with the GIFT architecture would further facilitate efforts to devise effective instructional strategy models in game-based learning environments. Finally, providing streamlined instrumentation and logging facilities for monitoring the operation of NLP-driven instructional strategy models, as well as learning processes and outcomes of students interacting with these new systems, will be critical for supporting the proposed research agenda on aligning instructional strategies and game designs in the generalized intelligent framework for tutoring.

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