Real-Time Narrative-Centered Tutorial Planning for Story-Based Learning

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Abstract. Interactive story-based learning environments offer significant potential for crafting narrative tutorial guidance to create pedagogically effective learning experiences that are tailored to individual students. This paper reports on an empirical evaluation of machine-learned models of narrative-centered tutorial planning for story-based learning environments. We investigate differences in learning gains and in-game performance during student interactions in a rich virtual storyworld. One hundred and eighty-three middle school students participated in the study, which had three conditions: *Minimal Guidance*, *Intermediate Guidance*, and *Full Guidance*. Results reveal statistically significant differences in learning and in-game problem-solving effectiveness between students who received minimal guidance and students who received full guidance. Students in the full guidance condition tended to demonstrate higher learning outcomes and problem-solving efficiency. The findings suggest that machine-learned models of narrative-centered tutorial planning can improve learning outcomes and in-game efficiency.

Keywords: Narrative-centered learning environments, Game-based learning environments, Dynamic Bayesian Networks.

1 Introduction

Recent years have witnessed significant growth in research on interactive story-based learning environments that create engaging and pedagogically effective learning experiences [1,2]. These environments promote students' active participation in engaging story-based problem-solving activities. A number of researchers have explored story-based learning environments for education and training. For example, story-based learning environments can support science education [3], social behavior education [4], and training [5].

Story-based learning environments actively observe students interacting within the storyworld to determine the most appropriate time to intervene with the next tutorial action to perform in service of guiding students' learning experiences. Through this process, story-based learning environments create effective narrative-centered tutorial planning by managing the story structure and scaffolding student interaction.

Given the potential that story-based learning environments have shown, we have developed two empirically driven models of tutorial planning: *tutorial intervention planning* [6] and *tutorial action planning* [7]. The tutorial intervention model determines when the next tutorial action should occur. The tutorial action model determines which narrative-centered tutorial action to perform. Both models were developed using empirically driven methods. By utilizing a corpus of human interactions within a story-based learning environment, dynamic Bayesian networks (DBN) were learned to model the two types of narrative-centered tutorial planning.

This paper reports on an empirical evaluation of the machine-learned models of narrative-centered tutorial planning for real-time interaction with a story-based learning environment. We investigate differences in learning gains and in-game performance during student interactions. Analyses reveal that the proposed approach offer significant potential for creating efficient learning processes and effective learning outcomes.

2 CRYSTAL ISLAND Story-Based Learning Environment

CRYSTAL ISLAND is a virtual learning environment developed for the domain of microbiology for eighth grade science education featuring a science mystery [3]. To devise accurate computational models of narrative-centered tutorial planning, a Wizard-of-Oz (WOZ) data collection was conducted with a customized version of CRYSTAL ISLAND. Wizards provide the tutorial and narrative planning functionalities while interacting with students in the environment. Throughout the corpus collection, detailed trace data was collected for all wizard decision-making and all navigation and manipulation activities within the virtual environment. The resulting corpus of trace data was utilized to learn the narrative-centered tutorial planning models.

2.1 Integrated Real-Time Model

To explore the real-time effectiveness of the machine-learned models of narrative-centered tutorial planning, the intervention model and the action model were integrated into the CRYSTAL ISLAND story-based learning environment (Fig 1). The environment is identical to the WOZ-enabled CRYSTAL ISLAND except non-player character interactions are driven by the tutorial planning models. Students interact with non-player characters to receive environmental information (e.g., How do you operate the testing equipment? or Where is the library?), and microbiology concepts (e.g., What is a waterborne disease?) using multimodal dialogue. Students select their questions using a dialogue menu and characters respond with spoken language.

Actions generated by the narrative-centered tutorial planning models are primarily initiated via the camp nurse. For example, when the model determines that it is an appropriate time to intervene to help the student examine patient symptoms to solve the mystery, the model directs the camp nurse to walk to the student. The camp nurse, using spoken language, informs the student that she should examine patients to determine their current symptoms. The camp nurse then guides the student to the infirmary to examine the patients.

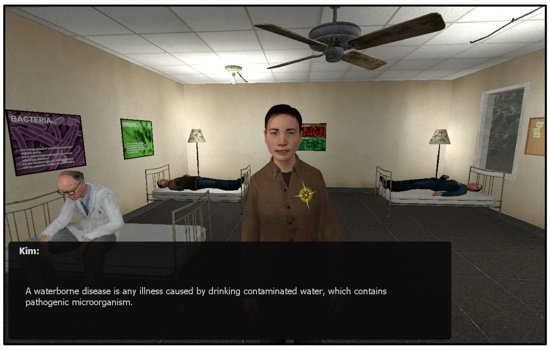

Fig. 1. CRYSTAL ISLAND story-based learning environment with integrated models

To solve the mystery, students complete a *diagnosis worksheet* to organize their hypotheses and record findings about patient symptoms and testing results. Once students have completed their diagnosis worksheets with the source and cause of the illness, they can submit their solutions to the camp nurse for review.

3 Empirical Study

Three experimental conditions were crafted to evaluate the effectiveness of the real-time narrative-centered tutorial planning: *Minimal* Guidance, *Intermediate Guidance,* and *Full Guidance*. Outcomes of the conditions were compared to determine the effectiveness of utilizing our machine-learned models.

Minimal Guidance. Students experience the storyworld controlled by a minimal narrative-centered tutorial planning model. This is a base model that includes the actions that must be achieved by the system (i.e., the user cannot achieve them without the system taking action). The minimal guidance model in this condition is not machine-learned; rather, it simply makes decisions once all pre-conditions are met for an action to be taken.

Intermediate Guidance. Students experience the storyworld controlled by an intermediate narrative-centered tutorial planning model. This is an ablated model inspired by the notions of *islands* [8]. Islands are intermediate plan steps through which all valid solution paths must pass. They have preconditions describing the intermediate world state, and if the plan does not satisfy each island's preconditions, the plan will never achieve its goal. Islands must occur at some intermediate time for achieving the overall goals. In our version of CRYSTAL ISLAND, the transitions between narrative arc phases represent "islands" in our narrative. Each arc phase consists of a number of potential tutorial action decisions; however, the phases are bounded by specific tutorial action decisions that define when each phase starts and ends. We employ these specific tutorial action decisions as our islands. The intermediate guidance tutorial planning employs only eight tutorial action decisions.

Full Guidance. Students experience the storyworld controlled by the full narrative-centered tutorial planning model. The model actively monitors students interacting within the storyworld to determine when it is appropriate to intervene with the next tutorial decisions to guide students. The model has full control of the tutorial intervention decisions (i.e., determining when to intervene) and tutorial action decisions (i.e., determining what the intervention should be). The full guidance tutorial planning model employs all 15 of the tutorial action decisions described in previous work [7].

3.1 Study Method

A total of 183 students interacted with CRYSTAL ISLAND. Participants were all eighth-grade students from a North Carolina public school ranging in age from 12 to 15 ($M = 13.40$, $SD = 0.53$). Twelve of the participants were eliminated due to hardware and software issues. Another twenty-one participants were eliminated due to incomplete data on either their pre-test or post-test. Among the remaining students, 68 were male and 82 were female.

Students were given 45 minutes to solve CRYSTAL ISLAND's science mystery. Immediately after solving the mystery, or 45 minutes of interaction, whichever came first, students exited the CRYSTAL ISLAND learning environment and completed the post-test. The post-test consisted of the same items as the pre-test, which was completed several days prior to the intervention. The post-test was completed by the students within 30 minutes. In total, the students' sessions lasted no more than 90 minutes.

4 Results

An investigation of overall learning found that students' CRYSTAL ISLAND interactions yielded positive learning outcomes. A matched pairs t-test between post-test and pre-test scores indicates that the learning gains were significant, $t(149) = 2.03$, $p < .05$. Examining the learning outcome for each condition it was found that students' CRYSTAL ISLAND interactions in the *Full Guidance* condition yielded significant learning gains, as measured by the difference of post-test and pre-test scores. A matched pairs *t*-test revealed that students in the *Full Guidance* condition showed statistically significant learning gains. Students in the *Intermediate* and *Minimal Guidance* conditions did not show significant learning gains (Table 1).

Table 1. Learning gains and *t*-test statistics.

Conditions	**Gain Avg.**	**SD**	***t***	***p***
Full	1.28	2.66	2.03	< 0.05
Intermediate	0.13	2.69	0.19	0.84
Minimal	0.89	3.12	1.23	0.22

In addition, there was a significant difference between the conditions in terms of learning gains. Controlling for pre-test scores using ANCOVA, the learning gains for the *Full* and *Minimal Guidance* conditions were significantly different, $F(2, 99) = 38.64$, $p < .001$ and the *Full* and *Intermediate Guidance* conditions were also significantly different, $F(2, 100) = 40.22$, $p < .001$. Thus, students in the *Full Guidance* condition achieved significantly higher learning gains than the students in the other two conditions.

We also conducted in-game problem-solving performance analyses to more closely investigate the effectiveness of the narrative-centered tutorial planning model. In order to compare the behavior of students problem-solving performances among the conditions, we investigated the students' gameplay efficiency by analyzing whether they solved CRYSTAL ISLAND's science mystery and their game completion time. Table 2 reports the game play performance for each condition.

Table 2. In-game problem-solving performances.

Conditions	Solved Mystery	Completion Time (s) Mean	SD
Full	92.73 %	1724	417.01
Intermediate	85.42 %	1761	445.66
Minimal	70.21 %	2229	461.55

To analyze the difference in the number of students who solved the mystery among the conditions, a chi-square test was performed. The results showed that the correlation is significant, (likelihood ratio, $\chi^2 = 9.37$, Pearson, $\chi^2 = 9.47$, $p < .01$), indicating that the number of students who solved the mystery varied significantly among the conditions. We also examined the differences in time it took students to solve the mystery. An ANOVA test was performed to investigate the differences among the conditions. The test revealed that differences were significant, $F(2, 122) = 15.13$, $p < .001$, which implied that the total time it took to solve the mystery varied significantly among the different conditions. Tukey's pairwise comparison tests further indicated that the *Full* and *Minimal Guidance* conditions are significantly different ($p < .001$), as well as the *Intermediate* and *Minimal Guidance* conditions ($p < .001$). However, Tukey's test did not reveal any significant differences between the *Full* and *Intermediate Guidance* conditions.

5 Conclusion

Creating narrative-centered tutorial planning is critically important for achieving pedagogically effective story-based learning experiences. We have presented an empirical evaluation of machine-learned models of narrative-centered tutorial planning and investigated differences in learning gains and in-game performance during student interactions with a story-based learning environment. It was found that students in a full guidance condition exhibited significant learning gains and problem-solving performances. Furthermore, a detailed analysis of the differences in learning and in-game problem-solving performance among the conditions showed that there were statistically significant differences between students who received full guidance and students who received intermediate or minimal guidance. The findings suggest that integrated machine-learned models of narrative-centered tutorial planning for real-time interaction can improve learning outcomes and in-game efficiency.

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