

Game Performance as a Measure of Comprehension and Skill Transfer

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Abstract

Intelligent Tutoring Systems (ITSs) have begun to develop hybrid systems that balance the learning benefits of ITSs with the motivational benefits of games. iSTART-ME (Motivationally Enhanced) is a new game-based learning environment developed on top of an existing ITS for reading comprehension (iSTART). In an 11 session lab-based study, 40 high school students interacted with the full iSTART-ME system and completed comprehension measures at multiple time points (pretest, posttest, retention, and transfer). The current work examined students' comprehension outcomes and how they were related to performance within three integrated practice methods: Coached Practice (non-game), Showdown (game-based), and Map Conquest (game-based). Results indicate that performance within the game-based practice environments was positively related to comprehension outcomes, whereas performance within the non-game environment had no relation to subsequent comprehension measures.

Introduction

Intelligent Tutoring Systems (ITSs) have been producing consistent learning gains for decades. However, a common problem with these systems is maintaining student engagement without reducing learning benefits. This is particularly problematic for long-term ITSs that require interactions spanning across days, weeks, or even months. Student interest within these tutoring systems often wanes over time due to the repetitive nature of practice tasks.

One previously successful solution to improve engagement has been to incorporate game-like components into educational environments (for a review, see Clark, Nelson, Sengupta, & D'Angelo, 2009). Several systems have taken this route to create combinations of Intelligent Tutoring and Games (McNamara, Jackson, & Graesser, 2010). One example of this endeavor is the Interactive Strategy Training for Active Reading and Thinking-Motivationally Enhanced (iSTART-ME) system which was built on top of an existing ITS (called iSTART) and

adapted into a game-based environment where students can practice strategies, earn points, advance through levels, purchase rewards, create a personalized avatar, and play educational mini-games. The current work investigates students' interactions with game and non-game based versions of strategy practice within iSTART-ME.

iSTART-ME

iSTART-ME is a game-based ITS designed to improve students' reading comprehension by teaching self-explanation in combination with effective reading strategies. iSTART-ME enhances the original ITS version of iSTART by adding in game-based features to maintain students' enjoyment and motivation over an extended period of training (Jackson & McNamara, 2011). All versions of iSTART are founded on research with a successful human intervention called SERT (Self-Explanation Reading Training; McNamara, 2004; O'Reilly, Taylor, & McNamara, 2006). Students who have been through iSTART have shown significant improvement in reading comprehension, comparable to the performance within SERT (Magliano et al., 2005).

iSTART training is separated into three distinct modules that instantiate the pedagogical principle of modeling-scaffolding-fading: introduction, demonstration, and practice, respectively. The Introduction module contains three animated agents that engage in a vicarious dialogue to introduce the concept of self-explanation and each of the reading strategies. The Demonstration module scaffolds the learner from interactive instruction to an applied setting. This module includes two animated agents who generate and discuss the quality of example self-explanations and prompt the learner to identify which strategies may have been used. The Practice module fades out more of the direct instruction and requires learners to generate their own self-explanations while an animated agent (Merlin) provides qualitative feedback on how to improve the self-explanation quality.

This feedback during practice is based on a natural language assessment algorithm that evaluates each self-explanation produced by the students (McNamara, Boonthum et al., 2007). The algorithm output is coded as a 0, 1, 2, or 3. An assessment of "0" relates to self-

explanations that are either too short or contain mostly irrelevant information. An iSTART score of “1” is associated with a self-explanation that primarily relates only to the target sentence itself (sentence-based). A “2” means that the student’s self-explanation incorporated some aspect of the text beyond the target sentence (text-based). If a self-explanation earns a “3”, then it is interpreted to have incorporated information at a global level, and may include outside information or refer to an overall theme across the whole text (global-based). This algorithm has demonstrated performance comparable to that of humans, and provides a general indication of the cognitive processing required to generate a self-explanation (Jackson, Guess, & McNamara, 2010).

Within iSTART there are two types of practice modules, both of which use the same natural language assessment algorithm. The first practice module is situated within the core context of iSTART (initial 2-hour training) and includes two texts. The second practice module is a form of extended interaction and operates in the exact same manner as the original practice module. During extended practice, a teacher can assign specific texts for students to read. These texts are either already in the system or can be added to the system on short notice. Because of the need to incorporate various texts, the iSTART feedback algorithm has been designed to adapt to new texts (McNamara, Boonthum et al., 2007), with performance comparable to humans (Jackson, Guess et al, 2010).

The extended practice module is designed to provide a long-term learning environment that can span weeks or months. Research on iSTART has shown that the extended practice effectively increases students’ performance over time (Jackson, Boonthum, & McNamara, 2010). Students have consistently demonstrated significant improvement in reading comprehension, with average effect sizes ranging from .68 to 1.12 depending on prior knowledge of the learner (McNamara, O’Reilly et al., 2007). However, skill mastery requires long-term interaction with repeated practice (Jackson, Boonthum et al., 2010). One unfortunate side effect of this long-term interaction is that students often become disengaged and uninterested in using the system (Bell & McNamara, 2007). Thus, iSTART-ME has been developed on top of the existing ITS and incorporates serious games and other game-based elements (Jackson, Boonthum, & McNamara, 2009; Jackson, Dempsey, & McNamara, 2010).

Game-based additions

To combat the problem of disengagement over time, the iSTART extended practice module has been situated within a game-based environment called iSTART-ME (motivationally enhanced). This game-based environment builds upon the existing iSTART system and was specifically designed to increase persistence and active engagement through extended practice. The iSTART-ME system and design rationale has been extensively described

in other papers, so only the relevant aspects will be described here (Jackson, Boonthum, & McNamara, 2009).

The main focus of the iSTART-ME project is to implement and assess game-based principles and features that are expected to support effective learning, increase motivation, and sustain engagement throughout a long-term interaction. The previous version of iSTART automatically progressed students from one text to another with no intervening actions. The new version of iSTART-ME is controlled through a selection that provides students opportunities to interact with new texts, earn points, advance through levels, purchase rewards, personalize a character, and play educational mini-games (using the training strategies).

In addition to other enhancements, iSTART-ME allows students to practice self-explaining within three different environments: Coached Practice, Showdown, and Map Conquest. These versions of practice situate the same task of self-explanation within different contexts.

Coached Practice (Figure 1) is a revised version of the original practice module within iSTART. Learners are asked to generate their own self-explanation when presented with a text and specified target sentence. Students are guided through practice by Merlin, a wizard who provides qualitative feedback for user-generated self-explanations. Merlin reads sentences aloud to the participant, stops after reading a target sentence, and asks the participant to self-explain the bolded sentence. After a self-explanation is submitted, Merlin provides feedback on the quality of the self-explanation using the automatic assessment algorithm. If the contribution quality is low, students can try again and use Merlin’s feedback to improve their current self-explanation. The only game-like elements within Coached Practice are a colored qualitative feedback bar (visually indicating: poor, fair, good, great) and points associated with each self-explanation.

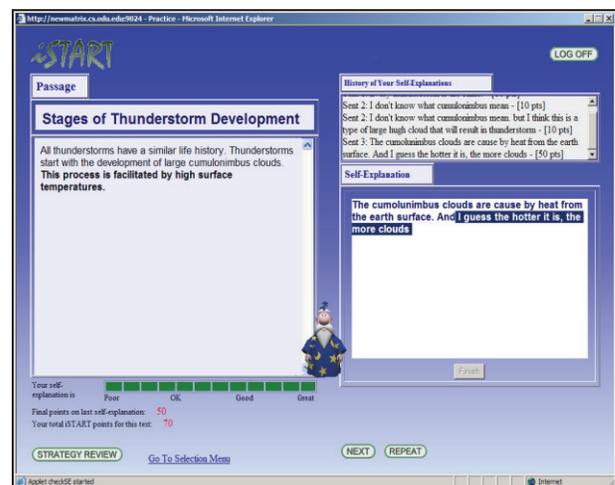


Figure 1. Screenshot of Coached Practice.

Showdown is a game-based method of practice that requires students to generate a self-explanation for a specified target sentence (see Figure 2). Participants compete against a computer player to win rounds by writing better self-explanations. Participants are guided through the game by text-based instructions. After the participant completes each self-explanation, the computer scores the self-explanation on a scale of 0–3 and displays the score as stars (using same algorithm as Coached Practice). The opponent’s self-explanation is also presented and scored. The self-explanations for the virtual player are randomly drawn from a database of existing, pre-evaluated self-explanations. The self-explanation scores are compared and the player with the higher score wins the round. For tie scores, the player is given another sentence worth two points instead of one. The player with the most points at the end of a text is declared the winner.

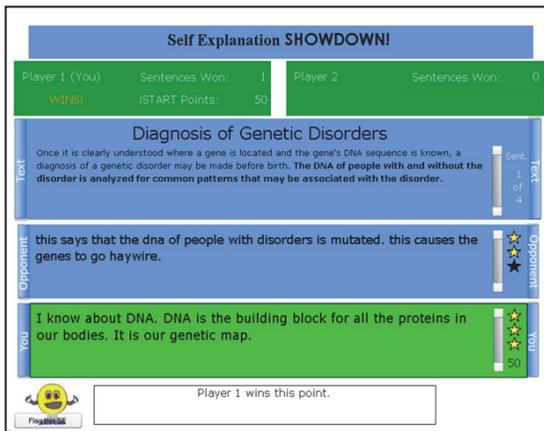


Figure 2. Screenshot of Showdown.

Map Conquest is the second game-based method of practice in which students generate their own self-explanations (Figure 3). In this game, the quality of a student’s self-explanation determines the number of dice that a student earns. The score of 0 to 3 is created utilizing the same natural language assessment algorithm as both Coached Practice and Showdown (0-3 dice are awarded per response). After a round of generating two self-explanations, students are transitioned into a series of map actions. When the students interact with the map, they attempt to occupy the entire board by allocating resources (i.e., troops) to their spaces, conquering neighboring territories, and defending their own spaces from CPU attacks. All of these actions (allocating, conquering, defending) occur within a single round of map interactions before the player is transitioned back to generate self-explanations and earn more dice. In this way, the game actions and practice are separate rather than integrated as in SE Showdown. This cyclic process between the game and practice continues until the student completes a self-explanation for each of the target sentences within a text.

Though the surface features of these practice methods differ, they all require students to perform the same learning task and method of assessment. During training

with iSTART-ME, students are allowed to freely select between these forms of practice.



Figure 3. Screenshot of Map Conquest.

Current Study

Previous research with the iSTART-ME system yielded positive, yet complex patterns of outcomes that examined multiple time-scales of intervention. The research indicated that after a short-term interaction (~60 minutes, including brief training), students who used a game-based method of practice (Showdown) performed worse than students using a non-game-based environment (Coached Practice; Jackson, Dempsey, & McNamara, 2012). However, in a longer-term pilot evaluation with full training (~6 hours across multiple sessions), students performed equally well using either the game or non-game-based practice environment. Therefore, one possible concern with integrating games into learning systems is that they have the potential to detract from the immediate pedagogical goals and reduce learning improvements in the short-term. However, across long-term training, the engagement fostered by the game environment may compensate for any distracting elements, thus allowing students to catch up in performance (Jackson, et al., 2012).

The current work was conducted to expand upon these findings and to more thoroughly explore the potential long-term benefits of game-based training environments.

Procedure

Participants in this study included 40 high school students from a mid-south urban environment. These students are a subset of 126 students who originally participated as part of a larger study that compared three conditions: iSTART-ME, iSTART-original, and no-tutoring control. The current work focuses only on those students who were assigned to the iSTART-ME condition.

All students participated in an 11-session experiment involving four phases: pretest, training, posttest, and retention. During the first session, students completed a pretest that included measures to assess their prior reading comprehension ability. During the 8 training sessions (completed within a 10 day span), participants completed all of the iSTART training (Introduction, Demonstration,

and initial Practice) and then transitioned into the iSTART-ME selection menu for the remainder of the training sessions. Students completed the posttest at session 10, which included measures similar to the pretest. Five days later, at the final session, students completed two comprehension measures, the retention and transfer tests.

Measures

All students completed the same number of testing and training sessions (i.e., pretest, training, posttest, and retention). Each of the three testing sessions included measures of student reading comprehension, and both the pretest and posttest had additional measures pertaining to students' attitudes, motivation, and enjoyment.

Students' reading comprehension was assessed using passage-specific comprehension measures. At pretest, posttest, and retention students were asked to read and self-explain a science passage of approximately 300 words covering one of the following topics: red blood cells, cellular growth & repair, or earthquakes/plate tectonics. These passages have been used during previous research with iSTART and were selected due to their similarity on linguistic difficulty measures via Coh-Metrix (Graesser et al., 2004). After reading and self-explaining the passage, students were presented with a series of open-ended questions (the text was not available after the questions appeared). Two types of questions were included and correct responses required information from either the textbase or situation model levels (e.g., McNamara et al., 1996; McNamara et al., 2006). The textbase questions involved information that could be found within a single sentence, whereas the situation model questions required students to generate an inference from information contained in at least two separate sentences. These two types of questions were designed to detect the level of comprehension most affected by training. In addition to these three science passages, students also completed a transfer comprehension assessment during the delayed retention test. This transfer task included a longer text of 600 words (on plant growth and development) and students were not prompted to self-explain while reading.

Results

The following analyses were conducted to examine students' choices to select particular environments during training, and how performance within those environments relates to overall comprehension. Thus, analyses examined the frequency with which each practice method was selected and how performance within each environment related to comprehension outcomes.

For each practice text, students were free to choose between the three different practice environments. Analyses investigating the frequency of environment selection found no differences between Coached Practice ($M=7.45$, $SD=4.67$), Showdown ($M=5.45$, $SD=3.79$), or Map Conquest ($M=8.31$, $SD=5.66$), through parametric, $F(2,56)=2.41$, $p>.05$, and non-parametric tests, $\chi^2(2)=3.88$,

$p>.05$. Additionally, there were no environment selection frequency differences between students of high or low pretest comprehension abilities, $F(2,54)=0.42$, $p>.05$. Therefore, students were equally likely to interact with any of the three practice methods during training.

Once students selected a practice environment their self-explanation performance was assessed using the same iSTART algorithm. Pearson correlations indicate that students' pretest comprehension has a significant positive relation to their performance within all three practice environments (see *Pretest* column in Table 1). Interestingly, performance within the two game-based methods of practice (Showdown and Map Conquest) is significantly positively related to comprehension measures at posttest, retention, and transfer (all $p<.01$). However, performance within the non-game method of practice (Coached Practice) was not related to comprehension scores at posttest, retention, or transfer (all $p>.05$).

Table 1. Correlations for overall comprehension outcomes.

		Pretest	Posttest	Retention	Transfer
CP Performance	r	.332*	.276	.212	.237
	(p)	(.039)	(.088)	(.194)	(.147)
SD Performance	r	.654**	.516*	.481*	.602**
	(p)	(.000)	(.002)	(.005)	(.000)
MC Performance	r	.535**	.563**	.496**	.532**
	(p)	(.001)	(.000)	(.002)	(.001)

CP = Coached Practice, SD = Showdown, MC = Map Conquest

We were further interested in how each practice environment may affect comprehension at different levels (i.e., textbase vs. inference questions). Correlation analyses revealed findings similar to the overall comprehension results (see Table 2). Performance within Map Conquest was positively related to all levels of students' comprehension at pretest, posttest, retention, and transfer. Performance within Showdown was related to students' bridging questions at retention, and all of transfer. Finally, performance within Coached Practice was related to students' pretest textbase questions, but was not related to any other measure of comprehension.

To explore these different effects further, median splits were created based on the performance within each practice environment (i.e., three separate median splits based on average performance). These median splits were used as a between-subjects factor to examine if high performing students within an environment maintained that ability on subsequent comprehension outcomes. A series of nine ANOVAs were conducted (which requires a Bonferroni corrected alpha of .0056 to reach significance) and found that students of high and low ability within Coached Practice did not have significantly different scores at posttest ($p>.05$), retention ($p>.01$), or transfer ($p>.05$). These tests also found that high and low performing students within Showdown did not differ at retention ($p>.006$), but high performing students scored higher on the posttest ($p<.002$) and transfer task ($p<.003$) than low performing students. Additionally, the final three ANOVAs found that high performing students within Map

Table 2. Correlations for types of comprehension questions.

		Pretest		Posttest		Retention		Transfer	
		Text	Inference	Text	Inference	Text	Inference	Text	Inference
CP Performance	r	.344*	.257	.210	.278	.237	.168	.208	.242
	(p)	(.032)	(.120)	(.198)	(.087)	(.146)	(.308)	(.205)	(.138)
SD Performance	r	.670**	.540**	.511*	.426*	.342	.544**	.547**	.588**
	(p)	(.000)	(.001)	(.002)	(.014)	(.051)	(.001)	(.001)	(.000)
MC Performance	r	.471**	.571**	.514**	.502*	.374*	.542**	.495**	.516**
	(p)	(.003)	(.000)	(.001)	(.002)	(.023)	(.001)	(.002)	(.001)

CP = Coached Practice, SD = Showdown, MC = Map Conquest

Conquest scored significantly higher than low performing students at posttest ($p < .001$), retention ($p < .003$), and transfer ($p < .001$). These results demonstrate that students' performance within the two game based environments persisted across later tests of comprehension, whereas students' performance within coached practice did not relate to comprehension outcomes. Based on these findings, the game-based environments seem to be engaging the students differently than the non-game environment and may provide a more accurate assessment of overall comprehension abilities.

Conclusions

The overarching goal of the iSTART-ME project has been to further our understanding of the benefits of adding game-based elements to ITSs. The current study focused on examining students' interactions within multiple practice environments, and how performance within those environments relates to potential improvements in primary learning outcomes (i.e., comprehension). The outcomes from this study provide an interesting within-subjects comparison between game and non-game based learning, using equivalent metrics of assessment across environments.

Results indicate that students' performance within the two game-based methods of practice was related to multiple comprehension outcomes. Thus, students who implemented the strategies successfully within the games also tended to apply those strategies well during subsequent comprehension tasks (even after a delay). In contrast, students' performance within the non-game based practice was not indicative of subsequent comprehension outcomes. This means that students did not apply the strategies in the same manner within this environment as they did during comprehension evaluations after training.

One potential explanation for this finding is due to the scaffolded nature of the non-game practice environment. During the non-game-based method of practice (Coached Practice), students are provided with formative feedback and are scaffolded through the interaction. In contrast, the game-based methods of practice (Showdown and Map Conquest) incorporate more implicit forms of feedback using student examples and game-based features. Therefore, it is likely that students learn strategies within Coached Practice (e.g., see Jackson, Boonthum et al., 2010), but the additional coaching from the animated agent

does not reflect students' true ability to apply the strategies. Rather, these results demonstrate that the unscaffolded interactions during gameplay are a more accurate measure of subsequent performance and indicative of transfer on comprehension tests. This assessment holds true at multiple levels of analyses: overall comprehension, textbase comprehension, and inference-based comprehension. Thus, performance within these games can provide feedback to students on their overall abilities and the results support the current practice environment design as valid assessment of students' comprehension abilities.

The current long-term evaluation goes beyond immediate short-term findings to explore the effects of games during prolonged interactions and skill acquisition (i.e., comprehension skills). This finding supports long-term learning trends from previous work (Jackson et al., 2012), and creates a promising foundation from which we can extend subsequent work and further contribute to the scientific research on game-based learning.

The development of iSTART-ME has allowed us to examine the effectiveness of a combined ITS and educational game system, as well as to more systematically evaluate the effects of game components in the context of an ITS. The system design provides a unique opportunity to simultaneously examine game and non-game environments that have the same underlying assessment metrics and pedagogical goals. Future work with iSTART-ME will include both global and local assessments of game-based performance, and further analyses of user performance, enjoyment, attitudes, engagement, and persistence across time different time scales. Additionally, several small-scale experiments are being implemented to examine the interactions between specific game components (e.g., teasing apart differences between Showdown and Map Conquest).

Both the current and future work of iSTART-ME helps to further the field of Intelligent Tutoring Systems and game-based learning. The design of iSTART-ME is modular and thus provides an interesting theoretical alternative to the growing number of fully immersive epistemic games. Ultimately, we expect hybrid ITS and game-based learning environments to dramatically impact the effectiveness of computer-based training and further our understanding of the complex motivational aspects of learning environments and their interplay with learning.

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