

NewtonianTalk: Integration of Physics Playground and AutoTutor using GIFT

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Abstract. Despite the popularity of games, there has been limited peerreviewed literature published on game-based learning for science. This paper will describe a project that combined an Intelligent Tutoring System (AutoTutor) with a physics game called Physics Playground. As part of this integration we used the Generalized Intelligent Framework for Tutoring (GIFT) to manage communication between the two technologies. We will also discuss the design of a study comparing two versions of the integration. This study is taking place over Spring of 2015 and will be studying the effects of integrating different levels of tutoring into a gamebased learning system.

Keywords: Game-based Learning, Intelligent Tutoring Systems, Physics, Playground, AutoTutor, GIFT

1 Introduction

There is growing evidence of video games supporting learning (e.g., Tobias & Fletcher, 2011; Wilson et al., 2009). Such research typically focuses on games explicitly designed for learning. However, games not explicitly designed for learning can also produce significant learning gains. In this research, we look at the potential benefits of adding intelligent tutoring into an existing game. This paper describes the design process for creating an ITS enhanced educational game called NewtonianTalk using the GIFT technology. Before we describe the integration we will briefly review the state of ITS and educational games.

2 Background

2.1 Intelligent Tutoring Systems

Intelligent tutoring systems (ITS) have proven very effective in improving training outcomes. Meta-analyses show effect sizes on the order of one sigma (Dodds &

Fletcher, 2004; VanLehn, 2011), which is approximately a full letter grade in traditional grading schemes. The long sought-after goal is a 2σ effect size (Bloom, 1984; Corbett, 2001).

Recent advances in natural language processing (NLP), semantic analysis, machine learning, and cognitive modeling have spawned ITSs with the potential to achieve this effect size (Graesser, Conley, & Olney, 2012). Although many of the current computer tutors tend to use heuristics that remain constant as they customize material for individual students, the next generation of tutors will implement more dynamic models that can infer hidden learner characteristics and recognize unanticipated behavior based on learner performance, past experiences, and lessons learned. Aside from these breakthroughs in AI, the next-generation ITSs may include game-like components that further engage the student in the learning experience.

In the research discussed here, the AutoTutor Lite ITS (ATL, Hu et al., 2009) uses an established method of engaging a learner in a natural-language tutorial dialog (Graesser, Olney, Haynes & Chipman, 2005). ATL appears as an animated “talking head” avatar at certain points during the game and engages the learner in conversation about key physics concepts.

2.2 Learning Support via Games

Well-designed games can be seen as vehicles for exposing players to intellectual problem solving activities (Gee, 2004). But problem solving can be frustrating, causing some learners to abandon their practice and, hence, learning. This is where the principles of game design come in: Good games can provide an engaging and authentic environment designed to keep practice meaningful and personally relevant. With simulated visualization, authentic problem solving, and instant feedback, computer games can afford a realistic framework for experimentation and situated understanding, and thus act as rich primers for active learning (Shute & Ventura, 2013).

Furthermore, within-game learning support enables learners to do more advanced activities and to engage in more advanced thinking than they could without such help. The complicated part about including learning support in games is providing support that does not disrupt engagement while learners are immersed in gameplay, and reinforcing the emerging concepts and principles that deepen learning and support transfer to other contexts.

2.3 Physics Playground

Research into what is called “folk” physics demonstrates that many people hold erroneous views about basic physical principles that govern the motions of objects in the world, a world in which people act and behave quite successfully (Reiner, Proffitt, & Salthouse, 2005). Recognition of the problem has led to interest in the mechanisms by which physics students make the transition from folk physics to more formal physics understanding (diSessa, 1982) and to the possibility of using video games to assist in learning (Masson, Bub, & Lalonde, 2011).

The game Physics Playground (PP) was designed to help middle school students understand qualitative physics (Ploetzner, & VanLehn, 1997). We define qualitative physics as a nonverbal understanding of Newton's three laws, balance, mass, conservation of momentum, kinetic energy, and gravity. PP is a 2D sandbox game that requires the player to guide a green ball to a red balloon. The player can nudge the ball to the left and right (if the surface is flat) but the primary way to move the ball is by drawing/creating simple machines on the screen that “come to life” once the object is drawn. Everything obeys the basic rules of physics relating to gravity and Newton’s three laws of motion. Using the mouse, players draw colored objects on the screen, which “come to life” as physical objects when the mouse button is released. These objects interact with the game environment according to Newtonian mechanics and can be used to move the ball. When objects interact within the game environment, they act as “agents of force” to move the ball around. The player creates simple levers, pendulums, and springboards to move the ball.

The difficulty of a puzzle was based on a number of factors including: relative location of ball to balloon, number of obstacles present, number of agents required to solve the problem, and novelty of the problem. Difficult problems provide greater weight of evidence to the estimate of a competency level than easy problems. Also, “elegant” solutions (i.e., those using a minimal number of objects) give greater weight to competency level inferences than regular solutions. Preliminary data suggest playing PP for four hours can improve qualitative physics understanding ($t(154) = 2.12, p < .05$) with no content instruction or other learning support (Shute, Ventura, & Kim, 2013).

3 Methodology: GIFT Management of ATL and PP

As education turns to more game-like ITS learning environments it is important to ensure that their learning pedagogy remain consistent with the learning sciences. To ensure a good balance between the motivating “skin” of the learning experience and the deep “muscle and skeleton” of science-based learning, it is important to adopt a general architecture of ITS learning. The GIFT framework provides such an architecture and allows the integration of independent learning technologies (Graesser, Hu, Nye & Sottolare, In Press). In this work, GIFT manages and controls data communication between ATL and PP.

While the vast majority of the components of an ITS may be made domain independent, there must always be a specific component of the architecture to deal with the problems that the instructor desires to teach. The fundamental problems of domain-dependent components are how to assess student actions, how to respond to instructional changes, how to respond to requests for immediate feedback, and an interface that supports learning (Sottolare, Goldberg, Brawner and Holden, 2012; Goldberg, Sottolare, Brawner, & Holden, 2012). The architecture designed must have built-in support for these types of instructional activities.

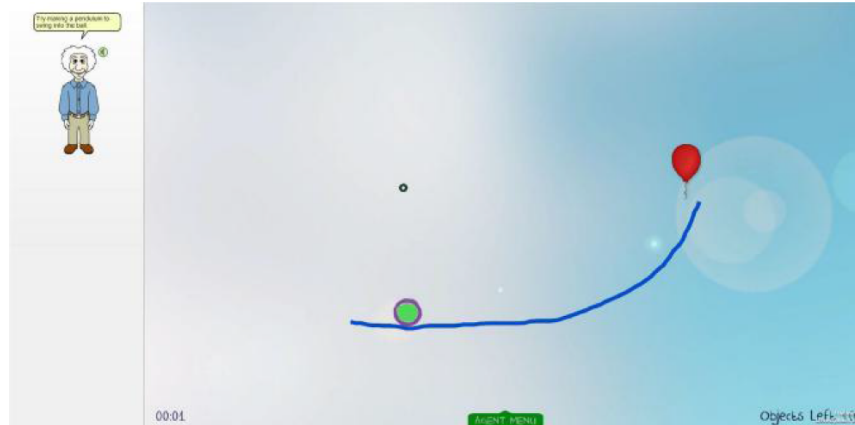


Fig. 1. NewtonianTalk Interface

Figure 1 displays the interface of NewtonianTalk. As can be seen, ATL is always displayed on the left next to the PP interface. There are 3 playgrounds in NewtonianTalk. Each playground teaches a physics concept with 3 puzzles (Impulse, Conservation of Momentum, Conservation of Energy). The first design decision that needed to be made was how to most effectively introduce dialogue into PP without disrupting game play. We chose the following pedagogy styles for instruction: information delivery through ATL, scaffolded question and answer selfexplanation in ATL, and PP puzzles with support instruction. The selection of the specific activity is handled by rules specified in the GIFT system that act conditionally on information sent from the PP puzzle as the student interacts with it. Below is the introductory explanation of Impulse to the player:

An unbalanced force can cause an object to speed up or slow down. Specifically, an impulse is required to change the speed of an object. Impulse is the product of force times time. To change ball's speed, a springboard exerts a force for an amount of time. Pulling the springboard down further increases the ball's speed even more by applying a greater force for a longer time.

After the player listens to further explanation as they play three PP puzzles. Figure 2 displays the puzzle for Impulse. As the springboard exerts a force up on the ball for an amount of time, it gives an impulse to the ball that changes the ball's motion. Increasing springboard's force or the time the springboard pushes up on the ball causes it to go even higher.

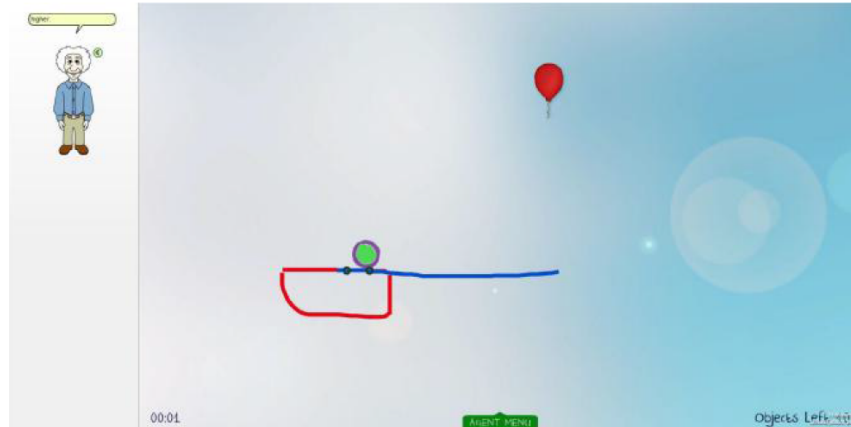


Fig. 2. Impulse puzzle with explanatory audio

After the player solves all 3 puzzles in the playground ATL poses a series of questions in natural language. Automated scores are calculated for the learner's performance. Below are questions for impulse:

- Q.** What is impulse? **A.** Impulse is force times time.
- Q.** How does an impulse affect an object? **A.** An impulse can change an object's speed.
- Q.** How could a force make a larger impulse? **A.** Increase the force or increase the amount of time.
- Q.** How can the same impulse be applied if the time of contact is reduced? **A.** To apply the same impulse over a smaller amount of time, the force must increase.

Once the player has answered the questions correctly or has maxed out the attempts (3 per question), the player then moves to the next playground. The player is given feedback in terms of percentages of completing the playgrounds and the ATL questions.

4 Discussion and Future Directions

This design process for this integration has identified some of the strengths and challenges for adding intelligent tutoring to an existing game environment that is mainly focused on simulation and experimentation. A strength of adding ITS interactions to such a game is that it allows instruction and discussion of the principles involved as they are encountered in the game (or, alternatively, fill them in when the learner struggles). Prior research on learning through exploring simulations indicates that such help may be important to learn from these activities efficiently (Graesser, Chipman, Haynes and Olney, 2005).

This approach can also be used as a model to enhance noneducational games to make them more effective for learning. For example, the game Portal 2 (despite not being learning-focused) showed significant benefits for certain types of problem solv-

ing skills (Shute, Ventura, and Ke, 2015). The current research integrates ITS into a Unity game, which is a popular engine. Such games may prove powerful learning environments with intelligent tutoring used to highlight and connect the key principles and concepts. However, the primary challenge of this work is to be able to integrate tutoring into an existing interface without being disruptive or introducing too much cognitive load.

We will be collecting data on NewtonianTalk in 2015 on an estimated 100 undergraduate psychology students. In addition to getting valuable usability data we also will test a hypothesis regarding instruction pedagogy. For this study, additional functionality is being specified that will leverage the ability of GIFT to manage and coordinate just-in-time feedback based on the learner's activities during a playground. Learners' freedom to explore in a playground may increase transferability of skills, but may also result in unproductive exploration. It is hoped that GIFT support will make exploration more effective.

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