Information Sciences 264 (2014) 4–18

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Designing game-based learning environments for elementary science education: A narrative-centered learning perspective

James C. Lester *, Hiller A. Spires, John L. Nietfeld, James Minogue, Bradford W. Mott, Eleni V. Lobene

North Carolina State University, Raleigh, NC, USA

ARTICLE INFO

Article history:
Available online 8 September 2013

Keywords:
Serious games
Game-based learning
Narrative-centered learning
Science education

ABSTRACT

Game-based learning environments hold significant promise for STEM education, yet they are enormously complex. Crystal Island: Uncharted Discovery, is a game-based learning environment designed for upper elementary science education that has been under development in our laboratory for the past four years. This article discusses curricular and narrative interaction design requirements, presents the design of the Crystal Island learning environment, and describes its evolution through a series of pilots and field tests. Additionally, a classroom integration study was conducted to initiate a shift towards ecological validity. Results indicated that Crystal Island produced significant learning gains on both science content and problem-solving measures. Importantly, gains were consistent for gender across studies. This finding is key in light of past studies that revealed disproportionate participation by boys within game-based learning environments.

Published by Elsevier Inc.

1. Introduction

There has been significant development in game-based learning in the past decade. Of particular interest is the potential that game-based learning environments have for integrating effective problem-solving episodes with highly engaging learning experiences. Recent advances include theoretical developments [22,24], the creation of game-based learning environments for a broad range of curricula [38,66], and the emergence of technically advanced game-based learning environments for both education [13,27,39] and training [32].

Although historically limited empirical evidence was available in support of educational games [1,8,26,53,59], in recent years game-based learning research has matured. Empirical studies have demonstrated that students achieve significant learning gains from interacting with educational games in a range of subjects [9,32,40]. Moreover, there have been several randomized controlled trials [1,9,25,44,45], as well as quasi-experimental studies [3,27,39,57] conducted with students in classroom settings that indicate that game-based learning environments are effective.

For the past four years, the authors have been designing, developing and iteratively refining a game-based learning environment for upper elementary science education, Crystal Island: Uncharted Discovery (Fig. 1). Our efforts have been guided by the principles of design-based research and design-experiment methodologies [7,10,14]. It has been suggested that design studies are "test-beds for innovation" whose intent is to "investigate the possibilities for educational improvement by bringing about new forms of learning in order to study them" [10]. The project has brought together researchers from computer

* Corresponding author. Address: Dept. of Computer Science, North Carolina State University, Engineering Building II, 890 Oval Drive, Raleigh, NC 27695-8206, USA. Tel.: +1 919 515 7534; fax: +1 919 515 7896.
E-mail address: lester@ncsu.edu (J.C. Lester).

0020-0255/$ - see front matter Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.ins.2013.09.005

Fig. 1. Crystal Island: Uncharted Discovery.

science, curriculum and instruction, science education, and educational psychology to build and systematically study the cognitive impact of 3D storyworlds.

This article reports on the design, development, and implementation of Crystal Island: Uncharted Discovery. The article is organized as follows. First, we situate our work on Crystal Island: Uncharted Discovery in the context of serious games and science education, and then discuss theoretical underpinnings in narrative-centered learning, problem solving, and engagement. Next, we discuss curricular, narrative interaction, and software platform design requirements. We then present the design of the Crystal Island: Uncharted Discovery learning environment, and describe its implementation through a series of field tests and a classroom integration study.

2. Literature review and theoretical underpinnings

2.1. Serious games and science education

Three recent policy reports have advocated the importance of game-based learning for educational purposes. *Learning Science Through Computer Games and Simulations* [50] concluded that games offer great promise because they "motivate learners with challenges and rapid feedback and tailor instruction to individual learners' needs and interests" (p. 21). These findings were echoed by the *New Media Consortium's Horizon Report*, which identified game-based learning as a key technology with great potential for significant impact on education [31]. Finally, the *National Education Technology Plan* [65] called for "simulations, collaborative environments, virtual worlds, games, and cognitive tutors" and discussed how they "can be used to engage and motivate learners while assessing complex skills" [65]. Taken together, these reports make a strong case that game-based learning is prominently positioned to make a significant impact on the educational landscape.

In addition to policy-related knowledge, advances in game-based learning have also taken place in the educational research arena. In a recent systematic review of empirical evidence on serious games, Connolly et al. [12] identified 129 reports on the impact on learning and engagement. The most frequently found outcomes were related to knowledge acquisition, content understanding, and motivation. Although the field continues to suffer from fragmentation and lack of coherence [37], substantial progress is being made in terms of synthesizing types of games and investigating their learning outcomes, e.g., students' achieving significant learning gains [3,27,39,46,57].

The serious games movement is responding to the desire to unite significant content with play as a way to promote twenty-first century skills [62]. The games within this genre layer social issues or problems with game play, helping players gain a new perspective through active engagement [31]. For example, Klopfer et al. in *Moving Games Forward: Obstacles, Opportunities,* & *Openness* [41] provide a conceptual path for educators and organizations interested in fostering the development of games for learning purposes. They make "a case for learning games grounded in the principles of good fun and good learning" (p. 1) and devote their efforts to motivating and informing educators and researchers who want to constructively participate, as creators and consumers, in the gaming domain.

There is a growing recognition that science classrooms are key to improving students' participation and performance in science [50]. While children enter school with curiosity about the natural world, many science classes fail to cultivate this interest into the scientific literacy needed to fuel our nation's progress. This has caused many experts to call for a new approach to science education, one that deemphasizes the rote memorization of "factlets" and the coverage of large bodies of content in favor of active engagement in problem solving and deep learning about core, cross-cutting concepts and processes [17,51].

The *Taking Science to School* report [17] asserted that K-8 students may learn deeper science knowledge when they engage in activities that are similar to the everyday activities of professionals who work in a discipline. This report presented four intertwined and equally important strands that define proficiency in K-8 science for all students: (1) understanding scientific explanations, (2) generating scientific evidence, (3) reflecting on scientific knowledge, and (4) participating productively in science.