Computers & Education 87 (2015) 24–34

Contents lists available at ScienceDirect

Computers & Education

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

Exploring the influence of game design on learning and voluntary use in an online vascular anatomy study aid

Andrea Gauthier [a, *], Michael Corrin [b], Jodie Jenkinson [b]

[a] Institute of Medical Science, Faculty of Medicine, University of Toronto, 1 King's College Circle, Toronto, ON, M5S 1A8, Canada
[b] Biomedical Communications, University of Toronto, Terrence Donnelly Health Sciences Complex, 3359 Mississauga Road, Mississauga, ON, L5L 1C6, Canada

ARTICLE INFO

Article history:
Received 27 November 2014
Received in revised form
17 March 2015
Accepted 18 March 2015
Available online 4 April 2015

Keywords:
Serious games
Interactive learning environments
Media in education
Teaching/learning strategies
Computer-mediated communication

ABSTRACT

This research explores the educational impact of an online study aid-game for studying human vascular anatomy (n = 24) versus a similar non-game study aid (n = 22) and how it relates to medical students' demographic traits and voluntary use over a 35-day period. Hierarchical linear regression models revealed that *study aid success rate* (a metric for assessing performance through the study aids) was a significant predictor of anatomy test improvement with the game ($\beta = 0.41$, $p = 0.05$), but not for the non-game ($\beta = 0.14$, $p = 0.56$). Our analyses suggest that game mechanics encouraged more specific problem-solving strategies than did the control study aid, leading to greater predictability of learning outcomes. There was a non-significant trend among game treatment participants, who were more likely to complete study tasks than those assigned to the control treatment ($p = 0.11$). It would appear that students' studying habits had the greatest influence (though opposite in both tools) on level of engagement in study aid use. However, contrary to expectations, self-reported gaming habits did not impact participation. Overall, these findings support the integration of game design into undergraduate study aids as a means of increasing use of supplementary educational tools and assessing knowledge.

1. Introduction

1.1. Background and theoretical framework

Learning human vascular anatomy is difficult. It requires an understanding of systemic and spatial interrelationships comprised of complex interconnected and branching networks (Hmelo-Silver & Azevedo, 2006)—the aorta alone has over 160 branching vessels. In addition, fine vascular structures are often difficult to preserve in dissection by novice learners, making it a challenge to study these structures in lab. To help students grapple with this material, interactive tools have successfully been used in anatomy instruction to increase engagement, knowledge retention, and systems thinking (Hilbelink, 2009; McCarroll, Pohle-Krauza, & Martin, 2009; Mcintire, 1995; Petersson, Sinkvist, & Wang, 2009). Many of these tools contain self-testing mechanisms; it has been shown that undergraduates' use of self-testing while studying is positively correlated with well-regimented studying habits and academic achievement (Hartwig & Dunlosky, 2012; Stewart, Panus, Hagemeier, Thigpen, & Brooks, 2014). When given a choice, high-performing students are more likely to choose a self-testing method over review-type studying (Kornell & Son, 2009).

Educational, or "serious", games are designed to support the learning process by integrating cognitive techniques for learning, such as self-testing mechanisms, with play and gaming elements (Gee, 2007; Landers & Callan, 2011; Squire, 2013). Game elements may include a storyline, goals, rules, penalties, achievements, intellectual challenges, scoring systems, and leaderboards (Westwood & Griffiths, 2010). These game design elements have potential to increase a student's willingness to participate in meaningful and intellectual play, thereby enhancing his or her understanding of target content and concepts (Gee, 2007; Squire, 2011).

* Corresponding author. Tel.: +1 905 599 0243.
E-mail addresses: andrea.gauthier@utoronto.ca (A. Gauthier), m.corrin@utoronto.ca (M. Corrin), j.jenkinson@utoronto.ca (J. Jenkinson).

http://dx.doi.org/10.1016/j.compedu.2015.03.017

Recent research has focused on using serious games and other digital applications both as a means of intervention and of assessment. Emerging frameworks for assessing learning through users' digital interactions are based largely on *educational data mining methods* and *evidence-centred design* (Halverson & Owen, 2014; Mayotte, 2010; Owen, Ramirez, Salmon, & Halverson, 2014; Reese, Tabachnick, & Kosko, 2014; Shute & Ventura, 2013). Educational data mining involves tracking users' click-stream data (actions taken by users while interacting with a digital application). These data can then be summarized and analysed for patterns and trends that, in the case of serious games, are indicative of learning. Evidence-centred design involves the interplay between three models: 1) the student model, that defines the intervention's learning objectives; 2) the evidence model, which describes behaviours that suggest that the student has met those learning objectives; and 3) the task model, that defines activities or problems that are presented to the user in order to elicit the behaviour of the evidence model (Mislevy & Haertel, 2006). When implemented carefully into a game's design, this framework enables researchers to make connections between students' in-game performance and learning.

For example, Halverson and Owen (2014) designed and tested a game, *Progenitor X*, with high school students to examine the link between gameplay performance and learning about stem cell biology. They developed their own framework ADAGE (Assessment Data Aggregator for Game Environments), based largely on evidence-centred design and educational data mining methodologies. The investigators found players' efficiency ratios—described as successful game cycle completions over cycle attempts—were significantly correlated with pre-post test gains. In evidence-centred design terms, they were able to conclude that higher completion efficiency (evidence model) of game puzzle cycles (task model) meant that players have a better grasp of stem cell concepts (student model). Additionally, by tracking players' behaviours through the click-stream data, the investigators were able to show that differential in-game behaviours led to variable game success and knowledge gains. This research contributes evidence linking gameplay interactions directly to learning. However, this type of methodology is still developing and additional studies are needed to add robustness to this field (National Research Council, 2011).

Additionally, it is important to consider the potential determinants of a serious game's impact, such as student type, previous gaming habits, or gender (National Research Council, 2011). As previously mentioned, high-achieving students with good studying habits may be more likely to engage in self-testing practices (Hartwig & Dunlosky, 2012; Stewart et al., 2014) and, if a game employs this technique, then these individuals may be more likely to play it; this effect may be enhanced if the student also displays high video gaming habits outside of school. Gender also has a known influence on gaming preferences, where females typically play less than males and generally gravitate toward more socially oriented games and males toward action-oriented games, though there is considerable variability (Greenberg, Sherry, Lachlan, Lucas, & Holmstrom, 2010). All of these aspects should be taken into account when evaluating the effectiveness and appeal of a serious game.

Many serious game-based research protocols take place in formal settings, such as investigators' labs or classrooms (Barab & Dede, 2007; Barab, Gresalfi, & Ingram-Goble, 2010; Charsky & Ressler, 2011; Kafai, 2009; Kafai, Quintero, & Feldon, 2009; Klopfer, Sheldon, Perry, & Chen, 2012), or in structured, informal environments like museums and after-school programs (Miller, Chang, Wang, Beier, & Klisch, 2011; Squire, 2011; Squire, DeVane, & Durga, 2008). Overall, there is a lack of research that implements serious games in unstructured, informal learning environments where students have absolute choice on where and when to play (National Research Council, 2011).

1.2. Summary of pilot study and goals of the current research

This research uses evidence-centred design and educational data mining techniques to explore the educational impact of learning with an online study aid-game versus a similar non-game study aid and how it relates to students' voluntary use and demographic characteristics. A pilot study by Gauthier and Corrin (2013) found that undergraduate anatomy students were significantly more likely to complete and attempt study aid tasks and engage in use sessions when given a game-study aid than a non-game-study aid over a period of one week. However, learning gains and how these related to gameplay were not considered. Additionally, though the study aids both contained the same learning material, the aesthetic differences between the two treatments possibly confounded the results. By ensuring that both treatments in a randomized trial have equivalent interaction and visual designs, we can tease out the unique contribution that game design makes to learning and engagement. In the present study, we sought to minimize these differences between both digital tools in order to explore how learning is related to study aid interactions.

This research is unique in that it places a serious game in an unstructured, informal learning environment (i.e. wherever the students see fit to use it). It represents a more contextually relevant learning experience as it is used by students who are actively learning the material and allowing these users freedom to interact with the study aids as they would with any supplementary material outside of the classroom.

Through a randomized trial, this study investigates how the presence of game design influences students' learning in an interactive study aid and how personal characteristics mediate voluntary use of the application. Specifically, we hypothesized that:

1. The presence of game design (experimental treatment) would encourage greater use (measured in completed study aid tasks, attempted tasks, and total usage sessions) and breadth of use (unique completed tasks), resulting in higher measured study aid performance (study aid success rate; refer to section 2.2)
2. Personal characteristics, such as gender, studying habits, and gaming habits would influence the voluntary use described above. For example, individuals who play video games on a regular basis would be more likely to engage in study aid tasks in the game group.
3. Higher study aid performance would be predictive of greater learning in both treatments, supporting the incorporation of evidence-centred, node-based study aids for vascular anatomy into students' regular studying practices.

2. Methods

2.1. Description of the study aids

Vascular Invaders is a web-based study aid with integrated game design elements, which is geared towards supporting undergraduate medical students' understanding of human vascular anatomy. The vascular system is represented by a network of nodes, each node