Digital Game based Learning for Undergraduate Calculus Education: Immersion, Calculation, and Conceptual Understanding

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ABSTRACT

This study has two goals: First, to investigate the effectiveness of using a digital game to teach undergraduate-level calculus in terms of improving task immersion, sense of control, calculation skills, and conceptual understanding. Second, to investigate how feedback and visual manipulation can facilitate conceptual understanding of calculus. 132 undergraduate students participated in a controlled lab experiment and were randomly assigned to either a game-playing condition, a practice quiz condition, or a no-treatment control condition. The authors collected survey data and behavioral-tracking data recorded by the server during gameplay. The results showed that students who played the digital game reported highest task immersion but not sense of control. Students in the game condition also performed significantly better in conceptual understanding compared to students who solved a practice quiz and the control group. Gameplay behavioral-tracking data was used to examine the effects of visual manipulation and feedback on conceptual understanding.

KEYWORDS
Calculus, Digital Game Based Learning, Higher Education, Math, Visual

INTRODUCTION

Calculus is the foundation for higher-level mathematics in disciplines such as physics, engineering, and economics. Calculus is not only important for understanding more advanced courses in school, it is also a significant predictor of one’s earnings at work beyond school (Rose & Betts, 2004). However, several studies have reported a disconnect between the calculus that students learned in classrooms and students’ ability to apply calculus concepts to other disciplines and to utilize calculus outside of schools (Lesh & Zawojewski, 2007). Students often fail to transfer their calculus knowledge because...
they lack hands-on experiences of applying their understanding to solving authentic problems; in fact, around 70% of problems in one calculus textbook are solved by mimicking the examples shown in the textbook (Lithner, 2004). This might cause students to be less motivated to learn because they do not understand the value of calculus in application. Studies have shown that students who experienced problem-solving scenarios in pre-calculus classes have better conceptual understanding of calculus applications, can identify and use appropriate resources, and are more motivated to take an active role in learning calculus (Stanley, 2002). Learning across multiple contexts (e.g., different media or different problem context) can also promote transfer because students can compare their experiences to abstract general concepts and construct a flexible understanding that can be applied to different contexts (Bransford, Brown, & Cocking, 1999).

Digital games have been proposed as an effective way to promote students’ conceptual understanding of abstract knowledge and problem-solving transfer (Boyle, Connolly, & Hainey, 2011; Garris, Ahlers, & Driskell, 2002; Gee, 2007). Modern digital games can facilitate meaningful problem-solving experiences for students, allowing them to visualize abstract concepts and situate the concepts in different contexts to gain a better understanding (Squire, 2003). They can provide immediate, or just-in-time feedback for students to assess and adjust their process (C.-Y. Lee & Chen, 2009). Games encourage players to form initial hypotheses, test them, observe the outcome, and revise their hypotheses. This process is similar to the process of experiential learning (Kolb & Kolb, 2005). In other words, digital game can simulate authentic problems for students to apply their calculus knowledge. They also allow students to visualize and actively manipulating factors to construct a flexible mental model which improves transfer across contexts.

While many studies have examined the use of digital games to enhance mathematics education, most of them focus on primary to secondary school mathematics or drill-and-practice for mathematical calculations (e.g., Ke, 2008a, 2008b; Mayo, 2009). Few studies have investigated using digital games to facilitate undergraduate-level mathematics, especially calculus, which is a complex foundational concept that affects student performance in more advanced courses. A major challenge of designing a calculus game is balancing the complex concepts and skills while keeping students immersed in the game. In this study we developed a game to teach undergraduate-level calculus called Mission Prime which is based on mathematical education principles.

The main goal of this study is to compare the effects of a digital game to teach university-level calculus to a traditional method of solving practice questions and a no-treatment control group. A secondary goal is to investigate (if any) what affordances of the game promote students’ conceptual understanding. We used behavioral-tracking data of player actions during gameplay to investigate whether the affordances of digital games to provide feedback and visual manipulation improved students’ conceptual understanding of calculus. The study design is a controlled lab experiment with random assignment that employs both pre- and post-test questionnaires paired with server-based player behavioral data to examine the following general research questions:

1. Is playing a calculus video game more effective in promoting conceptual understanding than traditional practice questions or no-treatment?
2. Is playing a calculus video game more effective in promoting calculation skills than traditional practice questions or no-treatment?
3. Is the experience of playing a calculus game more immersive than traditional practice questions or no-treatment?
4. Do the number of feedback provided by the video game and the ability to manipulate visual representations improve students’ conceptual understanding of the content mathematics?
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