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Using mobile applications for learning: Effects of simulation design, visual-motor integration, and spatial ability on high school students' conceptual understanding

June-Yi Wang, Hsin-Kai Wu*, Ying-Shao Hsu

Graduate Institute of Science Education, National Taiwan Normal University, PO Box 97-27, Taipei, 11699, Taiwan

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A B S T R A C T

The purpose of this study was to investigate the effects of simulation design, visual-motor integration, and spatial ability on students' conceptual understandings of projectile motion and collision. We developed three simulations including two mobile applications (app) and a computer simulation. One app (TA) employed the multi-touch feature for virtual manipulation, the other (TAG) implemented the multi-touch and tilt features, while the computer simulation (CS) was performed using a mouse. 211 10th graders were assigned to the three simulation groups. The results indicated that on the items of basic concepts, the CS and TA groups performed significantly better than the TAG group, whereas for the advanced concepts, the TA and TAG groups scored significantly higher than the CS group. Also, high visual-motor integration students did significantly better on the advanced concepts than low visual-motor integration students. Additionally, the interaction effect between simulation design and spatial ability showed that the two apps had a similar effect on students with different levels of spatial ability. The results suggest that mobile apps could narrow the performance gap between students with different levels of spatial ability, but effective interactions with the multi-touch interface of apps may require new skills such as visual-motor integration.

1. Introduction

The rapid emergence and advancement of mobile technologies have opened up new opportunities for teaching and learning (e.g., Motiwalla, 2007; Wu, Lee, Chang, & Liang, 2013). An increasing number of mobile devices, such as tablets and smartphones, have become part of classroom practice (e.g., El-Gayar, Moran, & Hawkes, 2011; Enriquez, 2010; Falloon, 2013; Murray & Olcese, 2011; Zydney & Warner, 2016). Yet, as Wedemeyer (2009) argued, educational technology must "go beyond the hardware and equipment" and "place software above hardware" (p. 118). Green, Hechter, Tysinger, and Chassereau's recent study (2014) of a selection rubric for mobile applications (apps) does indeed reflect the growing attention to the design of educational software for mobile devices. To extend the benefits of the mobile technologies, educational apps thus play a vital role in enhancing positive learning outcomes (Kucirkova, Messer, Sheehy, & Fernández Panadero, 2014; Schneps et al., 2014).

However, compared to research on computer-based educational software and simulations, studies of educational apps for mobile devices are still in their early stage, and are relatively few in number. For example, in the journal of Computers in Human Behavior, there have been more than 500 articles focusing on learners' use of simulations, whereas by July 2016 only 10 articles examining the effects of mobile apps were found when "app" was used as the search keyword. Additionally, some educational apps have not fully incorporated or utilized the features of tablets, including their intuitive interface, embedded sensors, and multi-touch screen (Wang, Wu, Chien, Hwang, & Hsu, 2015). Furthermore, research on innovative technologies in education has shown that various factors such as technology design, instructional methods, and students' characteristics could contribute to the effectiveness of technologies (e.g., Falloon, 2013; Wu, Lin, & Hsu, 2013). There is a need to systematically examine the possible effects of these factors on learning with educational apps.

This study was thus designed to address the aforementioned research issues. First, we developed educational apps on the basis of the design guidelines (Mayer & Moreno, 2003; Wang et al., 2015) to enhance students' learning of a physics topic. The topic covered

* Corresponding author.
E-mail address: hkwu@ntnu.edu.tw (H.-K. Wu).

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concepts of the projectile motion and collision of moving objects. These kinematic concepts were chosen because it has been well documented that students tend to hold nonscientific ideas about them (e.g., Dilber, Karaman, & Duzgun, 2009; Gilbert & Watts, 1983). Technologies could promote conceptual change in students' thinking by helping them make links between concepts and phenomena (Weller, 1995). Simulations could also support students' visualization of conceptual entities such as velocity, force, and acceleration (Christian, Esquembre, & Barbato, 2011; Wu & Huang, 2007).

Secondly, although a variety of simulations, probes, and multimedia tools have been designed for science learning, as indicated by a recent review of mobile apps, so far relatively little research has "isolated a particular design feature, making it impossible to discern the effectiveness of a single feature" (Zydney & Warner, 2016, p. 13). In this study, we exploited the features of tablets to produce two versions of an app offering students learning experiences through the touch sensory input and the tilt feature, and provided students with learning experiences that could seldom be replicated in computer simulations. In the mobile touchable version of the app (the TA app), the intuitive interface and multi-touch tablet screens were used; students could create one or more virtual objects by touching the screen and dragging the object(s) to set up the initial speed. In addition to the touch sensory input, the second touchable-with-gravity-sensor version of the app (the TAG app) implemented the tilt feature by utilizing the embedded sensors of tablets. When the virtual objects moved along the trajectories or during a collision, the students could tilt the tablet so that the magnitude and direction of gravity would change, and the trajectories would adjust accordingly. Furthermore, we designed a similar computer simulation that was performed using a mouse to create and control virtual objects and gravity. The three types of simulation design allowed us to investigate whether and how different features of tablets may support physics learning.

Thirdly, this study took students' characteristics into consideration by examining the effects of spatial ability and visual-motor integration on students' conceptual understanding. Previous research has reported a relationship between spatial ability and physics learning, where students with high spatial ability tend to demonstrate better performance than those with low spatial ability (Kozhevnikov, Motes, & Hegarty, 2007; Pallrand & Seeber, 1984; Uttal & Cohen, 2012). What remains unanswered is whether educational apps that allow students to have direct interactions, such as using the touch sensory input and the tilt feature with finger and bodily motions, would enlarge or narrow the performance gap between low and high spatial ability students. Additionally, the touch sensory input could involve visual-motor coordination. When interacting with mobile apps, students are expected to visually follow the movement of virtual objects while appropriately controlling their hands and fingers so that they could precisely click on these objects and drag them to different places. These interactions may require visual-motor integration ability, so this ability was another learning factor examined in this study.

2. Purpose and research questions of the study

To systematically examine how various factors affect learning with educational apps, the purpose of this study was to investigate the effects of simulation design, visual-motor integration (VMI), and spatial ability on high school students' conceptual understanding of the projectile motion and collision of moving objects. In this study, conceptual understanding refers to students' conceptions and ideas about the content and meaning of science concepts (Mäntylä & Koponen, 2006). The research questions guiding the study were as follows:

1. To what extent does students' conceptual understanding differ by the type of simulation design and their VMI ability?
2. To what extent does the effect of simulation design on students' conceptual understanding vary by their VMI ability levels?
3. To what extent does students' conceptual understanding differ by the type of simulation design and their spatial ability?
4. To what extent does the effect of simulation design on students' conceptual understanding vary by their spatial ability levels?

Although the learning topic chosen in this study was in the physics domain, many scientific concepts in chemistry as well as in biology involve dynamic systems and the motion of particles (e.g., chemical reactions, kinetic theory of gases, and energy transformation). The results of this study may be applicable to the learning of these concepts and can provide insights into the question of how mobile apps could promote understanding of the complex and dynamic concepts in science.

3. Theoretical background and empirical foundation

3.1. Designing apps for science learning

Previous research has identified students' difficulties in learning science concepts (e.g., Gilbert & Watts, 1983; Huddle & Pillay, 1996). For example, students rely on their experiences and observations of the behaviors of objects in everyday situations and develop their own conceptions of force and motion (Dilber et al., 2009). It has been argued that one source of students' difficulties may be the abstract and invisible nature of scientific concepts (Wu & Shah, 2004). Many entities represented in scientific concepts such as atoms and electrons are not observable to the naked eye, and complex scientific phenomena (e.g., electric currents and sound waves) could involve relationships or interactions among these invisible entities. Additionally, some interactions among the entities and objects could be dynamic and occur on a massive (or microscopic) scale. Therefore, computer simulations in physics such as Physlets (Cox, Belloni, Dancy, & Christian, 2003; K.; Lee, Nicoll, & Brooks, 2004) have been developed to help students overcome their learning difficulties. Computer simulations allow students to explore scientific phenomena that are impossible, difficult, or time consuming to accomplish in classroom settings (Jimoyiannis & Komis, 2001; Smetana & Bell, 2012). They also include entities or variables for students to manipulate and observe how the changes of entities or variables affect a system (Finkelstein et al., 2005; Rutten, van Joolingen, & van der Veen, 2012).

If a substantial amount of research has indicated the advantages of using computer simulations for science education, what new possibilities for science teaching and learning can be offered by educational apps on tablets? Studies in education and technology have started to explore the possibilities. To display the range of astronomical scales, Schneps et al. (2014) incorporated "pinch-to-zoom" navigation in their app of the solar system, and examined the effects of two display modes: one exaggerating the size of astronomical bodies relative to their orbits, and the other treating scale relationships more accurately. The results indicated that the latter display mode, including more realistic depictions of scale, was more effective in reversing students' misconceptions. Another study was done by Wang et al. (2015) in which two educational apps were designed to facilitate students' conceptual understanding of the projectile motion and collision. The two educational apps supported a mixed-reality learning environment, used the embedded sensors of tablets to collect gravity and velocity data, and linked students' bodily motion to the magnitude of gravity. After an instructional lesson with the use of the apps, students' scores on a concept test were significantly improved, but this rather