Effects of commercial video games on cognitive elaboration of physical concepts

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1. Introduction

Digital games consist of diverse and dynamically linked elements, a characteristic that supports their use for situational learning—that is, for creating scenarios in which players create knowledge bases consisting of information and skills obtained as a game progresses, and with those bases being transferable to real-life situations (Squire, 2003; Van Eck, 2006). By simulating real-world situations and presenting ill-defined problems, digital games position player activities within meaningful contexts, and offer opportunities for trial-and-error learning (Sampson & Panoutsopoulos, 2012). Because of these characteristics, computer simulation games are thought to have the potential to help students discover additional information about basic concepts (White, 1993; White & Frederiksen, 1998).

The past decade has witnessed the creation of a large number of commercial video games capable of simulating complex physical characteristics in ways that allow players to experience or observe realistic virtual examples of scientific principles (Mohanty & Cantu, 2011). World of Goo and Crayon Physics are two popular examples of games containing elements that match real-world physical characteristics and natural science laws. A large number of interesting scenarios covering a broad range of concepts can emerge from such characteristics (McDaniel & Telep, 2009). Accordingly, a growing number of researchers and educators are looking at ways to use popular commercial games as learning tools rather than develop games specifically designed for instructional purposes (Clark et al., 2011), with cost-effectiveness a strong motivator for this change (Proctor & Marks, 2013; Van Eck, 2006). However, at least one researcher has warned that “commercial games are not designed to teach, so topics will be limited and content may be inaccurate or incomplete” (Van Eck, 2006, p.7). Teachers must therefore incorporate other materials and learning tools in conjunction with commercial games to ensure or enhance their instructional effects (Moreno-Ger, Burgos, Martínez-Ortiz, Sierra, & Fernández-Manjón, 2008; Robertson & Howells, 2008; Yang, 2012). Masson, Bub, and Lalonde (2011) have also observed that many commercially successful games lack instructional or interpretive information that might contribute to a player’s conceptual understanding of events and the subsequent transfer of knowledge to novel
situations. Accordingly, our focus in this study is the effects of commercial games as tutorial tools on the cognitive elaboration of physical concepts that students have already learned, rather than teaching new concepts.

The cognitive structures underlying human reasoning are analogous to game world structures, with gameplay and game interfaces supporting player efforts to construct viable mental representations (Reese, 2007). Thus, simulation game situations can be designed to frame specified physical concepts, similar to the ways that instructors use stories as frames for organizing and integrating content knowledge (Gudmundsdottir, 1991). Using the subject of physics as an example, most object motion involves more than one concept—for instance, friction and gravity for a wheel rolling down an incline. Digital game designers often incorporate various physics principles into different game levels in order to increase difficulty. Concepts can be introduced or reinforced as players solve problems by trial-and-error in pursuit of increasing their game levels. Many of today’s most popular commercial games contain special elements such as rating mechanisms or the ability to collect game props to encourage players to repeat game levels. These and other game features can be used to create meaningful contexts to enhance cognitive elaboration, defined as the use of pre-existing knowledge in support of new learning (Pintrich, 1999). In one study, Becker (2007) used Reigeluth and Stein (1983) elaboration theory (including the strategies of elaborative sequences, prerequisite sequences, and summaries) when working with video game components that support the anchoring of new ideas and skills.

The goal of the present study is to investigate the potential use of commercial video games to promote learner elaboration of pre-existing concepts—specifically, the use of commercial game situations to encourage the organization of pre-existing knowledge nodes in learner memory for purposes of reinforcement.

2. Related work

2.1. Commercial video game pedagogy

The use of commercially available video games to create game-based learning environments and experiences is increasingly considered a tenable, valuable, and popular instructional approach (Kirriemuir, 2005; Papastergiou, 2009). Commercial off-the-shelf digital game-based learning (COTS DGBL) is viewed as having potential benefits in terms of the accurate representation of scientific laws, historical scenarios, and medical knowledge, among other concepts (Moreno-Ger et al., 2008). Some game companies are designing and releasing plug-in tools that support modding and game scene recoding to allow instructors to alter game content in ways that enhance student creativity and learning (Kafai, Heeter, Denner, & Sun, 2008). Such support increases the potential for mapping commercial game content or contexts to curriculums while overcoming the obstacles of low game quality and high costs (Prensky, 2003; Van Eck, 2006; Whitton, 2012).

Moreno-Ger et al. (2008) are among researchers who note that even though commercial game developers rarely contemplate educational uses for their products, teachers are recognizing that game content is sometimes sufficiently rich and detailed so as to have instructional value if managed and altered properly. Charsky and Mims (2008) give recommendations for instructors wanting to use commercial video games in history classrooms, including the suggestion that teachers work closely with academic researchers to organize data for implementation via video games. However, as Van Eck (2006) repeatedly stresses, topics are likely to be limited, and the potential is high for inaccurate or incomplete content. Many consider these to be the biggest obstacles to implementing COTS DGBL: it requires careful analysis and matching of content as well as the strengths and weaknesses of the game in question.

The literature is filled with case studies involving specific games and environments. Adams (1998) used SimCity 2000, a COTS game, in an introductory undergraduate urban geography class to present information on the complexity of issues faced by urban planners. Students used the game to construct a functioning city with buildings, roads, power plants and different types of zones (e.g., commercial and residential). The game presents challenges that encourage reflection on urban processes. Despite the short implementation period, Adams claims that one-third of the participating students acquired greater appreciation for urban government, urban planning, and difficulties associated with managing urban projects.

Yang (2012) investigated the use of two commercial games, Tycoon City (economics) and SimCity Societies (global issues), to teach problem solving skills and to enhance learning motivation in a group of Taiwanese ninth-grade civics students. Her experimental group engaged in online competition using a digital game platform, while a control group was taught using a combination of lectures and worksheets. Study results indicate (a) improvement in solving problems tied to addressing the needs of community residents, reducing environmental pollution, and reducing unemployment, and (b) a significant increase in the experimental group’s learning motivation. Academic achievement was similar in both groups.

2.2. Using commercial games to teach science principles

Developments in game design technologies have made it possible for many commercial games to precisely simulate complex real-world science principles, thereby giving learners opportunities for applying those principles to problem-solving (Mohany & Cantu, 2011). Crayon Physics (Purho, 2008) requires players to draw objects consisting of levers, pulleys, and other tools, and to creatively use physics concepts such as gravity to solve puzzles. Players use a mix of existing and new knowledge plus their imaginations to complete game tasks (Li, Ma, & Ma, 2012). El-Nasr and Smith (2006) investigated modding (i.e., the use of existing game engines to create new worlds for exploration or to make major changes to existing games) with WarCraft III to teach computer science, mathematics, physics, and aesthetic principles to a group of American high school students. Assigned tasks included adding a character model and animating characters so that they could move toward specific destinations. The authors reported that their students showed significant improvement in their understanding of math (3D math and simple vector geometry) and physics concepts (3D transformations and rotations) after completing these assignments. Masson et al. (2011) used a commercial game called Enigma, which emphasizes the observation and manipulation of realistic trajectories, to study the effects of gameplay on learner reasoning involving object motion. They found that students who spent time using the game for training purposes were better at generating or making judgments about statically depicted paths of moving objects. However, they also found that the students did not accurately transfer their game-based procedural learning to other situations because of inadequate interpretations of trajectory angles.
2.3. Multimedia learning and cognitive strategies

The present study is based on three assumptions tied to Mayer’s (2002) cognitive theory of multimedia learning: (a) human information processing consists of two separate channels—an auditory/verbal channel for processing auditory input and verbal representations, and a visual/pictorial channel for processing images; (b) learners are limited in terms of the amount of information they can process simultaneously using the two channels; and (c) learners who actively engage in information processing tend to construct coherent mental models so as to achieve meaningful learning (Fig. 1). In an earlier paper, Mayer (1997) observed that learners select relevant material for mental representation in working memory, organize the information into a coherent cognitive structure or working memory, and then connect the new information with existing knowledge stored in long-term memory. This model explains how learning from video games can be transferred to cognition, and how knowledge from gameplay is organized and assimilated.

Weinstein and Mayer (1986) note the importance of certain factors for efficient information processing, including selective attention, maintaining active messages in short-term memory, and both intrinsic and external links. They list five learning strategies based on these factors as rehearsal, elaboration, organization, comprehension, and affective/motivational. Due to their associations with intrinsic learner cognition, these are also referred to as cognitive strategies (Gagné, 1985). They are applicable to simple memory tasks such as text recall, as well as to complex tasks requiring interpretation (Weinstein & Mayer, 1986). As Bembenutty (2007) has observed, learner self-efficacy can be promoted by learning strategies, meaning that instructors can show their students how to use various strategies to enhance learning efficiency.

Elaboration entails the application of existing knowledge to new learning scenarios so as to establish meaningful links between the two. Mastery requires the use of information from multiple sources, including course materials, discussion content, and webpage knowledge, among many others. Information processing supports the retrieval of clues during new learning (Pintrich, 1999), as well as during pre-existing concept recall and reinforcement (Gagne, Bell, Weidemann, & Yarbrough, 1980). Becker (2007) notes that learners who use elaboration strategies can benefit from meaningful situations in support of new ideas or skill development, since they can provide important assistance in terms of knowledge migration and retention.

Becker worked with seven video game strategy components based on Reigeluth and Stein (1983) elaboration theory for educators:

1. Elaborative sequences that move from simple to complex, and that clearly describe game situations, purposes, and operational demands.
2. Prerequisite sequences that provide a practice mode for users to learn simple operations and to understand game recommendations.
3. Summaries in the form of “tab sheets” that show player achievement and status to help them understand how they can make further progress.
4. Knowledge synthesis at different game levels, with knowledge from one level leading to the next, thus helping players gather tips and form strategies.
5. Analogies that players can use to link elements from other games they have played, thus allowing them to infer methods or strategies from past experiences to level up.
6. Cognitive strategies or rules set by game designers that players must follow, thus supporting player motivation to discover built-in strategies for overcoming challenges and having fun in the process.
7. Learner control, an obvious requirement of all games. Good games allow players to win via multiple routes. The sense of control that emerges is a goal of good game design.

2.4. Concept maps

Novak developed concept maps as part of his work to help learners connect new learning with old experiences to form meaningful content, as well as to add clarity to the structure of an event (Novak & Gowin, 1984). Concept map-based learning emphasizes the active attention given by learners to information processing tasks so that received messages can be organized, refined, and saved in long-term memory for later retrieval (Gabel, 1999; Vos & Dryden, 1994). Concept maps have been applied to multiple educational settings in support of logical thinking and better understanding of subject content (Price, 2008; Roth & Roychoudhury, 1994). In some studies they have been tested as a learning assessment tool—their purpose in the present study (Chang, Sung, Chang, & Lin, 2005; Hwang, Wu, & Ke, 2011). Scoring schemes vary according to learning requirements and purposes (Bousquet, 1982; Schreiber & Abegg, 1991); we used the most common approach, as described in the Methods section that follows.
A growing number of researchers have experimented with concept map applications for game-based teaching, with positive results being reported in terms of learning effectiveness and motivation. Coller and Scott (2009) used concept maps to evaluate a video game-based numerical methods course that was part of a university’s mechanical engineering curriculum, and to compare it with a standard lecture/textbook-based instructional approach. They described the purpose of the concept map as providing glimpses into how numerical knowledge is organized in learner minds. According to their results, the game-based method was particularly useful in terms of evaluating learner understanding—that is, “tapping into the learner’s cognitive structure” and determining the sophistication (or lack of sophistication) of that understanding (see also Hwang, Yang, & Wang, 2013; Price, 2008).

Rice, Ryan, and Samson (1998) explored the use of concept maps to assess declarative knowledge of life science concepts for a group of seventh-grade students. Their approach was to create a table of specifications to reflect instruction, construct multiple choice test items based on those specifications, and then develop a concept map scoring rubric based on the multiple choice items. They concluded that the match between the map-scoring method and the construct to be measured is critical for measuring knowledge and comprehension level outcomes. Sims-Knight et al. (2004) describe the use of student-generated concept maps to assess learner understanding of how various aspects of the design process complement each other in the context of procedural knowledge in engineering courses. They reported that the maps provided instructors with useful information about what the learners understood, and produced both general and specific information for ongoing improvement.

3. Methods

3.1. Research framework and questions

Our motivation is to investigate the potential use of two existing commercial video games to promote learner elaboration of physical concepts, using concept maps and multiple-choice tests to measure differences in learner success before and after playing the games in a tutorial context. In our research framework, the sample was divided into one experimental (game-based review teaching method) and one control group (lecture-based review teaching method). The two teaching methods served as independent variables. Dependent variables were student concept map and examination scores.

We considered differences in types of player support when choosing Cut the Rope and Angry Bird Space for our experiments—for example, Angry Bird Space provides hints for props only, while Cut the Rope provides hints for operations, props, and leveling up. Both game designs match Becker’s (2007) criteria for using an elaboration strategy with a commercial game (see Section 2.3). The primary focus in Cut the Rope is pendulums; in Angry Bird Space it is circular motion. We also attempted to clarify whether game experiences affected cognitive elaboration processes in the form of learner mastery of game rules and skills for moving to higher game levels.

We addressed four research questions:

1. As measured by student concept maps, was the efficacy of the game-based review teaching method better, worse, or the same as that of the lecture-based review teaching method?
2. As measured by multiple-choice tests, was the efficacy of the game-based review teaching method better, worse, or the same as that of the lecture-based review teaching method?
3. When using the game-based review teaching method, did prior experience playing the two games affect learner concept map scores?
4. When using the game-based review teaching method, did prior experience playing the two games affect learner multiple-choice test scores?

3.2. Sample

Our initial sample consisted of 83 ninth-grade students (44 male, 39 female) between the ages of 15 and 16 in three classes in a junior high school in northern Taiwan; the gender distribution was comparable to that for all ninth graders in Taiwan in 2013 (52% male, 48% female) (Ministry of Education, 2013). The school’s location and student composition make it representative of junior high schools throughout the country. The normal class groupings are indicative of a random sample.

The experiment was conducted during a two-week winter semester period when teachers are allowed to present supplementary activities that are not part of the regular curriculum. During the preceding semester, all of the participants had taken a standard physics course that included units on pendulums and circular motion, therefore ensuring that our experiments involved a review of previously learned material.

We adopted a quasi-experimental design to test the research questions. A total of 83 participants from three classes signed informed consent forms at the beginning of the project. Combined, the two experimental groups had 32 male and 27 female students, while the control group had 12 males and 12 females. The group numbers ensured adequate sample sizes for responding to the third and fourth research questions. In response to the unequal distribution, we paid extra consideration to homogeneity during our statistical analysis. All three groups were taught by the same instructor. To avoid John Henry and Hawthorne effects, students were not told the purpose of playing the games prior to the experiment.

3.3. Multiple-choice tests and concept maps

We compared the ability of concept maps and multiple-choice tests to assess cognition levels (Van Boxtel, Van der Linden, & Kanselaar, 2000). The multiple-choice tests were written using materials provided by the publisher of the main textbook used in the preceding semester’s physics class. The two tests (one for the pendulum concept, the other for circular motion) contained 10 items worth 10 points each for a total score of 100. Each item had four answers to choose from. Scores were measured as the percentage of correct answers. Two sample items are.
1. For the pendulum concept and the corresponding concepts of swing angle and cycle:
   Q: How will the swing cycle of the pendulum change if it is affected by air resistance?
   (a) Increase.
   (b) Decrease.
   (c) No change.
   (d) Cannot be determined.
2. For the circular motion concept and the corresponding concepts of gravitation and centripetal force:
   Q: What kind of force acts on an object when its circular motion continues?
   (a) A centrifugal force that is the same as the movement direction.
   (b) A counterforce that is contrary to the movement direction.
   (c) An inertial force along a tangential direction.
   (d) A centripetal force perpendicular to the movement direction.

Results from Kuder-Richardson reliability (KR-20) analyses for the pendulum concept were 0.92 for the pre-test and 0.86 for the post-test. The respective scores for the circular motion pre- and posttests were 0.93 and 0.84. All four scores indicate acceptable internal consistency.

Scores for the four concept map items were determined according to Novak and Gowin (1984) criteria (Table 1). The participating instructor created maps for the two physical concepts and used them to rate student maps. Having a single rater ensured a high level of consistency. Performance was calculated as (concept map score of learners)/(standard concept map score) \times 100\%. Standard scores were 58 for the pendulum concept and 46 for the circular motion concept. Scores greater than 100 indicate that the student map was better than that created by the instructor. A concept map scoring example is shown in Fig. 2 and Table 2. The map contains five relationships, three meaningful hierarchies, one cross-link, and two examples, for a total score of 32. Using the above performance calculation with a standard score of 58, this map received a final score of 55.2%.

3.4. Commercial video game: Cut the Rope

Created by Zeptolab (2010), Cut the Rope was downloaded more than 400 million times internationally between 2009 and 2013 (Chris Buffa, 2013). Versions are available for smart mobile devices, tablets, and desktop computers. All object characters in the game follow Newtonian laws of physics (Shaker, Shaker, & Togelius, 2013). Players need to cut one or more ropes at precise moments so that pieces of candy tied at the end are released, hit stars according to a mix of gravity and tension, and then fall into the mouth of a frog-like figure. Players are given access to tools such as air cushions, constraining pins, bubbles, shooting-buttons, rockets, spikes, spiders, and suction cups, among others. To win, they must become familiar with the physical characteristics of each tool. A game screen shot is shown as Fig. 3. The game consists of 4 boxes with 9 levels per box, for a total of 36 levels. In our experiment, individual game time was limited to 30 min to support our efforts to measure progress.

We chose this game for four reasons:

1. The large number of physical properties involved, including pendulums, potential energy conversion, circular motion, reflection law, elastic potential energy, and buoyancy, among others.
2. The need for both speed and skill to cut ropes at precise times, as well as the need for patience to ensure that all of the stars are hit and collected. These features reward concentration.
3. The game’s repeatable level-based design with a smooth difficulty curve. The repetitive challenge characteristic contributes to player induction and physical knowledge consolidation.
4. The game’s special star rating system (1–3) for evaluating player skill, which encourages players to repeat challenges at the same level.

3.5. Commercial video game: Angry Bird Space

The operating platform of this physics-based strategy game, developed by Rovio Entertainment, supports smart mobile devices, tablets, and desktop computers. It is one of the most successful games ever created for this range of platforms (Cheng, 2012). Angry Bird Space was the most downloaded paid app game in 2012; in 2014 the number of downloads exceeded 200 million (Long, 2014; Makuch, 2012). In the original version of Angry Birds, birds are shot from slingshots to attack pigs placed around various buildings. Angry Bird Space inherited some of the features and elements of the original game, with the important exception of an interstellar space context that lacks gravity. Accordingly, in addition to horizontal projectiles and acceleration, players must consider centripetal force and reaction time when shooting...
The newest version has multiple types of angry birds, each with its own functions and features (http://www.angrybirdsnest.com/meet-the-birds-in-angry-birds-space/). A sample game screen is shown as Fig. 4. The total number of game levels is 120 (30 levels each for 4 planets). Student participants were limited to 30 min and the first planet.

We also had four reasons for choosing this game for our study:

1. It has a simple interactive engagement concept that allows players to try different methods in response to repetitive challenges at the same level. The difficulty curve is smooth and increases for each level, letting players learn new operations while connecting old and new experiences (Xu, 2011).
2. The game also has a 1-3 player skill rating system at each level. Stars are given when certain scores are achieved. The rating system considers multiple factors such as time lapse and number of birds used.
3. It has a response time management feature in which pig expiration times increase when houses collapse, adding to game playfulness and entertainment (Xu, 2011).
4. The game has multiple physical properties—for example, the above-mentioned lack of gravity in interstellar space. However, game objects are still affected by the gravitational pulls of nearby planets, thus forcing players to consider centripetal force and object reaction. These characteristics reflect the concepts that the study participants learned in their science classes.
3.6. Procedure

Our experimental procedure consisted of three steps:

1. Planning. Lesson plans were developed by the researchers and classroom instructor. Specifically, the instructor designed the teaching and review materials, standard concept maps, game record forms, scoring criteria, and multiple choice exams. The researchers inspected the two games to ensure that they included appropriate information regarding the pendulum and circular motion physical concepts.

2. Experiment. Two experiments involving the two physical concepts were completed over a two-week period. A total of 180 min each were spent on the two topics. Approximately 1 h was used to introduce concept maps. Pretests for the concept map and multiple-choice test groups required 30 min each. The students were also asked to complete questionnaires regarding their prior game experience. The 24 control group students listened to a 40-min lecture that was supplemented by a textbook and several handouts. The 59 experimental group students played the game in question for 30 min using a PC platform. The focus for the first week was the pendulum concept. During the Cut the Rope play sessions, students were free to repeat levels or move up to new ones. A teaching assistant was responsible for monitoring the process. All individual gaming sessions were recorded using screen capture software. At the end of the week, students in both groups were given 30-min concept map and multiple-choice posttests. The focus for the second week was the circular motion concept (Angry Bird Space). All procedures and processes were identical to those just described.

3. Scoring, as described in section 3.3.

4. Results

Data for students who returned incomplete or otherwise unusable test papers or did not play the games even though they were in the experimental group were removed from the statistical analysis. Valid data for the pendulum concept experiment were produced by 55 students in the experimental group and 18 students in the control group (Table 3). The corresponding numbers for the circular motion concept experiment were 48 and 15.

All statistical analyses were performed using SPSS 18. Our first task was to confirm consistency among all of the study participants in terms of their understanding of the two physical concepts. Independent sample t-test results for pretest scores using both assessment tools are shown in Tables 4 and 5. No significant differences and moderate effect sizes were found for the pendulum concept pretest scores (concept maps, t (58) = 1.61, p = .112 > .05, d = 0.322; multiple-choice exams, t (71) = 1.76, p = .082 > .05, d = 0.478). For the circular motion concept pretests there were also no significant differences, and the effect sizes were small (concept maps, t (61) = −0.52, p = .604 > .05, d = −0.153; multiple-choice exams, t (61) = 0.76, p = .451 > .05, d = 0.225).

4.1. Research questions

The first question addressed the efficacy of the game-based review teaching method compared to the lecture-based method as measured by concept map content. According to Levene’s test results, there was no significant difference (p = 0.282 > 0.05) between the variances, indicating homogeneity between the two groups (Table 6). Results from independent sample t-tests for both group scores indicate average increases of 0.279 points between pre- and posttests for the experimental group and 0.137 for the control group—a statistically significant difference with a large effect size (t (71) = 3.151, p = .002 < 0.05, d = 0.856). Levene’s test results for the circular motion concept experiment also showed no significant difference between the variances (p = 0.548 > 0.05), again indicating inter-group homogeneity (Table 7). Further,
no statistical significance was noted between pre- and posttest scores for the two groups \( (t (61) = 1.881, p = .065 > 0.05, d = 0.56) \). However, the large effect size \( (d > 0.5) \) suggests a considerable difference between the groups, with average score improvement being higher for students in the experimental group \( (0.061) \) than for those in the control group \( (-0.029) \).

The second research question was identical to the first except for the use of multiple-choice test scores. Levene’s test results for the pendulum concept experiment once again show no significant difference \( (p = .275 > 0.05) \) between the variances, indicating inter-group homogeneity (Table 6). In terms of independent sample t-test results, students in the experimental group gained an average of 2.360 points between pre- and posttests, while control group students lost an average of 0.560 points—statistically nonsignificant with a small effect size \( (t (71) = 0.656, p = .514 > 0.05, d = 0.18) \). Levene’s test results for the circular motion concept experiment indicate homogeneity between the groups, with no statistically significant difference between the variances \( (p = .703 > 0.05) \) (Table 7). Independent sample t-test results for scores between the two groups also failed to find any significant difference in terms of score improvement, with a trivial effect size \( (t (61) = 0.145, p = .884 > 0.05, d = 0.04) \). However, average scores were higher among students in the experimental group.

The third research question addressed whether prior game-playing experience affected learner posttest scores as measured by concept maps. Levene’s test results once again indicate inter-group homogeneity \( (Cut the Rope, p = .958 > 0.05; Angry Bird Space, p = .986 > 0.05) \). As shown in Tables 8 and 9, no significant differences were found in posttest concept map scores between learners with prior/no prior gaming experience for either game \( (Cut the Rope, t (53) = 0.536, p = .594 > 0.05, d = 0.15; Angry Bird Space, t (46) = -0.798, p = .432 > 0.05, d = -0.23) \). In both cases effect sizes were small.

The fourth question was identical to the third except for the use of multiple-choice exam scores. Levene’s test data again indicate inter-group homogeneity \( (Cut the Rope, p = .610 > 0.05; Angry Bird Space, p = .515 > 0.05) \). As shown in Tables 8 and 9, no statistically significant differences between experimental and control groups were observed for either game \( (Cut the Rope, t (53) = -0.642, p = .524 > 0.05, d = -0.17; Angry Bird Space, t (46) = 0.147, p = .884 > 0.05, d = 0.04) \). Effect sizes were small and trivial in both cases.

5. Discussion

According to the participants’ concept maps, students who played Cut the Rope experienced greater improvement in terms of reinforced pendulum-related concept knowledge compared to learners who reviewed the same physical concepts in a standard lecture-type classroom setting. The same result was not noted in the concept maps created by Angry Bird Space players, although there was a sizeable difference in effect size between the player/non-player groups. We will use the concept maps shown in Fig. 5 to explain our results.

Looking at the two maps drawn by a student in the experimental group, the posttest map was clearly better organized than the pretest map, with more meaningful hierarchies among specific concepts, double branches for similar concepts, and closer links among related concepts. Note that the posttest map contains two cross-links—a characteristic we observed in all maps drawn by the students in this group.

\[ \text{Table 4} \]

Pendulum concept pretest scores as measured by concept maps and multiple-choice exams.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of students</th>
<th>Concept maps Average score</th>
<th>S.D.</th>
<th>p value</th>
<th>Multiple-choice exams Average score</th>
<th>S.D.</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>55</td>
<td>0.020</td>
<td>0.048</td>
<td>0.112</td>
<td>56.73</td>
<td>20.372</td>
<td>0.082</td>
</tr>
<tr>
<td>Control</td>
<td>18</td>
<td>0.006</td>
<td>0.024</td>
<td></td>
<td>47.22</td>
<td>18.087</td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{Table 5} \]

Circular motion concept pretest scores as measured by concept maps and multiple-choice exams.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of students</th>
<th>Concept maps Average score</th>
<th>S.D.</th>
<th>p value</th>
<th>Multiple-choice exams Average score</th>
<th>S.D.</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>48</td>
<td>0.207</td>
<td>0.17</td>
<td>0.604</td>
<td>51.67</td>
<td>17.785</td>
<td>0.451</td>
</tr>
<tr>
<td>Control</td>
<td>15</td>
<td>0.235</td>
<td>0.22</td>
<td></td>
<td>48.00</td>
<td>10.142</td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{Table 6} \]

Data for effects of both review teaching methods for the pendulum concept.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of students</th>
<th>Concept maps Average score increase</th>
<th>S.D.</th>
<th>p value</th>
<th>Multiple-choice exams Average score increase</th>
<th>S.D.</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>55</td>
<td>0.279</td>
<td>0.168</td>
<td>0.002</td>
<td>2.360</td>
<td>15.511</td>
<td>0.514</td>
</tr>
<tr>
<td>Control</td>
<td>18</td>
<td>0.137</td>
<td>0.159</td>
<td></td>
<td>-0.560</td>
<td>18.934</td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{Table 7} \]

Data for effects of both review teaching methods for the circular motion concept.

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of students</th>
<th>Concept maps Average score increase</th>
<th>S.D.</th>
<th>p value</th>
<th>Multiple-choice exams Average score increase</th>
<th>S.D.</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>48</td>
<td>0.061</td>
<td>0.148</td>
<td>0.065</td>
<td>6.880</td>
<td>20.437</td>
<td>0.885</td>
</tr>
<tr>
<td>Control</td>
<td>15</td>
<td>-0.029</td>
<td>0.202</td>
<td></td>
<td>6.000</td>
<td>20.284</td>
<td></td>
</tr>
</tbody>
</table>
One of the two cross-links shows that the student in question understood (a) connections between both potential and kinetic energy and the laws of conservation of energy for a pendulum, and (b) that both kinds of energies are associated with Newton’s first law of motion.

In terms of game elements, our results suggest three key factors tied to the effects of the two games on concept elaboration, the first being the amount and type of interpretive information a game offers— that is, “game hints.” As shown in Fig. 6, the Cut the Rope players in this study benefited much more than the Angry Bird Space players in terms of the kinds of information they had access to. Cut the Rope provides hints that help players overcome obstacles, get higher scores by collecting game props, and understand the functions of props/game objects. In comparison, Angry Bird Space hints are mostly limited to game prop functions. As shown in the lower left-hand corner of Fig. 6, Cut the Rope hints help players recall and organize relationships among rope tension, gravity, and counterforces. These hints are examples of scaffolding, which some researchers describe as a useful tool for refining strategies and making connections between games and the kinds of formalized knowledge required in school-based contexts (Clark et al., 2011; Fisch, 2005).

The second key factor is the 1–3 rating mechanism found in both games (Fig. 7). Screen-capture videos taken during the experiments show that some study participants repeated the same game level in an effort to earn three-star ratings—an example of repetition that can help learners master targeted concepts. While many commercial games have similar rating mechanisms for player performance evaluation (see, for example, Age of Empires), their scoring systems tend to have much larger ranges. A mechanism limited to three stars may have advantages in terms of player motivation toward goal achievement. The third factor, game prop collection, is similar to the second factor in terms of encouraging players to repeat the same game level—in the case of Cut the Rope, the motivation is to collect the three stars (Fig. 8). This represents another possible strategy for motivating players to repeatedly practice target concepts.

The lack of statistically significant differences between the two groups in terms of improved scores on the multiple-choice exam suggests that concept maps are more appropriate than multiple-choice exams for evaluating cognition levels. As Yang (2012) notes, multiple-choice tests simply require students to recall or recognize information and meaning (see also Chu, Lee, & Tsai, 2011). She is one of many researchers suggesting that learning outcome assessment tools should encourage students to organize principles, develop new models, or consider the effectiveness of concepts—the main strengths of DGBL. Our results confirm previous descriptions of concept maps as suitable assessment tools that allow for graphic depictions of relationships among related learning concepts, thereby supporting efforts by learners to classify and organize knowledge.

Our finding that learner game-playing experience did not affect the efficacy of the game-based review teaching method suggests that instructors have greater leeway in terms of choosing commercial games in support of classroom instruction. Companies are making major investments in casual app games—both entertainment and educational—for use with smart mobile devices, and most of them feature

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**Table 8**

Data for analysis of the effect of game-playing experience on posttest scores for the pendulum concept for study participants in the game-based review teaching method group.

<table>
<thead>
<tr>
<th>Experience level</th>
<th>Number of students</th>
<th>Concept maps</th>
<th>Multiple-choice exams</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average score</td>
<td>S.D.</td>
</tr>
<tr>
<td>Experienced or master</td>
<td>26</td>
<td>0.311</td>
<td>0.159</td>
</tr>
<tr>
<td>Inexperienced</td>
<td>29</td>
<td>0.287</td>
<td>0.178</td>
</tr>
</tbody>
</table>

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**Table 9**

Data for analysis of the effect of game-playing experience on posttest scores for the circular motion for study participants in the game-based review teaching method group.

<table>
<thead>
<tr>
<th>Experience level</th>
<th>Number of students</th>
<th>Concept maps</th>
<th>Multiple-choice exams</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average score</td>
<td>S.D.</td>
</tr>
<tr>
<td>Experienced or master</td>
<td>22</td>
<td>0.247</td>
<td>0.139</td>
</tr>
<tr>
<td>Inexperienced</td>
<td>26</td>
<td>0.285</td>
<td>0.185</td>
</tr>
</tbody>
</table>

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Fig. 5. Two concept maps drawn by the same student in the pendulum experiment group. Left, pretest; right, posttest.
simple, repetitive level-based designs. This enhances their potential for use by instructors who are concerned with “ease of use” and “usefulness” in games they are considering for instructional purposes (Proctor & Marks, 2013).

6. Conclusion

While commercial simulation games are capable of presenting realistic physical phenomena (e.g., the parabolic shapes of object trajectories), they offer little in the way of significant conceptual advancement due to their lack of adequate instructional information (Masson et al., 2011). Inadequate interpretations of perceptual events jeopardize the transfer of perceptual experience to new situations. It is
therefore necessary to incorporate tutorials or supplemental tools into games to explain basic principles—in the case of this study, the principles of physical mechanics (Masson et al., 2011; Rodrigues & Carvalho, 2013). Thus, our goal was to clarify whether two widely available commercial games can help learners to elaborate their knowledge of physics concepts after studying basic conceptual knowledge under regular classroom conditions.

Anderson (1982) is one of many educational psychologists who have noted that during the learning process, skill and knowledge acquisition are initially dependent on declarative knowledge, followed by a practice-dependent transformation into procedural knowledge that becomes increasingly automated. This transformation is a key factor in effective learning (Gros, 2007). Automation means that intermediate steps are performed without interpretation, with inputs and outputs not requiring access to short-term memory (Ericsson & Simon, 1980).

For subjects that are rich in procedural concepts (especially the sciences), instructors frequently use graphics and specific examples to explain concepts for consolidation and elaboration. However, such methods are considered inefficient for transforming declarative knowledge into procedural knowledge. Cognitive skill acquisition is a “learning by doing” process that translates declarative knowledge into procedural knowledge (Wang & Chen, 2010), leading some researchers and instructors to experiment with educational video games in support of such transformations (Kebritchi, 2008; Wang & Chen, 2010). Digital games can foster procedural knowledge by providing information about task performance and simulating how tasks should be done (Dickey, 2007).

In their study of designing an educational game aimed at teaching programming, Wang and Chen (2010) noted at least three key factors for consolidating and elaborating programming concepts: trial-and-error, progressive challenges, and feedback based on learner actions. Our study verifies that some commercial games possess these characteristics, all of which contribute to cognitive elaboration. In addition to providing players with procedural knowledge by simulating complex realistic physical phenomena, some commercial games contain features that motivate players to repeat game levels—a potential strategy for reviewing and strengthening targeted learning concepts.

There are three other potential advantages to using commercial games as review tools, the first being entertainment value, which can help build motivation to continue playing the games after school, perhaps contributing to further concept elaboration.

According to Csikszentmihalyi’s (1997) flow theory, flow occurs when players are engaged in a physical, mental, or combined activity at a level of immersion that causes them to lose track of time and sense of the outside world—a state that usually occurs when they are performing at an optimum level. Player flow can be disrupted if a game overemphasizes instructional content or incompatible additive material (Van Eck, 2006; Wang & Chen, 2010). In comparison to educational games, commercial games are more likely to provide endogenous

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1 Declarative knowledge consists of facts, data, concepts, and principles.
2 Procedural knowledge consists of knowledge of how to perform a task, action, or process.
fantasy elements—one of four main factors that make games intrinsically motivating and that encourage flow (Malone & Lepper, 1987). We did not follow up to determine whether the participating students continued to play the same games after our experiment. If they did, we believe that play would support further cognitive elaboration.

A second advantage is cost. It is worth noting that the versions of the two games used in this research were free-to-play, meaning that players would only need to pay if they wanted to achieve higher game levels or obtain additional game props. This overcomes the obstacle, noted by Whitten (2012), that commercial games and site licenses can be expensive—especially if hardware purchases are required. The economics of app development and marketing is encouraging many game companies to create high-quality casual and/or mobile games that can be played for free on various platforms (Wilcox, 2014)—an obvious advantage to educators dealing with limited budgets.

The third advantage is physics engines—software frameworks or APIs capable of calculating various physical effects (e.g., rotation, gravity, ropes) and exporting the results to animation software or game engines to render motion. This process creates opportunities for the elaboration of various physical concepts. One example of a physics engine is found in Angry Bird Space—Box2D, an open-source two-dimensional physics simulator engine. Box2D is capable of creating constrained rigid body simulations of convex polygons, circles, and edge shapes, with jointed bodies acted upon by various forces (Shankar, 2012). Another example is PhysX, a physics engine used to model the physical and mechanical behaviors of rigid 3D objects (Bhandwaldar, Ghule, Gandhi, & Bansode, 2014). The development of multiple physics engines suggests that the future will bring many new commercial games featuring physical concepts, with some more suitable than others for instructional or review use.

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References
