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Enhancing Orbital Physics Learning Performance through a Hands-on Kinect Game

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Abstract

Practicing is very important in the process of learning physics. Experiencing physics laws and observing the phenomenon in the experiments and labs help students learn. However, some contexts like the law of orbits in physics cannot be practiced directly and students can only learn it from animation or drawings. We have designed a Kinect game for students to experience orbital physics and conducted a pilot in a summer camp of Athabasca University's science outreach program to verify the hypotheses include whether the students' attitudes toward computer/video games will affect their perceptions toward the developed Kinect game or not, and whether their performance in the game will be influenced by the lack of prior knowledge of the law of orbits or not. The quantitative analysis results showed that there was a positive correlation between students' gaming performances and what they knew about the relevant physics knowledge. Also, it shows that the students' attitudes toward computer/video games do not affect their perceptions toward the developed Kinect game in terms of its usability.

Keywords

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Introduction

With the advancement of motion-sensing technologies, the potential for natural user interfaces (NUIs) to provide a space to enhance creative thinking seems promising (Chao, Hwang, Fang, & Chen, 2013). Many virtual reality applications and games have been designed and implemented for students learning Physics by playing. However, only few of them take Physics rules and equations into consideration in the game design. Amongst those games in which more accurate Physics rules have been applied, they do not provide students immersive experiences in playing. Rezaei and Skinner (2012) have investigated whether integrating motion-sensing games into the mobile learning system can assist in enhancing learning achievement and learning retention. They have found that the motion-sensing games can provide students a relaxed and interactive learning experience via bodily

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movements. Students can learn knowledge from the external stimuli gradually. Moreover, Ou and colleagues (2011) use mobile learning system with motion-sensing games to correct student's misconceptions. Their experiment results show that student's learning retention significantly exceeded those who use a mobile learning system without motion-sensing games. Li and colleagues (2012) explore how training with webcam-based motion-sensing games affect autistic students' sensory integration. They have found that not only the participants perceived positive attitude toward the game but also the game improves the effect of the training and makes students hope the training can be continued longer and take the training every day.

Kissco (2011) expresses his excitement by predicating that Kinect will become a focal classroom technology in the next few years. Hsu (2011) explores the idea of using Kinect as interactive technology to help teaching and learning. She has found that Kinect has the potential to enhance classroom interactions and to engage students participating learning activities. Jamie and McRae (2011) develop a molecular manipulation game with human gesture interface by using Kinect to allow students playing "elements" and learning. They think such game can be used in lectures, tutorials, and even by students at home. Lee, Liu and Zhang (2012) develop a Kinect game to enhance children's math learning experience as children have difficulty in learning arithmetic math.

Lee and colleagues (2012) try to integrate embodied interaction into learning to enhance student's learning experience and to improve student's learning performance by using Kinect. Their research results also found that the intrinsic motivation of students is high and the students do still pay attention on learning due to they can see their peers and adjust themselves based on peer observation. Nakamura et al. (2013) investigate the relationships between student learning attitudes and the effects of using Kinect self-learning systems. They use a questionnaire to identify whether student learning attitude is "active" or "passive" and they evaluate student learning performance by comparing 21 checkpoints of the results of student's pre- and post-test. They have found a strong negative correlation between passive learning attitude and the effect of using Kinect self-learning system.

In this research, we have developed a Kinect game which only has accurate Physics laws but also provides students (from elementary level to pre-university level) immersive experiences in playing via a natural user interface. Student perceptions toward the proposed game in terms of technology acceptance are explored through a pilot conducted in a summer camp of Athabasca University's Science Outreach program.

We have several hypotheses for the proposed game. The first expectation the research team has to see is the correlation between student's prior knowledge of the orbital physics and the performance of the game-play in terms of how much time spent and how many balls thrown for reaching the level goals. If the correlation can be found, then the use of the proposed game is meaningful. Second, as we know that people may have different attitudes toward computer and video games, we hope to see that there is no relationship between student's attitude toward computer and video games and his or her performance of the game-play. If there is no positive correlation found, then the proposed game can be used for all students learn orbital physics instead of few students who like playing game very much. At last but not least, we expect to see that the proposed game is easy to learn due to the use of natural user interface for the game-play and students' perceived easy to learn can make them feel the game is useful for learning orbital physics.

Methods

The game design

The first step in completing the orbital physics Kinect game is to encapsulate several loose methods contained in the main game loop into a single player class. The player class would handle Kinect events and would update its internal components such as Gesture Engines and hand positions. Then when called for drawing, it would generate a texture to be displayed as a representation of the player. The drawing is a skeleton mirroring the user's movements as Fig. 1 shows.

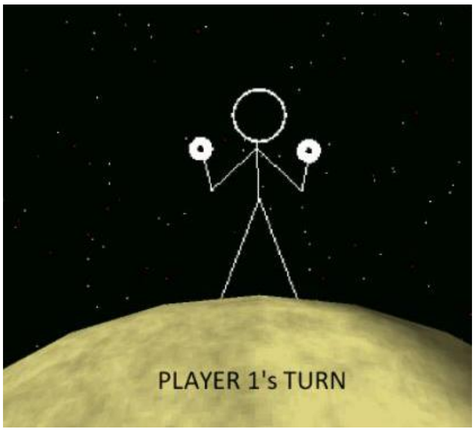

Figure. 1. Player's Skeleton is Detected and He or She is Going to Use His or Her Hand to Throw the Ball

As for how balls are thrown: first the distance is measured between the right hand and the chest, if the distance surpasses a certain threshold then a ball is thrown at the same speed the hand is moving (as if it were actually being thrown). The speed is measured by calculating the position difference between skeleton updates, then using a scaling factor. The skeleton itself is drawn by taking the position of key joints (head, hip, shoulders, elbows, hands) and scaling them depending on the height of the person. This is done by measuring the distance from the head to the hip and again using a scaling factor.

Technical enhancements of the Kinect interface

The original prototype was too slow. We first enhanced the system to speed up the game through "recycling" skeleton frames and passing them onto the gesture recognition engines instead of having each gesture recognition engine poll the Kinect for its own frame. This worked well since with one player there are two gesture recognition engines (one for each hand) calling the Kinect plus the event in the game loop itself makes three event calls total.

Though this wasn't enough, the game was still lagging and even recycling the Depth frame did no good as we suspect the Depth frame was not under such lag as the skeleton frame. The problem was in the gesture recognition engine itself, it was very elegant and multi-purposed but for this game we only need to detect grabbing motions. So we made a hand tracking library and managed to make a leaner, faster gesture recognition engine for the game (Gonzalez, & Woods, 2002). Fig. 2 shows the overview of the in-house gesture recognition engine. First, the Depth data is clipped into two 150x150 pixel images centered around each of the two hands. Then, the image is equalized and a set of concentric circles are placed over the depth image and the number of overlaps are counted. At the end, the shape of the hand is determined via the number of overlaps.

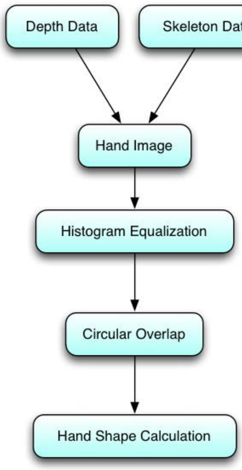

Figure 2. The Overview of the in-House Gesture Recognition Engine

In Fig. 3, the number of overlaps starting from the centre would be 2, 4, 4, and 2. By averaging the number of overlaps we get an approximation of how many fingers are disjoint from the hand. That number will be near 1 to 2 when it is a fist and near 3 to 4 when the hand is open. This method is incredibly fast, almost as fast as the refresh rate of the depth video image itself. The reason it is fast is because we have reduced the amount of pixels required to iterate through. Instead of going through 150x150 (equals to 22500 pixels) it goes through four circles worth of pixels and applies a similar clustering algorithm as the first hand library did with its centroids.

Figure 3. The Overview of the in-House Gesture Recognition Engine

The game

At the end, a fast enough orbital physics Kinect game with seven levels was developed. The game allows individual player standing in front of Kinect and playing the game with his or her right hand and arm. The game has tutorial mode and can be played in either single player mode or tournament mode. Players can start with tutorial mode and get themselves familiar with the game.

In the tutorial mode, the player will experience the game-play from first level which has no gravity setting and the player can throw the ball just like shooting dart, to second level which has gravity setting and the player needs to throw the ball into a basket nearby, to fifth level which the player needs to throw the ball with certain speed so the ball can go into an orbit and hit the basket behind the player's skeleton, and to seventh level which the player needs to shoot the ball in a scenario that three planets A, B, and C are in a line and the player needs to shoot the basket from planet A to C by considering the different gravity that each planet has.

The Pilot

The subjects

We conducted a small pilot to verify our hypotheses by recruiting the students who were participating in the Science Outreach event – Lego Robotics Camp. The science outreach events held by AU is intended for students who are interested in science. The game designed and implemented is teaching science relevant topic – Orbital Physics. The students might have more willingness in trying the proposed game.

Before starting to analyze the collected data with quantitative approaches, the reliability and validity of the collected data has to be tested. Although the questionnaires are adopted from previous research and its reliability and validity have been proved, the student age-range of this pilot is pretty wide and some questions may not be easy to understand for grade 4 students, for instances, "playing computer/video games improves my eye and hand coordination" and "playing computer/video games enhances my imagination." After item removal, the original twenty CGAS questions become ten questions that cover three factors – Like, Learning, and Confidence – as the Social factor has only two items left; and the original eighteen revised TAM questions become seven questions that cover two factors – Easy to Learn and Useful. The features of the proposed game like tournament mode, the social factor and natural user interface are used for discovering its relationships with the student's perceived easy of use separately.

The demographic section collected student's grade and gender information, experiences of playing computer/video games, and average time spent every day in playing games. Table 1 lists basic information for the 20 students.

Table 1. Demographic Information of the Students

Grade	N	Male	Female	Play game before (%)	Hours spent in playing game (hours/day)
4	3	2	1	100	2.14
5	4	4	0	100	1.43
6	6	5	1	100	3.31
7	3	3	0	100	0.50
8	2	1	1	100	0.75
9	1	1	0	100	4.57
10	1	1	0	100	5.57
Total	20	17	3	100	

The experiment design

In the first day of the summer camp, we took a short period of time to show the students the Kinect game and explained the purpose of the game. We also told the students that the pilot is going to be held in the second day and their parents need to sign the consent form if anyone who is interested in joining the pilot. We then delivered the consent forms to all participants. In the morning of the second day, the researchers collected the signed consent forms and all students in the camp were welcome to join the pilot as long as their parents signed the consent form. At the end, twenty students from grade 4 to 10 joined the pilot including seventeen male students and three female students.

In the second day, we first told the students to make pseudo-name for their avatars for the game-play later. Then, they were asked to do a short pre-test (five multiple choice questions regarding the Physics concepts and knowledge which the game covers). As some of students are younger (i.e., grades 4 and 5), we had a science faculty member to explain each question and answer options for them together and asked them to choose one option as their answer of the question. When they finished the pre-test, they were asked to register their avatars for playing the game in tournament mode as Fig. 4 shows. After the tournament, the students were asked to fill up a questionnaire with total 43 questions.

Figure 4. A Female Student is Playing the Game

The instruments

Users' technology acceptance is a growing research field in information systems research. The technology acceptance model was proposed by Fred D. Davis in 1986 and has become one of the most common theories used to explain the users' behavioral intention of using an innovative technology. The original TAM has four constructs: the perceived ease of use, the perceived usefulness, the attitude toward using the innovative technology, and the behavioral intention of using the innovative technology.

Some researchers have examined the acceptance factors for educational games or entertainment games by adding their own variables to the original model to explore the influences of different external variables, for instances, gender, gaming experience, learning opportunities and the unified theory of acceptance and use of technology (UTAUT) (Bourgonjon, Valcke, Soetaert, & Schellens, 2010; İbrahim, 2011). In the pilot of this research, an external variable (i.e., natural user interface) is proposed for inclusion in the original TAM.

The proposed research model is altered from the research done by İbrahim (2011) and Bourgonjon et al. (2010). Different from previous models, this research has three moderators: gaming experience, and natural user interface feature as variables. The questionnaire was adopted from previous research results and its validity and reliability have been proven (Lu, Chang, Kinshuk, Huang, & Chen, 2011; Lu, Chang, Kinshuk, Huang, & Chen, 2014a).

The questionnaire consists of three sections. The first section has four demographic questions about avatar names, gender, gaming experience, and time spent on playing game. The second section is Computer Game Attitude Scale (CGAS) adopted from our previous research in which twenty 5-point Likert questions existed for four factors – Like, Learning, Social, and Confidence (Jones, Chang, & Kinshuk, 2014). The third section is a revised technology acceptance model questionnaire adopted from our previous research in which eighteen 5-point Likert questions plus one open-ended question existed for four factors – Easy to Learn, Useful, Fun, and Features of the proposed game (Lu, et al., 2014a). The open-ended question is asking students their suggestions on the enhancement and improvement of the proposed game.

The pilot asked students to put their character names on the sheets instead of their real names so all data collected from the pilot was anonymous and cannot be tracked back to particular students. At beginning, all data came from the paper-based tests and questionnaire. Then the research team converted them into electronic ones and so it can be fed into SPSS and can be analyzed later. All data are collected directly from the students at the same day after the pilot. The research team uses SPSS to do quantitative data analysis such as descriptive analysis, t-test, Pearson Correlation and ANOVA.

Results

Reliability and Validity Analysis

The data collected for the remained questions is analyzed before using it to verify the hypotheses. The Cronbach's alpha for the computer game attitude scale section is 0.796, indicating that the questionnaire (and its items) can be seen as reliable because its internal consistency is good enough (i.e., exceeds 0.75) (Hair, Anderson, Tatham & Black, 1998). On the other hand, the Cronbach's alpha for the revised technology acceptance model section is .915, is also good enough for doing further analysis.

Next, the internal commonality of items for each factor is examined using principal component analysis. Tables 2 and 3 list the results of factors in principle component analysis for both of the computer game attitude scale section and the revised technology acceptance model section.

Table 2. Validity Analysis Results of the Computer Game Attitude Scale

Factor **Item**	**1**	**2**	**3**
Factor 1: Confidence			
I_{14}: I am good at playing computer/video games.	.921		
I_{17}: I am skilled computer/video game player.	.862		
I_{5}: I always try to solve the current quest/question/mission in the computer/video game.	.828		
I_{18}: I would enjoy a school subject more if I could play a related educational computer/video game.	.673		
Factor 2: Learning			
I_{4}: I am very interested in solving quests/questions/missions in computer/video games.		.826	
I_{3}: Using computer/video games in school is a good way to learn.		.805	
I_{9}: Playing computer/video games make me happy.		.793	
Factor 3: Liking			
I_{12}: I talk about computer/video games with my friends.			.831
I_{11}: When I have free time, I play computer/video games.			.726
I_{10}: Playing computer/video games is part of my life.			.607
Eigenvalue	4.087	1.880	1.359
% of variance	40.87	18.798	13.586
Overall α=0.796, total variance explained is 67.54%			

Table 3. Validity Analysis Results of the Revised Technology Acceptance Model

Factor **Item**	**1**	**2**
Factor 1: Easy to Learn		
I$_2$: The terms and functions in the game are easy to understand.	.962	
I$_3$: I have no difficulty in using it.	.813	
I$_{17}$: I would like the game to be used in a school class to teach science.	.751	
I$_5$: This game provides me enough information for what I want to know.	.703	
Factor 2: Useful		
I$_7$: I could use the information provided by the game to adjust my strategy in throwing the ball into the basket.		.949
I$_{18}$: I would like some directions in playing the game by having a teacher guide me.		.840
I$_4$: I can get needed information quickly within the game.		.672
Eigenvalue	4.731	1.002
% of variance	67.582	14.321
Overall α=0.915, total variance explained is 81.903%		

The lack of prior knowledge

The pre-test has five multiple choice questions which are related to the Physics concepts and knowledge which the game covers. Although the overall correctness of the pre-test that students have done has no correlation found, we do find the students who correctly answered item #2 – A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow? –have significantly different game-play performance than those who answered the item wrong. Table 4 lists the results of the correspondent independent t-test.

To correctly answer this item the students need to know that the cannon ball will be pull to the ground by the gravity from the moment it has been shot out from the cannon. This background theory of this item is needed for understanding how to put a satellite in the orbit of a planet. This finding confirms our expectation and makes the proposed game capable of being used for students learning the law of orbit in physics as well as being used for implicitly knowing whether students understand the necessary prior knowledge or not while playing the game.

Table 4. Independent t-test (the correctness of answer for item #2 in the pre-test)

		Levene's Test for Equality of Variances				
		F	Sig.	t	df	Sig.
Balls	Equal variances assumed	2.634	.122	-2.507	18	.022
	Equal variances not assumed			-2.276	10.527	.045
Time	Equal variances assumed	1.096	.309	-2.136	18	.047
	Equal variances not assumed			-2.023	12.383	.065

Attitude towards computer games

Students have their own learning preference. Some of them may prefer reading alone over listening to a lecture and some may want to get their hands dirty in hands-on practices. While some may be impressed and can learn quickly through watching a documentary movie, some others may want to interact with peers either physically or virtually (sometimes via avatars or even with virtual characters). Therefore, it is important to find out if students who like computer and video games very much have better game-play performance (i.e., the time spent and balls thrown for reaching the level goals) than those who don't like computer and video games so much.

Table 5. Correlation Between Game-Play Performance and computer game attitude

		Like	Learning	Confidence	CGAS
Balls	Pearson Correlation	-.013	.044	-.079	-.030
	Sig. (2-tailed)	.957	.854	.741	.899
	N	20	20	20	20
Time	Pearson Correlation	-.002	.072	-.055	.000
	Sig. (2-tailed)	.995	.762	.819	.999
	N	20	20	20	20

Table 5 lists the correlation analysis results and there is no correlation found in-between the game-play performance and the factors of computer game attitude scale. This finding encourages us as the proposed game can be fairly used for all students despite of their attitudes toward computer and video games. This finding also in align with previous studies (Lu, et al., 2014a).

The features of the game

Due to many questions in the revised technology acceptance model section of questionnaire are difficult for the students to understand and have been removed, only two factors – Easy to Learn and Useful – are kept in the stage of quantitative analysis. However, we still have student responses for the following questions which are used for getting students' perceptions toward the easy of use, the natural user interface (NUI) feature, the tournament mode feature, and the play-with-peers feature:

- I_1: The screens are easy to use. (easy of use)
- I_9: It is easy to use gesture to play. (NUI)
- I_{11}: It is fun to play with other players in the tournament. (tournament)
- I_{12}: The freedom allowed makes the game more interesting. (NUI)
- I_{16}: I would play the game if many of my friends are playing. (play-with-peers)

We first would like to know whether the natural user interface feature that the game has makes the students feel the game is easy to use and easy to learn. From the correlation analysis results listed in Table 6, we can see that the natural user interface feature does have significant positive correlations to students' perceived easy of use and easy to learn. Moreover, the feature also indirectly supports the students' perceived usefulness of the game. This finding is also align with previous studies (Lu, et al., 2014b).

We can see the tournament mode of the game may not so helpful in terms of making the game more useful for students from Table 7. On the other hand, the play-with-peers feature does make students perceived usefulness of the game. This finding makes the game capable of applying into the existing curriculum and teachers can use the game in the classroom as teaching assisted tool.

Table 6. Correlations Among the NUI and the Perceived Easy of Use, Usefulness and Easy to

		I_9	I_{12}	**Useful**
I_1 (easy of use)	Pearson Correlation	.829**	.744**	.721**
	Sig. (2-tailed)	.000	.000	.000
	N	20	20	20
Ease to Learn	Pearson Correlation	.816**	.865**	.687**
	Sig. (2-tailed)	.000	.000	.001
	N	20	20	20

**. Correlation is significant at the 0.01 level (2-tailed)

Table 1. Correlations Among the Tournament and play-with-peers Features and the Perceived Usefulness

		I_{11}	I_{16}
Useful	Pearson Correlation	.354	.804**
	Sig. (2-tailed)	.126	.000
	N	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

Conclusions

The research team developed a Kinect game for students learning the law of orbit in physics. In order to make sure that the game can be fairly used in traditional classroom learning and for everyone, a small pilot has conducted and the collected data has been analyzed. The results show that the game can be used for everyone despite of the student's attitude towards computer and video games. Also, the game-play performance can be seen as a measure of student's understanding of the prior knowledge. The use of arm and hand to play the game makes student perceive the game is easy to use and learn. Furthermore, this feature indirectly help student perceive usefulness of the game. At last, the play-with-peers feature not only has positive correlation to the student's perceived usefulness towards the game, but also makes the game become a teaching assisted tool in the classroom for teachers.

The results suggest that teachers may use the proposed natural user interface based game to assess their students' understanding of the correspondent knowledge in Physics. Moreover, through the game-play, the teachers can consider the use of such game as an implicit assessment tool and no need to concern whether or not a student has experience in playing any kind of games. On the other hand, for educational game developers and researchers, the results confirm that natural user interface make students feel the educational game is useful indirectly due to they can learn how to play the game easily.

The pilot was conducted in a summer camp of Athabasca University's science outreach program. Due to the limited time we had in the summer camp as there were plenty scheduled activities for students to do in the camp, the game-play time each student had was not long enough for us to apply post-test to verify the effect of learning the law of orbit via playing the game. On the other hand, although the tournament feature of the game didn't show its value on the perceived usefulness at this moment, perhaps it can be proved to be useful for the winners – win match more often, the effect of learning more obviously – as it provides students a platform of competition.

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