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Is immersion of any value? Whether, and to what extent, game immersion experience during serious gaming affects science learning

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Abstract

Many studies have shown the positive impact of serious gaming on learning outcomes, but few have explored the relationships between game immersion and science learning. Accordingly, this study was conducted to investigate the effectiveness of learning by playing, as well as the dynamic process of game immersion experiences, and to further identify whether, and to what extent, immersion affects science learning through serious gaming by using the techniques of cluster analysis. A total of 63 seventh-grade students participated in the study, and a quasi-experimental research design was employed. The results demonstrated that the students gained a holistic understanding of the relevant scientific concepts because their performances on the scenario-based science assessment were significantly improved across serious gameplaying occasions, and the effect of learning was retained long term. Moreover, serious gaming provided students with the experience of immersion insofar as the students indicated a greater degree of immersion in the game over time. Furthermore, two core clusters presenting meaningful patterns, high gaming performance/high immersion and high science learning/low immersion, were revealed. Finally, various interpretations and implications of the obtained data are discussed.

Introduction

The development of computers and other technological innovations have resulted in new ways of thinking about how the goal of involving students in the learning process can be achieved (Jonassen & Land, 2012). Video games, which synthesize a variety of these technological advances and boast attractive features that have made them increasingly popular with fans all over the world, possess the potential to successfully transform education and provide a more comprehensive record of learning than conventional lectures (Annetta & Cheng, 2008; Arora, Kaur, Gupta & Bhardawaj, 2014). Over the past decade, many studies have shown that, if properly used, video games do have a positive effect on education and can enhance student learning by providing a learner-centered context (Connolly, Boyle, MacArthur, Hainey & Boyle, 2012). This kind of serious gaming, which harnesses the power of fun and enjoyment, presents an especially unique opportunity for science learning, since the subject of science is often considered abstruse and challenging (Cheng & Annetta, 2012; Cheng, Su, Huang & Chen, 2014). The experience of game immersion is generally considered the driving force behind the success of

Practitioner Notes

What is already known about this topic

- Serious gaming, harnessing the power of fun and enjoyment, has positive impact on student learning outcomes.
- Game immersion experience has a hierarchical structure consisting of three stages: engagement, engrossment and total immersion.
- Gaming performance is the variable that partially mediates the effect of the first stage of immersion, engagement, on game-based science learning.

What this paper adds

- Serious gaming facilitated student science learning, especially in terms of higher-order cognition, as student performances on scenario-based science assessment significantly improved through playing *Virtual Age*.
- Serious gaming provided individuals with a progressive process of game immersion, a gameplay experience that is dynamic, moving along the path of time.
- When it comes to the issue of how game immersion experience affects science learning through serious gaming, there were actually two different cohorts of learners presenting meaningful patterns, high gaming performance/high immersion and high science learning/low immersion.

Implications for practice and/or policy

- The obtained results imply that learning by gaming can be effective for student science learning, especially in terms of their higher-order cognition, and the impact can be long term. Researchers and educators can take into accounts while developing new curriculum and designing new learning tools.
- The study offers further evidence to researchers and educators with respect to whether, and to what extent, immersion affects science learning and gaming performance through serious play. This is the question that researchers who deal with serious gaming were eager to know, but has not been thoroughly answered before.
- Traditional methods used by most of previous studies that take all participants as a whole to run statistical analyses without considering individual differences might obscure the actual effect of game immersion experience on science learning.

serious gaming. Brown and Cairns (2004) provided evidence showing that game immersion experience actually consists of three different stages, namely, engagement, engrossment and total immersion. The experience of immersion moves along the path of time, and different barriers should be overcome in order to proceed into the next stage. Empirically, research by Cheng, She and Annetta (2015) has confirmed the hierarchical structure of game immersion.

Although we may now have a better understanding of game immersion experiences, it remains unclear how such immersion actually affects student science learning and gaming performance through serious play. If game immersion is really a progressive, sub-optimal experience as proposed (Cheng, She & Annetta, 2015; Brown & Cairns, 2004; Jennett *et al*, 2008), will students become increasingly immersed over time through serious gaming? Moreover, even though serious gaming can provide learners with the experience of game immersion, the evidence remains lacking regarding the issues of whether learners are required to be fully immersed in the gaming process to generate science learning outcomes, or what levels of immersion are necessary for game-based science learning. The intricate relationships between immersion and science learning through serious gaming are of increasing interest to researchers; however, they have so far yet to be fully revealed. Therefore, by using the techniques of cluster analysis, the present study sought to examine the effectiveness of learning by playing and the dynamic process of immersion experiences through serious gaming, in addition to further investigating whether, and to what extent, game immersion experiences affect student science learning and gaming performance in a well-developed serious educational game called *Virtual Age*.

Literature review: science learning through serious gaming

Traditional science classes, which generally involve the teacher lecturing, place most of the burden of communicating learning materials on the instructors. However, a growing number of studies on learning sciences have offered evidence that teaching and learning are never as simple as merely transmitting ideas in the same form from one person to another. Teachers have to be committed to student learning and realize that teaching must be more than telling (Crosby & Harden, 2000). Learners should be put in the center of the science learning process, and instructors should serve as facilitators who help the learners make sense of ideas and construct their own knowledge in science classrooms. In such learner-centered learning environments, students are encouraged to become active and self-regulated learners, and meaningful learning is more likely to take place (Hassard & Dias, 2008). Although the paradigm shift from traditional approaches focusing on how teachers teach to the learner-centered perspective emphasizing how students learn has become a trend in science education today (Anderson, 2002), some teachers and students remain resistant to change because of their anxieties about losing focus without content-driven lectures. Moreover, many practical constraints, such as time limitation for instruction or issues such as teachers often emphasize one-way lectures and easily ignore individual differences, affecting conventional science learning environments, usually doom learner-centered designs to failure and demotivate students in their efforts to learn science.

Recently, however, the emergence of using video games in science education has made learner-centered science learning more efficient and effective. Serious gaming can facilitate student science learning through *transformational play* by situating the learner within a rich interactive context in which the scientific content is embedded in a series of authentic problems (Barab *et al*, 2009). Learning simultaneously occurs through the continuous solving of problems and overcoming of challenges in the game. Student motivation and engagement can be potentially increased because pleasure and instructional materials are combined into a whole in the virtual world, which allows the learner to engage in a recursive game cycle so that deeper learning is fostered (Squire, Barnett, Grant & Higginbotham, 2004). Complex and abstract scientific concepts are visualized through tangible representations in the simulated game world, wherein one can generate hypotheses and test strategies iteratively without any need to worry about real-life consequences (Spires, Rowe, Mott & Lester, 2011). Many natural phenomena that cannot be produced in real-world situations, as well as many experiments and human behaviors that cannot be easily investigated, are allowed to be harmlessly simulated and evaluated in the game (Farrington, 2011; Kobes, Helsloot, de Vries & Post, 2010). Appropriate scaffoldings are offered by the provision of cues and partial solutions which keep the learners progressing and controlling their own learning through serious gaming (Federation of American Scientists, 2006). In brief, such gaming provides great opportunities for science education, as what cannot be done in traditional science learning settings might now be realized in the virtual contexts of games.

Two models have been proposed to explain how serious gaming affects learning. The input–process–output model posited by Garris, Ahlers and Driskell (2002) suggests that instructional content integrated with appropriate game features triggers a recurring cycle that includes user judgments, user behaviors and system feedback. The cycle engages individuals in continuous gameplay, and then, through a debriefing process, the achievement of learning outcomes is approached. A study by Kiili (2005), on the other hand, presents an experiential gaming model, one which also describes learning as a cyclic process of constructing cognitive structures through direct experience in the game world. The model resembles the human blood-vascular system, consisting of an ideation loop to generate solutions, an experience loop to test solutions and a challenge bank to motivate and engage the learners by constantly pumping appropriate tasks. By testing solutions and solving tasks over and over, one gets to master the game and subject matter, such that various positive effects are generated.

Obviously, either of the models assumes that a state of complete absorption, which is generally called flow (Csikszentmihalyi, 1990), is the key leading to successful learning outcomes through serious gaming. However, flow refers to an optimal, extreme experience, in which one is entirely involved in the process of an activity for its own sake without expectations for rewards or other positive outcomes. Some researchers have suggested that the term "immersion," which refers, in this context, to the extent of involvement in a game, might be a more appropriate way of describing an individual gaming experience. Put another way, this notion of immersion suggests that one can be involved in a game without being intensely involved in it (Cheng, She & Annetta, 2015; Brown & Cairns, 2004; Jennett *et al*, 2008). Similarly, some studies related to computer-mediated activities have also indicated that flow, which need not be a totally optimal state, can actually be divided into three stages, namely, flow antecedents, experiences and consequences (Chen, Wigand & Nilan, 1999; Hoffman & Novak, 1996).

According to Brown and Cairns (2004), game immersion also consists of three stages, with different barriers existing between the stages, such that a gamer cannot progress from one stage to the next until certain barriers are overcome. To get into the first stage, engagement, players must be satisfied with the game features and feel control over the game, as well as be willing to invest time and effort into the game. As players become further involved with the game, they enter the second stage, engrossment, in which their perceptions of their surroundings and physical needs decrease and their emotions are highly attached to the game. Finally, during the last stage, total immersion, individuals might feel like they are actually the avatars and thus empathize with their situations. When they have reached the stage of total immersion, players are entirely cut off from reality, and the game is all that matters to them. They are so absorbed in the game even to the extent as being in the game. However, total immersion is an intense experience that is relatively difficult to achieve. In our previous study (Cheng, She & Annetta, 2015), construct validity approaches including exploratory and confirmatory factor analyses were employed to empirically confirm the three stages of game immersion experience and to further verify its hierarchical structure. In addition, when investigated via correlation and path analyses, our previous data also demonstrated that while all three stages of game immersion were positively correlated with student gaming performance (game scores, how students performed in the game), only the first stage, engagement, was positively correlated with student science learning outcomes (test scores, how students performed on science knowledge assessment). Furthermore, our results indicated that gaming performance partially mediates the effects of game immersion experiences on science learning through serious gaming.

Researchers generally consider engagement is an issue in science learning. Because the subject of science is often considered abstruse and challenging, many students actually cannot engage in science learning activities and fail to achieve better understanding of science (Lee & Anderson, 1993). However, serious gaming has the potential to increase student engagement in a way that it integrates science learning content and activities with unique game features. It further provides students with a subject impression of immersion that one feels like he/she is the avatar in the virtual world with a comprehensive, realistic experience, and research argues that immersion enhances science learning by at least authorizing multiple perspectives, situated learning and transfer (Dede, 2009). Despite the fact that we now may have begun to get a preliminary picture about what is actually meant by game immersion and the fact that a previous study by Cheng, She and Annetta (2015) has offered rudimentary support for the idea that gaming performance might be a mediator between engagement and science learning through serious gaming, there are still some issues which have not been clearly understood yet. First, is game immersion really a progressive, sub-optimal experience that moves along the path of time? Do students really experience different degrees of game immersion through serious gaming? Although the hierarchical structure of game immersion experiences has already been verified in our previous study, to date, there is still no evidence to empirically support the supposition that there is a dynamic aspect to game immersion. Second, why are there positive correlations between all the three stages of immersion experiences and student gaming performances, while a positive correlation exists only between the first stage, engagement and student science learning? Because previous studies have usually employed traditional methods that look at data from all the participants collectively to run statistical analyses without considering individual differences, is it possible that the actual effects of game immersion experiences on science learning have been obscured? With these concerns in mind, and based on our previous research, the current study was conducted to further delve into the issues of whether, and to what extent, game immersion experience is necessary for science learning outcomes and/or gaming performance through serious gaming. To those ends, three specific questions were addressed:

1. Does playing *Virtual Age* facilitate student science learning?
2. Do students experience different degrees of game immersion when playing *Virtual Age* over time?
3. How do the game immersion experiences affect student science learning and gaming performance through serious gaming?

Materials and methods

Virtual Age

Virtual Age is a well-developed serious educational game that was developed according to three principles—realization, concretization and gamification—to ensure its effectiveness (Cheng, She & Annetta, 2015; Cheng, Lin & She, 2015). By appropriately integrating scientific content with game features, it is designed to provide students with a serious gaming process and a certain degree of game immersion experience. Specifically, the scientific concepts of biological evolution are situated in the game context of *Virtual Age*.

There are two game levels in *Virtual Age*, the Mesozoic Era and the Cenozoic Era, with representative creatures from each era used as in-game characters. The main game mechanism is that students have to manipulate different in-game characters to compete with non-player characters (NPCs) for survival. The game scenes for each era were created according to its geological morphology, with the Cenozoic Era being made up of more varied landforms than the Mesozoic Era. Every in-game character is designed to have different attributes based on its own ecological niche and actual habitus, so that students can learn the various environments of the Mesozoic and Cenozoic Eras and the morphologies and characteristics of representative creatures from each era. Moreover, by confining the movements of different characters within different habitats, students can realize the relationships between creatures and the environment.

In the game, players have to properly occupy resource areas (which are filled with representative plants of each era) to produce enough biomass, so that they can reproduce more offspring or summon new species. Because the game was designed so that mutations resulting in different

Figure 1: Key features of Virtual Age. *(A) Attractive graphics/images; (B) autonomy; (C) clear rules/goals; (D) competitiveness*

traits randomly occur whenever players reproduce their in-game characters and so that natural disasters determining which species and with what traits can survive also happen at random during the gaming process, the mechanism of natural selection is effectively embedded within the game. A player's gaming performance (game score), showing how well students can perform in the game, is represented in a simple fashion according to what characters are used and whether they are alive or dead, the degree of symbiosis achieved and how many resource areas are occupied or not. Continuous attacks on the same NPC performed by the player can additionally result in bonus points. Previous research by Cheng, Lin and She (2015) has provided solid evidence supporting the conclusion that *Virtual Age* is well designed and effective for learning about biological evolution.

Several key features of *Virtual Age* were designed in order to facilitate game immersion experiences (Figure 1):

1 Attractive graphics/images: The game scenes and in-game characters with which students are familiar are employed and created by using appropriate representations, such that they can easily grab the attention of students.
2 Autonomy: Students have full authority to select their in-game characters in *Virtual Age* through reproduction or by summoning new species, and clear user interfaces with understandable icons allow them to exert control over the game at will.
3 Clear rules/goals: In addition to competing with NPCs for survival, two additional victory requirements are set for each level. Game instructions explaining the rules and requirements

are provided in *Virtual Age*, allowing students to visit at any time and allowing the players to quickly get an idea about how to play the game.

4 Competitiveness: A scoring system and ranking board assessing student gaming performances are also included in *Virtual Age*. Game scores were simply calculated according to student in-game behaviors, such as the number and type of characters used, whether the characters are alive or dead, how many resource areas are occupied or not occupied by NPCs, whether continuous attacks on the same NPC are performed, etc.

Participants

Seventy-five seventh graders participated. Of these, 12 were excluded from the analyses due to their failure to complete the research procedure (eg, students did not finish four sessions of play or they did not accomplish all tests), resulting in a total of 63 students ultimately being considered in the study.

Instruments

Scenario-based science assessment

Based on the scientific concepts situated in *Virtual Age*, a science assessment was developed to further investigate the knowledge constructions and cognitive structures of students. The assessment includes 10 open-ended, scenario-based questions, with five questions intended to assess student understanding of the Mesozoic Era and the other five questions emphasizing the content relating to the Cenozoic Era. One middle school biology teacher and two science education experts were invited to review the assessment, so that content and face validity could be assured. For each question, a screen capture of *Virtual Age* is used to create a context/scenario instead of a brief description of the scenario. The scenario is then followed by several related questions to measure student higher-order cognitive knowledge and the use of information rather than rote learning. An example question from the scenario-based science assessment is provided in Figure 2.

A rubric scoring scheme was created in order to examine student performance on the assessment. The rubric scoring scheme consists of both quantity and quality measures for each of the 10 questions. In terms of quality, it addressed the correctness and appropriateness of the concepts used by students in responding to each question. Then, by using the rubric scheme, student answers to each question can be classified as accurately correct (AC), partially correct (PC) or incorrect (IC), with 2, 1 or 0 points scored accordingly, and the resulting numerical values can then be used to represent the given performance in terms of quantity. In addition, the validity of the rubric scoring scheme was ensured by expert review.

Finally, a given student's performance on the scenario-based science assessment was calculated by adding the scores for the 10 questions together. The responses of 20% of the participants were scored by three researchers independently to determine inter-rater reliability. The correlation coefficients (r) between the three raters were .980, .993 and .983, respectively, and the average was .985.

Game immersion questionnaire (GIQ)

The GIQ was adopted from previous research by Cheng, She and Annetta (2015). The questionnaire was developed on the basis of the immersion theory proposed by Brown and Cairns (2004), and included a total of 24 items. These items can be further categorized into three subscales, namely, engagement (nine items), engrossment (seven items) and total immersion (eight items). A five-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) was employed for each item. The internal structure of the GIQ was rigorously tested by construct validity approaches including exploratory factor analysis and confirmatory factor analysis in the study by Cheng, She and Annetta (2015), so the validity and reliability were strong. In the present study,

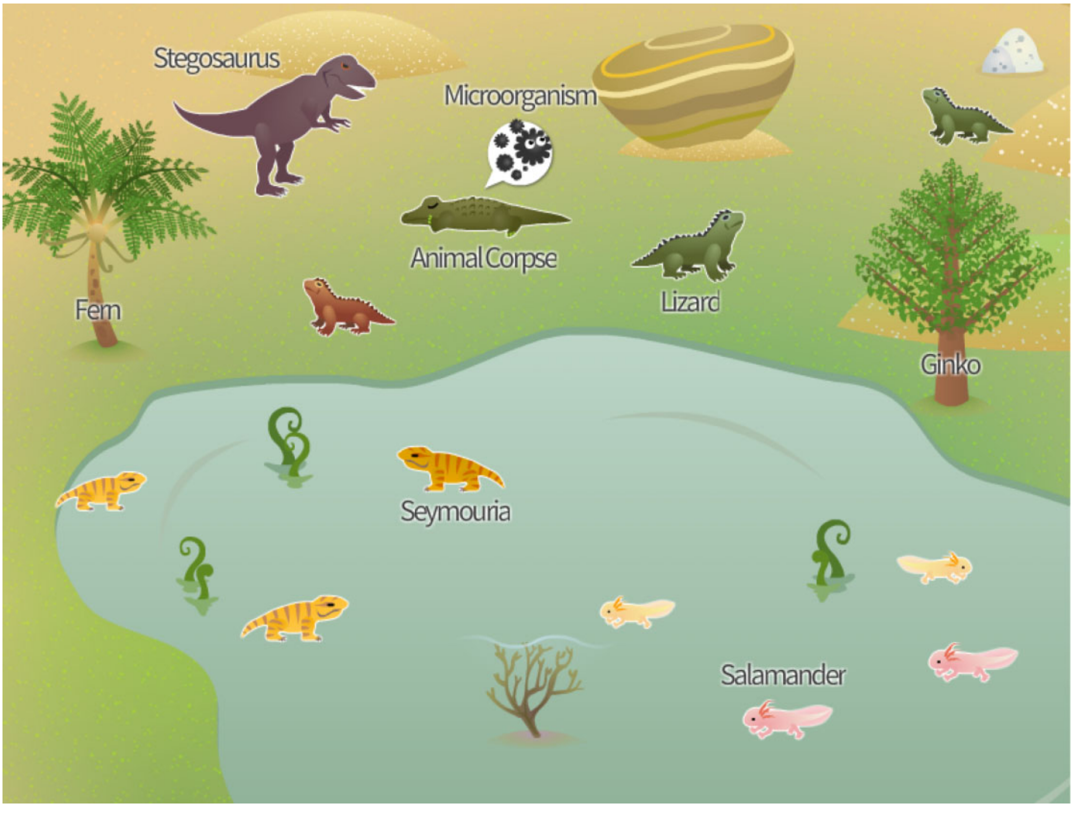

Figure 2: An example question of the scenario-based science assessment. The picture is of a balanced swamp ecosystem. This ecosystem contains lizard, salamander, seymouria, stegosaurus, fern, ginko biloba and microorganisms (bacteria). Please answer the following questions:

1. *Using this ecosystem as an example, please divide all living organisms in the picture into "producers," "consumers" and "decomposers" and explain what standards were used to determine which of the three groups the living organism belongs to.*
2. *From the evolutionary point of view, if a "drought" occurs and causes drastic changes to this ecosystem to the extent that all the green plants dies off, exposing the yellow surface of the earth, please predict what sort of impact this natural disaster will have on Tuatara, and explain the reasoning of this prediction.*

the Cronbach's α values for each subscale were .96, .95 and .96, respectively, and that of the whole questionnaire was .98. Sample questions of GIQ are provided in Appendix, and the whole questionnaire can be accessed from our previous study (Cheng, She & Annetta, 2015).

Research design

A quasi-experimental one-group pretest–posttest research design was used. Before the research was conducted, all of the participants were asked to take the scenario-based science assessment and the GIQ as a pretest of higher-order cognitive knowledge and to determine a pre-play baseline of immersion. Then, the students were required to learn by playing *Virtual Age* on their own for four sessions (45 minutes each). The GIQ was administered right after every session in order to investigate the game immersion experiences of students for each play session. In addition, the scenario-based science assessment was administrated after the first session of *Virtual Age* play as the first posttest (posttest 1), and the second posttest (posttest 2) of the assessment was conducted after all the four sessions were concluded. One month later, the science assessment was administered with the students again to examine the retention effects of serious gaming.

Data analysis

Whether the differences in student higher-order cognitive knowledge or game immersion experiences reach significance was tested by the method of one-way repeated-measures analysis of variance (repeated-measures ANOVA). Further, as the currently available studies do not provide any models delineating the potential relationships between science learning, immersion experience and gaming performance through serious gaming, in this study cluster analysis, specifically, K-means algorithm, a particular modeling technique of finding homogeneous groups based on similarity and/or difference of the objects (Jain, Murty & Flynn, 1999), was adopted as the means for determining the underlying information present in the collected data. Because the dataset was not large, the suitable number of clusters was decided by parameter exploration, with the criteria of allowing the variation between features in the same cluster to be the smallest and the variation between features in different clusters be the largest (De Jong, 1975; Hsieh, Jhan & Chen, 2014; Kaufmen & Rousseeuw, 1990; Shih, Huang, Hsu & Chen, 2012). Two core clusters presenting meaningful patterns were obtained. Cluster analysis is an exploratory method that discovers structures and finds groups in data; hence, the interpretations of cluster analysis results were focused on describing the means for each cluster on each dimension (StatSoft, n.d). Then, Pearson's correlation coefficients were calculated to assess the bivariate interrelations between student science learning, immersion experience and gaming performance in each cluster, and finally, the main predictors for science learning or gaming performance were revealed by stepwise regression analyses, with variables entered at the .05 significance level and removed at the .01 significance level.

Results

Science learning outcomes

Table 1 represents the statistical differences in student performances on the scenario-based science assessment by using an one-way repeated-measures ANOVA with four test occasions (pretest, posttest 1, posttest 2 and delayed test) as within-subject factors. The results indicated that there were significant differences in student performances between the four test occasions ($F = 9.19$, $p < .001$, $\eta^2 = .13$). A series of the follow-up post-hoc analyses revealed that student higher-order cognitive knowledge was significantly improved after playing *Virtual Age*. Compared with the pretest, student performances on both posttest 1 ($p < .001$) and posttest 2 ($p < .001$) were significantly better. Moreover, the effect of learning seemed to be retained long term as the student performances on the delayed scenario-based science assessment were also significantly

Table 1: Results of repeated-measures ANOVA showing the difference in test occasions in terms of student performances on scenario-based science assessment

	Occasions	M	SD	df	*MS*	F	*Post-hoc analyses*
Science learning ($n = 63$)	Pretest	4.05	4.71	2.48	279.17	9.19***	Posttest 1 > pretest (***)
	Posttest 1	6.87	6.36				Posttest 2 > pretest (***)
	Posttest 2	8.05	7.66				Delayed test > pretest (***)
	Delayed test	8.16	8.14				

***$p < .001$.

Pretest: before *Virtual Age* play; Posttest 1: after the first session of *Virtual Age* play; Posttest 2: after all the four sessions of *Virtual Age* play; Delayed test: 1 month later.

better than their performances on the pretest ($p < .001$). The results indicated thus that science learning through serious gaming can be effective and retained.

Game immersion experience

A series of one-way repeated-measures ANOVA using five gameplay occasions (pre-play, first play, second play, third play and fourth play) as within-subject factors was performed for each dimension of game immersion experience (Table 2). The results indicated that no significant differences in either engagement or engrossment between the five gameplay occasions were found. Mean values of both engagement and engrossment were larger than 3, indicating that students readily had positive degrees of both and entered into the two stages from the very beginning of their play. However, a significant within-subject effect on the dimension of total immersion was revealed ($F = 3.95$, $p < .001$, $\eta^2 = .06$). Compared with pre-play, students experienced a significantly higher degree of total immersion during the second ($p < .05$), third ($p < .05$) and fourth ($p < .01$) play sessions. Moreover, the extent of total immersion that students experienced during the fourth play session was significantly higher than that which they experienced during the first play session ($p < .05$). These results imply that students got more immersed in *Virtual Age* as the number of times of gameplay increased. In other words, students needed more time to get totally immersed in the game than they required to experience the other two stages, engagement and engrossment, of game immersion experience.

The interplay of science learning, game immersion experience and gaming performance

As a result of cluster analysis by using the K-means algorithm, two core clusters presenting meaningful patterns were obtained. Different trends were revealed in the two clusters: high gaming performance/high immersion (cluster 1, $n = 19$) and high science learning/low immersion (cluster 2, $n = 44$) (Table 3). Generally, students in cluster 1 had comparatively lower performances on the scenario-based science assessment across the four test occasions, but their gaming performances across all four play sessions were higher than those of the students in cluster 2. Regarding game immersion experiences, students in cluster 1 experienced a much higher positive degree of engagement, engrossment and total immersion across the four play sessions, and they got more immersed in the game as the number of gameplay sessions increased. In terms of cluster 2, learners showed relatively better performances on all the four tests of the scenario-based science assessment. Their gaming performances were not as good as those of the students in cluster 1, and they did not report experiences of engrossment and total immersion across the four play sessions (ie, the mean values were smaller than 3). They only experienced a slightly positive extent of engagement during the second, third and fourth play sessions. One-way repeated-measures ANOVAs with four test occasions (pretest, posttest 1, posttest 2 and delayed test) as within-subject factors were then applied for clusters 1 and 2 respectively. The results indicated that there were significant differences in student performances on the scenario-based science assessment in cluster 1 ($F = 3.08$, $p < .05$, $\eta^2 = .15$) and cluster 2 ($F = 6.79$, $p < .001$, $\eta^2 = .14$). For cluster 1, student performances on the delayed test were better than those on the pretest ($p < .05$), while the learners in cluster 2 had better performances on posttest 1 ($p < .001$), posttest 2 ($p < .001$) and the delayed test ($p < .01$) than on the pretest.

We further examined the bivariate interrelations between science learning, immersion experience and gaming performance by testing Pearson's correlation coefficients in each cluster. In cluster 1, student gaming performances were positively correlated to the students' experiences of engrossment ($r = .57$, $p < .01$) and total immersion ($r = .54$, $p < .01$) during the fourth play session, whereas in cluster 2, there was a positive correlation between student science learning and their experiences of engagement during the first play session ($r = .41$, $p < .01$). Stepwise regression methods were then applied to build models for predicting student gaming performance or science learning in each cluster. In cluster 1, the experience of engrossment ($\beta = .57$) was the

Table 2: Results of repeated-measures ANOVA showing the difference in gameplay occasions in terms of student game immersion experience

	Game immersion experience													
	Pre-play		*First play*		*Second play*		*Third play*		*Fourth play*					
	M	SD	M	SD	M	SD	M	SD	M	SD	df	*MS*	*F*	*Post-hoc analyses*
Engagement	3.44	0.70	3.25	1.11	3.45	0.91	3.54	0.86	3.57	0.98				
Engrossment	3.15	0.70	3.03	1.03	3.19	1.02	3.12	1.04	3.23	1.07				
Total immersion	2.73	0.88	2.92	1.06	3.12	1.14	3.09	1.01	3.18	1.10				
Engagement (pre-, first, second, third, and fourth play)											2.95	1.31	2.35	
Engrossment (pre-, first, second, third, and fourth play)											3.12	0.49	0.72	
Total immersion (pre-, first, second, third, and fourth play)											2.92	2.90	3.95**	Second > pre-play(*) Third > pre-play (*) Fourth > pre-play (**) Fourth > first play (*)

*$p < .05$, **$p < .01$.
Pre-play: before *Virtual Age* play; first play: after the first session of *Virtual Age* play; second play: after the second session of *Virtual Age* play; third play: after the third session of *Virtual Age* play; fourth play: after the fourth session of *Virtual Age* play.

Table 3: Student game immersion experience, conceptual comprehension and gaming performance of each cluster

	Cluster 1 (n = 19) *High gaming performance/ high immersion*		*Cluster 2* (n = 44) *High science learning/ low immersion*	
	Mean	SD	*Mean*	SD
Pretest	2.47	3.19	**4.73**	**5.11**
Posttest 1	3.53	3.19	**8.32**	**6.85**
Posttest 2	5.21	5.45	**9.27**	**8.19**
Delayed test	5.37	4.98	**9.36**	**8.96**
Pre. engagement	**3.67**	**0.68**	**3.34**	**0.69**
Pre. engrossment	**3.34**	**0.80**	**3.07**	**0.64**
Pre. total immersion	**3.00**	**1.05**	2.61	0.77
First engagement	**4.31**	**0.77**	2.80	0.91
First engrossment	**4.02**	**0.90**	2.60	0.75
First total immersion	**3.92**	**0.84**	2.48	0.83
Second engagement	**4.35**	**0.59**	**3.06**	**0.75**
Second engrossment	**4.23**	**0.66**	2.74	0.80
Second total immersion	**4.26**	**0.66**	2.63	0.94
Third engagement	**4.36**	**0.56**	**3.19**	**0.72**
Third engrossment	**4.23**	**0.71**	2.64	0.74
Third total immersion	**4.21**	**0.59**	2.60	0.73
Fourth engagement	**4.55**	**0.62**	**3.14**	**0.78**
Fourth engrossment	**4.34**	**0.66**	2.75	0.83
Fourth total immersion	**4.32**	**0.65**	2.68	0.85
First game score	**1905.79**	**932.90**	1429.98	651.63
Second game score	**2222.11**	**1214.38**	1900.00	1088.18
Third game score	**2737.78**	**1278.37**	2368.48	1195.00
Fourth game score	**3453.33**	**2568.22**	3301.79	2466.67

Game immersion experiences larger than 3 are presented in bold.
The highest gaming performances and science learning outcomes are presented in bold.

Table 4: Pearson's correlations between game immersion experience, gaming performance and conceptual comprehension of each cluster

			Game immersion experience		
			Engagement	*Engrossment*	*Total immersion*
Cluster 1 (high gaming performance/ high immersion)	First play	First game score	.17	.13	.39
		Science learning (posttest 1)	.22	.23	.22
	Fourth play	Fourth game score	.42	.57*	.54*
		Science learning (posttest 2)	−.36	−.25	−.19
Cluster 2 (High science learning/low immersion)	First play	First game score	.18	.13	−.02
		Science learning (posttest 1)	.41**	.13	.10
	Fourth play	Fourth game score	−.05	−.17	−.17
		Science learning (posttest 2)	.21	−.13	−.14

*$p < .05$, **$p < .01$.
Pearson's correlations were run for only first and fourth play because both the assessment of scenario-based questions and the GIQ were taken in the two plays.

Table 5: Summary of stepwise multiple regression analyses for variables predicting gaming performance and conceptual comprehension in each cluster

	Variable	β	R^2	F *value*	*Adjusted* R^2 *model (%)*
Cluster 1					
Fourth game score	Fourth engrossment	0.57	0.28	7.57*	27.9%
Cluster 2					
Science learning (posttest 1)	First engagement	0.41	0.17	8.42**	14.7%

*$p < .05$, **$p < .01$.

major predictor that could be used for predicting student gaming performance during the fourth play session, accounting for 27.9% of the variance. On the other hand, engagement ($\beta = .41$) was the significant variable for predicting student science learning during the first play session, contributing 14.7% of the variance.

Discussion

Serious gaming offers an elaborate, technologically enhanced, learner-centered context which emphasizes the dynamic nature of the processes of understanding (Hannafin & Land, 1997). In addition, it possesses many unique features that make it more likely to engage students in the learning processes continuously than do traditional approaches. Over the past decade, the potential of science learning through serious gaming has attracted much attention from researchers and educators alike. Studies related to serious gaming are actually numerous; however, most of them have mainly focused on examining the consequences and end-products of learning through serious gaming by simply using final scores on a game as indicators (Connolly *et al*, 2012). There is a shortage of research, however, tackling the issue of gameplay experiences, dubbed immersion and science learning. Therefore, this study was conducted to investigate the effectiveness of learning by gaming and the dynamic feature of immersion, and to further identify whether, and to what extent, immersion affects science learning through serious gaming by using the techniques of cluster analysis. Three significant breakthroughs were revealed in the present study. First, serious gaming facilitated student science learning, especially in terms of higher-order cognition, for the long term. Second, serious gaming did provide individuals with a progressive experience of game immersion. And finally, the cluster analysis results demonstrated that two core clusters presenting meaningful patterns, high gaming performance/high immersion and high science learning/low immersion, emerged. These breakthroughs are discussed in more detail below.

In accordance with many previous studies (Cheng & Annetta, 2012; Cheng *et al*, 2014; Echeverría, Barrios, Nussbaum, Améstica & Leclerc, 2012; Klisch, Miller, Beier & Wang, 2012), our research has provided evidence supporting the positive effect of serious gaming on student scientific understanding. Despite some reviews of serious gaming-related literature indicating that the academic value of video games in science learning remains inconclusive (Girard, Ecalle & Magnan, 2013; Young *et al*, 2012), broad claims concerning the issue generally suggest that the reason that some games do not appear to be academically valuable might be the inappropriate integration of learning content or the failure to situate sound instructional design in the game (Gunter, Kenny & Vick, 2008; O'Neil, Wainess & Baker, 2005). The obtained results in the present study indicate that *Virtual Age*, a well-developed serious game which emphasizes learning processes within the game mechanism, is academically effective. In addition, two other significant points can be addressed. First, in contrast with most of the currently available data, our study adopted open-ended, scenario-based questions for examining student higher-order cognitive knowledge/thinking instead of multiple-choice assessments. Open-ended, scenario-based questions were designed to accentuate student cognitive structures and deeper understanding rather than low-level memorization, as participants were required to further process the learned information or knowledge by providing full, meaningful responses including supporting facts and evidence (Schuwirth & Van Der Vleuten, 2004). The improvement in student performances on the scenario-based questions implies that they did gain a holistic understanding of the situated scientific concept through *Virtual Age* play. In other words, *Virtual Age* can be effective in facilitating student higher-order cognition. Second, the results of our study also indicated that the enhancement of higher-order cognitive knowledge by seriously playing *Virtual Age* can be long lasting. Whether the knowledge acquired through serious gaming persists in the long term is of much importance; however, very few state-of-the-art studies have addressed the question previously (Brom, Preuss & Klement, 2011; Mortara, Catalano, Fiucci & Derntl, 2014). Accordingly, the absence of long-term data is often another concern impairing the effectiveness of learning by gaming in some reports (Girard *et al*, 2013; Leach & Sugarman, 2005). Encouragingly, the present study offers empirical evidence showing that by connecting learning content with meaningful actions in the virtual contexts, serious gaming has the power to facilitate the retention of knowledge, in particular, higher-order cognition, for the long term, a finding which should not be overlooked.

In addition, the concept of game immersion, an important experience of interaction describing the degree of involvement with a game, was proposed recently (Cheng, She & Annetta, 2015; Brown & Cairns, 2004; Jennett *et al*, 2008). Compared with flow, which refers to an extreme, optimal state, immersion is concerned with the suboptimal, progressive experience of engaging in a game. It is a relatively new concept which still needs to be supported by more empirical evidence. Although previous research by Cheng, She and Annetta (2015) has provided evidence that supports the hierarchical structure of game immersion experiences, so far, its dynamic characteristic has not been fully explored and verified. Inspiringly, our research takes one step ahead to provide supportive data further certifying that serious gaming did provide individuals with immersion, a gameplay experience that is actually dynamic, moving along the path of time. Players became more involved in the game as time went by, and the stage of total immersion was rather difficult to reach in comparison with the stages of engagement and engrossment, results supporting the notion that the students needed more time to get into the stage of total immersion through serious gaming. This empirical support should enable researchers to lay a robust foundation for the idea of game immersion, one which future work should then be able to take into account.

Otherwise, there remains a lack of evidence available for addressing how game immersion affects science learning through serious gaming. Even though our previous study (Cheng, She & Annetta, 2015) made preliminary efforts to investigate the relations between immersion and game-based science learning, the traditional methods which used data from all the participants collectively to run statistical analyses without considering individual differences might have obscured the actual effects of game immersion experiences on science learning. Accordingly, this issue was delved into by the techniques of cluster analysis in the present study. Meaningful findings were approached.

The data of cluster analysis indicated that engagement is essential to successful learning through serious gaming (cluster 2); yet deeper immersion is required to master the game (cluster 1). From the results, we can see that students in cluster 2 generally had relatively better science learning performances on the pretest and all the other three test occasions. Namely, they possessed more prior knowledge, and they easily learned more effectively than their counterparts in cluster 1 through interacting with *Virtual Age*. They learned the situated concepts very quickly as they promptly got significant improvements on posttest 1, and the experience of engagement during the first play session strongly predicted how much better their student science learning outcomes were. Researchers generally agree that student existing knowledge prior to instruction is one of the important factors affecting student science learning (Hewson & Hewson, 2003), and the findings from research on cognitive processing have revealed that new information can be easily organized and integrated into existing cognitive schemas when the knowledge structures of student are large and well connected (Greitzer, Kuchar & Huston, 2007). Therefore, the students with more prior knowledge in cluster 2 could easily catch the learning objectives in the game and categorize new information in terms of what they already knew. They did not need to be very immersed in the game in order to generate learning outcomes, but the degree of engagement at the beginning did determine their success in learning.

On the other hand, the learners with lower prior knowledge in cluster 1 placed more attention on the gameplay than on learning. They could readily become involved in the game, and their immersion experiences became deeper as time went by. Whether they could sustain immersion to the end was crucial to their gaming performances. Since their existing cognitive structures were not as well connected as those of the students in cluster 2, meaning that they could not catch the learning objectives in the game promptly, the only thing they could do was to keep trying and playing. It is worth noting that the performances of those learners in cluster 1 on the scenario-based science assessment progressively improved as the number of *Virtual Age* playing sessions increased. Finally, they got a significant improvement on the delayed test 1 month later, although they did not have enough prior knowledge before exposure to *Virtual Age* and did not learn the situated concepts as readily as their counterparts in cluster 2. It was thus implied that for them, the serious impacts of game immersion experiences might be revealed not in the short term, but in the long term. After being fully immersed in the game, they needed more time to digest what was learned through interacting with the game and organizing the information into their structured schemas. They are likely to be those students who generally lack learning motivations in traditional educational settings, and their motivations can be increased because of serious gaming. If post-exposure tests are the only method used to examine student science learning through serious gaming, as was the case in most of the currently available studies, the effects of immersion might be underestimated. The results seem to be really in alignment with the research by Cheng, Lin and She (2015), which also showed that students with strong participation and intensive interactions with the game mechanism can perform better on the delayed test.

It turns out that serious gaming really can be effective for student science learning in both cluster 1 and 2. For students with more prior knowledge (cluster 2), they can learn scientific concepts through serious gaming very quickly and efficiently. Engagement in which players are attracted by, able to exert control over and willing to invest time and effort into the game might be enough for debriefing science learning outcomes through serious gaming for. But for those with lower prior knowledge, their learning through serious gaming is gradually progressive; giving more time and allowing them to be fully immersed in and interact with the game as well as organize new information into structured schemas can be helpful. However, how to help those learners readily concentrate their attention on not only the gameplay aspect but also the learning materials embedded in the game (eg, through the provision of appropriate scaffoldings) is still an important topic for future work (Cheng *et al*, 2014). In brief, the obtained results are valuable since they offer further evidence with respect to whether, and to what extent, immersion affects science learning and gaming performance through serious play. This is the question that researchers who deal with serious gaming are eager to answer, but that has not been thoroughly answered before.

Conclusions

In summary, the results of this study provide empirical support confirming that the use of interactive computer games can be effective for student science learning, especially with regard to higher-order cognitive knowledge. Even if the game in question is integrated with scientific concepts that are usually abstruse, with an appropriate design, it can still provide individuals with immersion experiences, allowing them to become more involved with the game over time. Taking a step further from previous studies, the present research additionally offers evidence showing that when it comes to the issue of how game immersion experiences affect science learning through serious gaming, there are actually two different cohorts of learners. For learners with more prior knowledge who can readily catch the learning objectives and learn the situated concepts, the first stage of game immersion, engagement, is crucial for the success of learning through serious gaming. But for those with lower prior knowledge who need more time to digest what is learned and organize information into schemas, full immersion is required in order to master the game, and the impacts of immersion on game-based science learning might be revealed in the long term. While the empirical investigation of immersion in serious gaming is in its infancy, these results should encourage researchers that efforts to use games for science learning are on the right track.

Statements on open data, ethics and conflict of interest

a. The relevant dataset is open and available at: https://goo.gl/4jwSGS
b. The study was carried out following the BERA Ethical Guidelines. All participants were well informed about the research objectives and contents and were assured about the privacy. None of the personal identifiers was reported in the study.
c. There is no any potential conflict of interest in the work.

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Appendix

Sample questions of game immersion questionnaire

Engagement

I like the appearance and style of the game.
I would like to spend time playing the game.
It is easy for me to control the game.

Engrossment

I often feel nervous or excited because of the game.
While playing the game, I often cannot hear people who are calling me.

Total immersion

My consciousness completely transfers from the real world to the game world while playing the game.
I used to be so integrated into the avatar in the game that I could feel his/her feelings.