Australasian Journal of Educational Technology, 2018, 34(4).

Effects of digital game-based learning on achievement, flow and overall cognitive load

Chi-Cheng Chang
Department of Technology Application & Human Resource Development, National Taiwan Normal University, Taipei, Taiwan R.O.C.

Clyde A. Warden
Marketing Department, National Chung Hsing University, Taichung, Taiwan R.O.C.

Chaoyun Liang
Department of Bio-Industry Communication and Development, National Taiwan University, Taipei, Taiwan R.O.C.

Guan-You Lin
Department of Technology Application & Human Resource Development, National Taiwan Normal University, Taipei, Taiwan R.O.C.

The purpose of this study was to examine differences in learning achievement, flow, and overall cognitive load between digital game-based learning (DGBL) and traditional computer-based learning (CBL). This study was conducted with 103 Taiwan college students: 50 college students in the experimental group used DGBL; 53 students in the control group used CBL. Results show the DGBL participants displayed significantly better learning achievement, flow, and lower cognitive load compared to the CBL participants. Learning achievement and flow exhibit a positive correlation, while negatively correlating with overall cognitive load. These results align with the existing research concepts of flow theory, cognitive theory of multimedia learning, and cognitive load theory.

Introduction

Digital game-based learning

Previous computer-based learning (CBL) research describes how computers enhance learner motivation, improve efficiency, and increase achievements (Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). Compared to mid-2010s' more powerful hardware and software and Web-based experienced, earlier CBL simulations and games can appear weak. Digital game-based learning (DGBL) is now at the forefront of educational interest with a larger emphasis on learner-control (Huang, Huang, & Wu, 2015). Features of DGBL include increased learner interest, learner-control, real-world augmentation, and interaction – all difficult to execute in a CBL context.

With improvements in digital media and game technology DGBL has drawn increased attention from educators. The high fidelity (realistic appearance) interaction of DGBL systems allow learners to freely control objects within games with the sense of virtually being there (Schrader & Bastiaens, 2012), which attracts learners' interests and concentration while helping them become immersed in the learning (Girard, Ecalle, & Magnan, 2012). DGBL is an example of learning through playing. Numerous studies have shown that DGBL enhances learning motivation and achievement (Giannakos, 2013; Liu, Cheng, & Huang, 2011; Papastergiou, 2009; Schrader & Bastiaens, 2012). However, most of these studies focus on comparing DGBL and traditional classroom learning. Few studies compare differences between DGBL and non-game-based CBL.

DGBL and flow

Flow can be characterised as a psychological state during which gamers experience enjoyment and loss of distractions (Kiili, de Freitas, Arnab, & Lainema, 2012; Pearce, Ainley, & Howard, 2005). Factors contributing to the phenomenon flow include highly focused on an activity, leading to immersion; coherence of activity, leading to deeply engaged participation without interruption; balances between skill ability and skill demands, triggering feelings of pleasure; a deep sense of control over the surrounding environment; a distorted temporal experience causing a sensation of loss of self; and an innate feeling of reward, leading to satisfaction (Brom et al., 2014; Keller, Bless, Blomann, & Kleinbohl, 2011). In short, those experiencing flow experience a sense of concentration, immersion, engagement, enjoyment, free control, loss of oneself, and satisfaction.

Schrader and Bastiaens (2012) show virtual presence among middle school students is significantly stronger for DGBL users than non-game-based CBL users. Virtual presence means one feels presence or the illusion of presence created by virtual locations or spaces, such as websites, online games, and 3D virtual reality environments. Virtual presence includes an awareness of and synchronous communication within a virtual space. Virtual presence facilitates learner interests and attention, which enhances concentration, immersion, and flow. Kiili (2005) believes that virtual presence is an important construct of flow. Some multimedia learning environments are embedded with game scenes to enhance virtual presence (Omale, Hung, Luketkehans, & Jessamine, 2009; Sancho, Torrente, & Fernandez-Manjon, 2009). Lepper, Iyengar, and Corpus (2005) report traditional classroom learning usually rewards students with extrinsic incentives, while games reward learners with intrinsic incentives. Extrinsic incentives refer to factors such as peer support, teacher encouragement, and the environment. Intrinsic incentives refer to factors such as personality, cognitive styles, and learning preferences. Therefore, a DGBL environment can facilitate learner intrinsic motivation, and attract learners to become engaged with their learning experience (engagement) (Dickey, 2005; Wu, Li, & Rao, 2008). Engagement helps learners become immersed in learning, which is also beneficial for flow. In a DGBL environment, reality and interaction are the key factors enhancing learner flow (Faiola, Newlon, Pfaff, & Smyslova, 2013; Kiili et al., 2012).

Numerous studies reveal DGBL can facilitate learner flow and enhance learning achievement when compared with traditional classroom learning (Admiraal, Huizenga, Akkerman, & Dam, 2011; Choi & Baek, 2011; Kiili et al., 2012). Some studies also show that flow is helpful for learning (Pekrun & Stephens, 2012; Skadberg & Kimmel, 2004). High flow implies that game participants feel pleasant, delighted, focused, and in control of learning, leading to better learning achievement. However, the majority of these studies do not compare differences in flow between DGBL and non-game-based CBL.

DGBL and cognitive load

Cognitive load is defined as a multidimensional construct, representing the load that performing a learning task imposes on the learner's cognitive system (Paas, van Merriënboer, & Adam, 1994). The cognitive load, imposed on working memory by various learning tasks, is generated from either the intrinsic nature of the learning material, resulting in an intrinsic cognitive load, or from the form of the material, resulting in an extraneous cognitive load (Sweller, Ayres, and Kalyuga, 2011). Unlike intrinsic cognitive load, which is associated with the characteristics of the task, extraneous cognitive load can be altered according to an instructional design or the demands required by a learning procedure (Skulmowski & Rey, 2017). As a consequence, well-designed materials often decrease extraneous cognitive load and enhance learning (Ayres & Paas, 2007; Mayer, 2010a; Sweller, 2010a). Cognitive load theory argues that overloading working memory interferes with learning. Therefore, instructional procedures are effective when cognitive overload is eliminated (Ayres & Paas, 2007; Paas, Renkl, & Sweller, 2003; Sweller et al., 2011). Overall cognitive load, intrinsic and extraneous, should not exceed working memory capacity. By reducing cognitive load, the ability to process necessary information may be eased.

Cognitive theory of multimedia learning elaborates how people learn from words and pictures through processing in separate channels (e.g., verbal and non-verbal or visual) (Mayer, 2010a, p. 47). Each channel can process only a small amount of information at a time, while meaningful learning involves engagement in the proper cognitive processing. Based on cognitive load theory (Paas et al., 1994) and cognitive theory of multimedia learning (Mayer, 2010a), many instructional design principles have been developed and used by different evidence-based researchers. The multimedia principle states that people learn more deeply from words and pictures than from words alone (Fletcher & Tobias, 2010). Low and Sweller's (2010) modality principle states that people learn better from graphics and narration (spoken text) than graphics and printed text alone. In other words, presenting information in a mixed visual and auditory mode, rather than a single mode, expands effective working memory capacity and reduces extraneous cognitive load. Similarly, Mayer's (2010b) modality principle states that people learn more deeply from multimedia information when the words are spoken rather than printed (p. 169). Sweller's (2010b) redundancy principle states that people learn better when the same information is not presented in more than one format. That is, instructions that present the same information in different forms or with unnecessary explanatory materials increase extraneous cognitive load, that interferes with learning (p. 167). Similarly, Mayer's (2010c) redundancy principle states that people learn more deeply from graphics and narration (spoken text) compared to graphics, narration (spoken text), and printed text (p. 198).

Based on the multimedia principle as well as the modality and redundancy principles, we can conclude that appropriate displays of information or media lower extraneous cognitive load and enhance learning achievement. In contrast, additional or insufficient information can increase extraneous cognitive load and interrupt learning. Many studies have shown that a well-designed multimedia environment can lower extraneous cognitive load and enhance learning (Cheon & Grant, 2012; Zheng, McAlack, Wilmes, Kohler-Evans, & Williamson, 2009). The previous studies mentioned above focused on multimedia learning rather than DGBL, and did not compare the differences between DGBL and traditional classroom learning.

According to cognitive theory of multimedia learning (Mayer, 2010a) and cognitive load theory (Paas et al., 1994), DGBL environments that include detailed information lower extraneous cognitive load, leading to better learning. Rich multimedia in DGBL environments may impact the effectiveness of cognitive processing (Huang, 2011). Games are a composite of rich media, and the amount of information may exceed a user's working memory load (Kiili, 2005). Multimedia learning environments with high interaction can facilitate learning motivation, but they have a possibility of pressuring a learner's cognitive processing capacity and interrupting learning (Huang, 2011). Although DGBL environments include high levels of interaction, facilitating motivational processing, learners may be unable to sustain the interaction due to a limitation on cognitive processing capacity (Ang, Zaphiris, & Mahmood, 2007). In other words, during motivational processing, it is difficult for learners to control highly interactive DGBL environments because of a limited cognitive processing capacity.

Within a DGBL environment, non-linear presentations of information may increase learners extraneous cognitive load (Zumbach & Mohraz, 2008). Digital game users need to expend a considerable amount of mental effort when simultaneously interacting with game environments, objects, and game tasks (Huang, 2011). In complicated digital game environments, the load from multiple interactions, user interfaces, and identity constructs can potentially exceed a user's cognitive capacity (Ang et al., 2007). Learners need to spend a considerable amount of cognitive processing effort on the game environment and accompanying social stimuli (Huang & Johnson, 2008).

Therefore, in a DGBL environment, a learner who cannot appropriately control his/her learning processes will face limited cognitive processing capacity, resulting in interrupted learning. How and in what way DGBL increases overall cognitive load remains an important issue requiring research attention (Ang et al., 2007; Huang, 2011; Huang & Johnson, 2008; Schrader & Bastiaens, 2012; Zumbach & Mohraz, 2008).

Research objectives and questions

Differences in learning achievement, flow, and overall cognitive load between DGBL and non-game-based CBL were examined in the current study. Additionally, relationships among flow, overall cognitive load, and learning achievement were also explored. Our research questions were:

(1) What is the difference in learning achievement between DGBL group and CBL group?
(2) What is the difference in flow between DGBL and CBL groups?
(3) what differences exist in cognitive load between DGBL and CBL groups?
(4) What are the relationships among the variables of learning achievement, flow, and overall cognitive load for the DGBL and CBL groups?

Method

Participants

Participants in the current study consisted of Taiwan college students enrolled in a general education course titled Life and Technology. Participants were 103 students from two classes, with a mean age of 19 . One class of 53 students (32 females and 21 males) was selected as the control group. The second class of 50 students (36 females and 14 males) was selected as the experimental group. The control group used CBL, and the experimental group used DGBL.

The two groups used learning materials related to knowledge of carbon footprints, which included remedial materials related to energy saving and carbon reduction. In recent years, environmental issues have received increased attention within classrooms. The main goal of this class, irrelevant of the experimental status, was to increase student internalisation and awareness of their own carbon footprints and behaviours that lead to low-carbon lifestyle.

Research design

Different media learning methods were implemented as the independent variable – CBL and DGBL. Dependent variables included achievement test scores, flow, and overall cognitive load – administered to the two groups after the experiment. Scores of students' prior knowledge, derived before the experiment, were held as covariate variables.

Multivariate analysis of covariance (MANCOVA), with a covariate variable of prior knowledge, was employed to examine differences on achievement test scores, flow, and cognitive load between both groups. Finally, Pearson correlation was performed to examine any relationships among achievement test scores, flow, and overall cognitive load.

Instrument

Prior knowledge test and achievement test
The prior knowledge test focused on basic concepts of energy conservation and carbon emission reduction, measured with ten multiple choice questions. The achievement test focused on more detailed knowledge about carbon footprint concepts. In order to increase content validity, the tests were reviewed and revised by three experts – experts on energy saving, carbon emission reduction, and carbon footprint. Item analysis for the two tests employed a difficulty index and discrimination index.

The overall difficulty index for the two tests was 0.697 and 0.683, suggesting that difficulty was moderate but partially easy. The overall discrimination index was 0.296 and 0.319, which was acceptable. The KR-20 coefficient for the two tests was 0.832 and 0.896, suggesting that the internal consistency among the questions in the two tests was adequate.

Cognitive load questionnaire
The cognitive load questionnaire was based on the definition of cognitive load from Sweller et al. (2011) and the cognitive load questionnaires proposed by Paas et al. (1994) as well as work from Ayres and Paas (2007). Paas et al. (1994) state that cognitive load includes both mental load and mental effort. Mental load refers to the aspect of cognitive load that originates from the interaction between task and subject characteristics. It can

thus be expected that cognitive capacity demands are an a priori estimate of cognitive load (Paas, Tuovinen, Tabbers, & Van Gerven, 2003, p. 64). Mental effort is the aspect of cognitive load that refers to the cognitive capacity, which accommodates the demands imposed by the task.

The cognitive load questionnarire measured mental pressure caused when attempting to master learning materials. It consisted of two constructs: difficulty (mental load and intended intrinsic cognitive load) and negative pressure (mental effort and intended extraneous cognitive load). Overall cognitive load is assumed to be the sum of intrinsic cognitive load and extraneous cognitive load (Leppink & van Merriënboer, 2015; Sweller, 2010a; Sweller et al., 2011). Difficulty refers to levels of difficulty and ease of comprehension in a learning task. Negative pressure is the perceived degrees of loading caused by the presentation method of learning material. The questionnaire consisted of 5-point Likert-type scale response options from 1 (*extremely weak*) to 5 (*extremely strong*), with participants indicating how they felt in the experiment. Questions consisted of the following:

- Difficulty:
  - I think the content of the learning material is very difficult.
  - I think the content of the learning material is very complex.
  - I think the content of the learning material is not easy to comprehend.
  - I think the content of the learning material is beyond my comprehension.
- Negative pressure:
  - I do not like the display method of the learning material.
  - The display method of the learning material is not interesting to me.
  - The display method of the learning material requires strenuous effort when learning.
  - The display method of the learning material is not helpful for me.

Bartlett’s test of sphericity was statistically significant (B = 507.246, p < 0.001), meaning that there were common factors within the questionnaire. The Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) was greater than 0.5 (KMO = 0.728); therefore, a factor analysis was performed. Principal component analysis (PCA), with orthogonal rotation, was conducted. Factor loadings for each question were greater than 0.5; therefore, all questions possessed adequate individual item quality. Two constructs were extracted based on their eigenvalues, all greater than 1. The total accumulated variance of the two constructs was greater than 70% (CV1 + CV2 = 38.230% + 32.241% =70.471%), suggesting that the construct validity of the questionnaire was good. The reliability coefficients of the questionnaire were greater than 0.7 (α = 0.715), as measured by Cronbach’s alpha, indicating good reliability.

Flow questionnaire

The flow questionnaire, developed by Pearce et al. (2005), was modified and employed in this study. Some words and modalities were modified to meet the needs of the DGBL and CBL environments. Liu et al. (2011) also used the questionnaire for measuring learner flow within DGBL. The questionnaire consisted of three constructs: enjoyment (measuring learners’ levels of enjoyment from the game), engagement (measuring learners’ levels of concentration toward the game), and control (measuring learners’ perceived degrees of control of the game environment).

Twelve questions were included on this questionnaire, a 5-point Likert-type scale with response options from 1 (*extremely weak*) to 5 (*extremely strong*). Participants were required to respond to each question according to their own feelings at the time. Scores were totalled across the three constructs. Higher scores represent higher levels of flow. Questions consisted of the following:

- Enjoyment:
  - The learning inspires my curiosity.
  - The learning is enjoyable.
  - The learning is interesting.
  - The learning is unpleasant (reverse question).

- Engagement:
  - I cannot focus when engaging in the learning process (reverse question).
  - I can become distracted during the learning process (reverse question).
  - I work hard to be engaged in the learning process.
  - I am concentrated when learning.
- Control:
  - I feel frustrated in the learning process (reverse question).
  - During the learning process, I am skillful (able to control the learning).
  - I know how to operate or participate in the learning activity.
  - I can easily follow the learning process that is convenient for me to operate.

Bartlett's test of sphericity was statistically significant ($B = 764.242$, $p < 0.001$), meaning that there were common factors within the questionnaire. Kaiser-Meyer-Olkin measure of sampling adequacy was greater than 0.5 ($KMO = 0.850$); therefore, factor analysis was called for. Principal components analysis (PCA), with orthogonal rotation, resulted in factor loadings for each question greater than 0.5. Three constructs were extracted based on eigenvalues greater than 1. The total accumulated variance of the three constructs was greater than 70% (CV1 + CV2 + CV3 = 32.461 + 26.427 + 13.768 = 72.656%), implying that the construct validity of the questionnaire was good. Cronbach's alpha results showed the reliability coefficients of the scale was greater than 0.8 ($\alpha = 0.890$), indicating a good reliability.

DGBL material on carbon footprint

The DGBL learning materials included a LAMP (Linux, Apache, MySQL, PHP) server, with a user interface developed in Flash (Adobe Corporation). The 3D game model was designed with Maya 3D animation software. Learning material included 3D multimedia, video, and interactive Flash activities. Learners interacted with the learning material through mouse and keyboard actions, visiting scenes and completing challenges.

Concepts of carbon footprint and carbon emissions were integrated through the gaming interface to includes virtual settings the learner participated in. The learning topics were:

- Carbon footprint: Concepts of carbon footprint; Applications of carbon footprint; Calculations of carbon footprint
- Carbon label: Concepts of carbon label; Applications of carbon label; Advantages of carbon label
- Low-carbon diet: Reasons for a low-carbon diet; Advantages of a low-carbon diet.

The goal of the game was to raise player awareness of the amount of carbon emissions they produced in the game, and how to reduce carbon emissions by quantifying their carbon footprint. Players chose daily life actions that impacted carbon emission amounts. After completing six scenarios, a total carbon emissions score was calculated for the player. Players saw their scores change as they completed scenarios and could compare their progress to other learners through a leaderboard.

Figure 1 shows the start of the game – choices at breakfast. The virtual day then progresses to decisions to be made at school, such as physical activity and lunch options. Players go on to a field study at a farm, with activities including a carbon label instructional video and shopping choices. This is followed with a walk in a park, dinner at a restaurant and, finally, returning home – all with instructional content, videos, and choices. A total carbon emission score is produced to show the player's carbon footprint. Learners next participate in a summative assessment through a game with questions related to the information in the preceding virtual day.

Figure 1. Breakfast time at home
Description: The user can choose between two dishes – resulting in different carbon emission scores.

CBL material on carbon footprint
Media for the CBL control group were text, images, and videos without presenting any 3D media or virtual environment. This stimulus focused on three activities. In the first activity, a video about global warming was viewed – acting as an introduction to the course. In the second activity, instruction on carbon footprints is presented – information about the concept of carbon footprints, carbon labels, and low-carbon diets. This learning content was the same as the DGBL material. Finally, students were asked to calculate their total carbon emissions generated from their one-day carbon footprints on the Green Living, Environmental Protection Administration website, as shown in Figure 2.

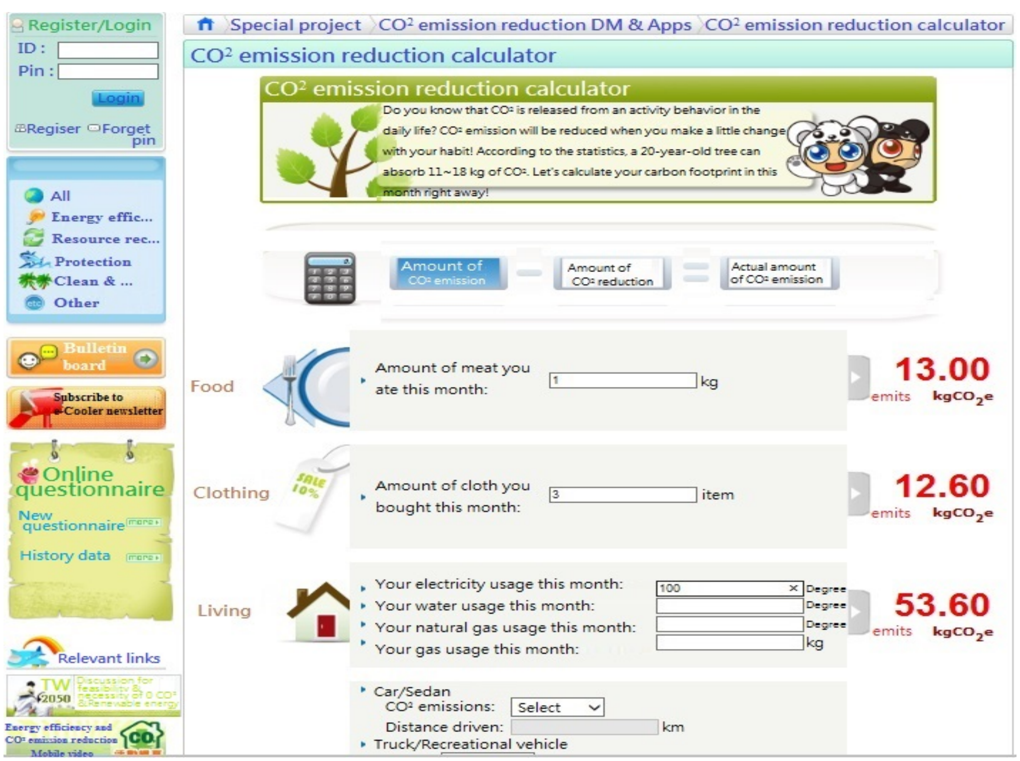

Figure 2. Carbon footprint calculator on the web page of the Environmental Protection Administration

Experiment procedure

The experimental procedure consisted of an early phase of a prior knowledge testing, with before-class guidance (first week) and a phase of a teaching experiment (second week). In the first week, students received a short description (5 minutes) of the learning tools and were then directed to complete the prior knowledge test (15 minutes). The remainder of time (30 minutes) included a brief lecture on global warming and carbon footprint concepts. During the second week class meeting, the experimental group used the DGBL environment, whereas the control group used the non-game-based CBL environment (95 minutes for each in PC classrooms). In both cases, an instructor was present to help with learning guidance and learning problems. When the PC task was complete, respondents completed the achievement test and the flow and cognitive load survey (20 minutes).

Both groups had the same learning content on carbon footprints, the same instructor, and the same instructional schedule and class hours in order to ensure the internal and external validity of the teaching experiment. Moreover, the instructor guided the learning processes of both groups to prevent one group from receiving more information than the other.

Results

Differences on achievement test, flow, and cognitive load between both groups

No difference in prior knowledge on carbon footprints is exhibited between experimental and control groups ($p > 0.05$). The MANCOVA results show significant outcome differences in achievement test ($p < 0.01$), flow ($p < 0.01$), and cognitive load ($p < 0.01$) between the two groups (see Table 1). This indicates a differential impact in achievement test, flow, and cognitive load.

Table 1
MANCOVA on achievement test, flow, and cognitive load for both groups

Wilk's Λ (Sig.)	Source	Dependent variable	F	Sig.	Effect size
0.871 (0.003**)	Covariate (Prior knowledge test)	Achievement test	22.99	0.000***	0.19
		Flow	0.49	0.485	0.01
		Cognitive load	44.58	0 .000***	0.31
	Between-group (treatment)	Achievement test	4.57	0.035*	0.05
		Flow	7.56	0.007**	0.07
		Cognitive load	7.61	0.007**	0.07

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 2 shows that the experimental group exhibit significantly better achievement and flow with lower cognitive load compared to the control group. In other words, the DGBL material results in significantly better achievement and flow and lower cognitive load than the non-game-based CBL. Results are further analysed by effect size (η^2):

η^2 = SStreatment/SStotal
SStreatment = between-group variance
SStotal = the sum of the squared deviations of each score from the grand mean.

Cohen (1988) proposed a rule to interpret effect sizes for ANOVA and AVCOVA: a correlation of $0.059 > \eta^2 \geqq 0.01$ is small, $0.138 > \eta^2 \geqq 0.059$ is moderate, and $\eta^2 \geqq 0.138$ is large. Based on these rules, learning achievement exhibits a small effect while flow and cognitive load exhibit moderate effects.

Table 2
Descriptive statistics for achievement test, flow, and cognitive load

Dependent variable	Control group		Experimental group	
	Adj- M	**Adj-standard deviation**	**Adj-M**	**Adj-standard deviation**
Achievement test	74.38	1.88	80.16	1.94
Flow	44.50	0.99	48.42	1.02
Cognitive load	5.09	0.58	2.79	0.60

Relationships among achievement, flow, and cognitive load between both groups

Pearson correlation is used to examine correlations among the achievement on carbon footprints, flow, and cognitive load. As shown in Table 3, total achievement and flow ($p < 0.05$) exhibited a significant positive correlation; achievement and cognitive load had a significant negative correlation ($p < 0.05$); flow and cognitive load also exhibited a significantly negative correlation ($p < 0.01$). This suggests learners with lower cognitive load obtain higher achievement and flow, while learners with higher cognitive load experience lower achievement and flow. The experimental group shows a similar relationship as the two groups combined. The control group differed in that achievement was not significantly correlated with cognitive load.

Table 3
Correlations among achievement, flow, and cognitive load for both groups

Variables	Achievement	Flow	Cognitive load
Total			
Achievement	1.00		
Flow	0.20*	1.00	
Cognitive load	-0.27*	-0.37**	1.00
Control group			
Achievement	1.00		
Flow	0.12	1.00	
Cognitive load	-0.33**	-0.28*	1.00
Experimental group			
Achievement	1.00		
Flow	0.27*	1.00	
Cognitive load	-0.21*	-0.39**	1.00

*$p < 0.05$, **$p < 0.01$

Discussion

Statistically significantly higher flow and lower cognitive load is experienced by DGBL learners compared to learners in non-game-based CBL. In other words, learners in DGBL experience more positive psychological feelings and lower cognitive load, which is reflected in learning performances. This result is consistent with other studies on flow (Admiraal et al., 2011; Choi & Baek, 2011; Kiili et al., 2012) and studies on cognitive load (Cheon & Grant, 2012; Korakakis, Pavlatou, Palyvos, & Spyrellis, 2009; Zheng et al., 2009). However, these previous studies did not simultaneously explore flow and cognitive load.

In summary, DGBL learners experience higher flow and lower cognitive load, suggesting they also obtained higher learning achievement. In contrast, some previous studies have argued that rich multimedia and/or large amounts of information present in DGBL environments may exceed learner working memory load (Ang et al., 2007; Huang, 2011; Kiili, 2005). Some previous studies have found animations, simulations, and DGBL can increase the amount of cognitive load among learners (Ang et al., 2007; Ayres & Paas, 2007; Huang, 2011; Huang & Johnson, 2008; Zumbach & Mohraz, 2008). Nevertheless, the current study does find negative results.

This study reveals a significantly positive relationship between achievement and flow and a significantly negative relationship between achievement and cognitive load. Flow and cognitive load exhibit a significantly negative correlation. Consequently, a learner's psychological state and load affect learning achievement. During the learning, a student with high flow or low cognitive load experiences better learning achievement. Some studies report high flow results in better learning achievement (Admiraal et al., 2011; Choi & Baek, 2011; Kiili et al., 2012; Pekrun & Stephens, 2012) and low cognitive load results in better learning achievement (Cheon & Grant, 2012; Zheng et al., 2009). However, these studies did not directly examine correlations between flow and cognitive load, as done here.

Several critical questions arise from the current results. Do all CBL instructional modalities underperform in comparison with DGBL, especially in terms of cognitive load? Even though learners could lose themselves in a state of flow, is flow always positively related to learning achievement? One major variable in these questions is the design of the DGBL material. DGBL can lower cognitive load and enhance flow and learning achievement, but these results are limited here to the specific multimedia design in the current study. Any external validity claims must be contextualised within the DGBL design under consideration.

Conclusions and implications

Implications for teaching practice

This study shows that DGBL learners exhibit higher achievement and flow along with lower cognitive load than the non-game-based CBL learners. Students with low cognitive load or high flow show better learning achievement. This study supports instructors' efforts to integrate digital games into instruction in order to simultaneously eliminate learning pressure and enhance learning achievement. As an added benefit, learners in the current study experience immersion in a flow state generated from the learning experience. In other words, students are able to concentrate better when learning and experience less stress from learning tasks, all leading to enhanced learning achievement.

Contribution and significance of the study

Previous DGBL studies examine the relationship between flow and learning effect (Admiraal et al., 2011; Choi & Baek, 2011; Kiili et al., 2012) or the correlation between cognitive load and learning effect (Cheon & Grant, 2012; Korakakis et al., 2009; Zheng et al., 2009). Only a few studies directly examine the relationship between flow and cognitive load. None of the existing studies examine relationships among flow, learning effect, and cognitive load. Thus, the contribution of the current study is meaningful and significant as it directly examines the correlation between flow and cognitive load and the relationships among flow, learning effect, and cognitive load. This is important because there is now evidence to support the theoretical assumptions surrounding these vital learning variables. The current results also demonstrate the importance of flow theory, cognitive load theory, and cognitive theory of multimedia learning within the context of DGBL instructional modalities.

Limitations and recommendations

The overall features of the DGBL were examined in this study. It is suggested that rich media features, for example, simulated scenarios, interests, interactions, learner control, multimedia visualisation, and 3D animations, be the focus of future research. Based on different designs of learning material, differences in learning achievement, flow, and cognitive load, as well as relationships among learning achievement, flow, and cognitive load could be further examined. Different types of cognitive load could also be examined, including intrinsic, extraneous, and germane cognitive loads rather than overall cognitive load alone. Additionally, the challenge-skill balance in flow theory and expertise reversal effects on cognitive load theory suggests that a learner's prior knowledge can affect flow and cognitive load. Hence, prior knowledge was employed as a covariate variable in the current study. It would be beneficial to educators and researchers in the field if some teaching strategies or models for DGBL could be explored in future research.

References

Admiraal, W., Huizenga, J., Akkerman, S., & Dam, G. T. (2011). The concept of flow in collaborative game-based learning. *Computers in Human Behavior*, *27*(3), 1185–1194. https://doi.org/10.1016/j.chb.2010.12.013

Ang, C. S., Zaphiris, P., & Mahmood, S. (2007). A model of cognitive loads in massively multiplayer online role playing games. *Interacting with Computers*, *19*(2), 167–179. https://doi.org/10.1016/j.intcom.2006.08.006

Ayres, P., & Paas, F. (2007). Making instructional animations more effective: A cognitive load approach. *Applied Cognitive Psychology*, *21*(6), 695–700. https://doi.org/10.1002/acp.1343/epdf

Brom, C., Buchtová, M., Šisler, V., Děchtěrenko, F., Palme, R., & Glenk, L. M. (2014). Flow, social interaction anxiety and salivary cortisol responses in serious games: A quasi-experimental study. *Computers & Education*, *79*, 69-100. https://doi.org/10.1016/j.compedu.2014.07.001

Cheon, J., & Grant, M. M. (2012). The effects of metaphorical interface on germane cognitive load in web-based instruction. *Educational Technology Research and Development*, *60*(3), 399–420. https://doi.org/10.1007/s11423-012-9236-7

Choi, B., & Baek, Y. (2011). Exploring factors of media characteristic influencing flow in learning through virtual worlds. *Computers & Education*, *57*(4), 2382-2394. https://doi.org/10.1016/j.compedu.2011.06.019

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* Hillsdale, NJ: Erlbaum. https://www.sciencedirect.com/science/book/9780121790608

Dickey, M. D. (2005). Three-dimensional virtual worlds and distance learning: Two case studies of active worlds as a medium for distance education. *British Journal of Educational Technology*, *36*(3), 439–451. https://doi.org/10.1111/j.1467-8535.2005.00477.x/pdf

Faiola, A., Newlon, C., Pfaff, M., & Smyslova, O. (2013). Correlating the effects of flow and telepresence in virtual worlds: Enhancing our understanding of user behavior in game-based learning. *Computers in Human Behavior*, *29*(3), 1113–1121. https://doi.org/10.1016/j.chb.2012.10.003

Fletcher, J. D., & Tobias, S. (2010). The multimedia principle. In R. E. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp.117–133). New York, NY: Cambridge University Press. https://doi.org/10.1017/CBO9781139547369

Giannakos, M. N. (2013). Enjoy and learn with educational games: Examining factors affecting learning performance. *Computers & Education*, *68*, 429–439. https://doi.org/10.1016/j.compedu.2013.06.005

Girard, C., Ecalle, J., & Magnan, A. (2012). Serious games as new educational tools: How effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning*, *29*(3), 207–219. https://doi.org/10.1111/j.1365-2729.2012.00489.x/epdf

Huang, W.-H. (2011). Evaluating learners' motivational and cognitive processing in an online game-based learning environment. *Computers in Human Behavior*, *27*(2), 694–704. https://doi.org/10.1016/j.chb.2010.07.021

Huang, W.-H., & Johnson, T. (2008). Instructional game design using cognitive load theory. In R. Ferdig (Ed.), *Handbook of research on effective electronic gaming in education* (pp. 1143–1165). Hershey PA: Information Science Reference. https://doi.org/10.4018/978-1-59904-808-6.ch066

Huang, Y. M., Huang, S. H., & Wu, T. T. (2015). Embedding diagnostic mechanisms in a digital game for learning mathematics. *Education Technology Research and Development*, *62*(2), 187–207. https://doi.org/10.1007/s11423-013-9315-4

Keller, J., Bless, H., Blomann, F., & Kleinbohl, D. (2011). Physiological aspects of flow experience: Skills-demand-compatibility effects on heart rate variability and salivary cortisol. *Journal of Experimental Social Psychology*, *47*, 849–852. https://doi.org/10.1016/j.jesp.2011.02.004

Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. *Internet and Higher Education*, *8*(1), 13-24. https://doi.org/10.1016/j.iheduc.2004.12.001

Kiili, K., de Freitas, S., Arnab, S., & Lainema, T. (2012). The design principles for flow experience in educational games. *Procedia Computer Science*, *15*, 78–91. https://doi.org/10.1016/j.procs.2012.10.060

Korakakis, G., Pavlatou, E.A., Palyvos, J.A., & Spyrellis, N. (2009). 3D visualization types in multimedia applications for science learning: A case study for 8th grade students in Greece. *Computers & Education*, *52*(2), 390–401. https://www.learntechlib.org/p/66681/

Lepper, M. R., Iyengar, S. S., & Corpus, J. H. (2005). Intrinsic and extrinsic motivational orientation in the classroom: Age differences and academic correlates. *Journal of Educational Psychology*, *97*(2), 184–196. https://doi.org/10.1037/0022-0663.97.2.184

Leppink, J., & van Merriënboer, J. J. G. (2015). The beast of aggregating cognitive load measures in technology-based learning. *Educational Technology & Society*, *18*(4), 230–245. Retrieved from http://www.jstor.org/stable/jeductechsoci.18.4.230

Liu, C. C., Cheng, Y. B., & Huang, C. W. (2011). The effect of simulation games on the learning of computational problem solving. *Computers & Education*, *57*(3), 1907–1918. https://doi.org/10.1016/j.compedu.2011.04.002

Low, R, & Sweller, j. (2010). The modality principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp.147–158). New York, NY: Cambridge University Press.

Mayer, R. E. (2010a). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31–48). New York, NY: Cambridge University Press.

Mayer, R. E. (2010b). Principles for managing essential processing in multimedia learning: Segmenting, pretraining, and modality principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 169–182). New York, NY: Cambridge University Press.

Mayer, R. E. (2010c). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 183–200). New York, NY: Cambridge University Press.

Omale, N., Hung, W. C., Luketkehans, L., & Jessamine, C. P. (2009). Learning in 3-D multiuser virtual environment: Exploring the use of unique 3-D attributes for online problem-based learning. *British Journal of Educational Technology*, *40*(3), 480–495. https://doi.org/10.1111/j.1467-8535.2009.00941.x/epdf

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, *38*(1), 1-4. https://doi.org/10.1207/S15326985EP3801_1

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist*, *38*(1), 63–71. https://doi.org/10.1207/S15326985EP3801_8

Paas, F., van Merriënboer, J. J. G., & Adam, J. J. (1994). Measurement of cognitive load in instructional research. *Perceptual and Motor Skills*, *79*, 419–430. https://doi.org/10.2466/pms.1994.79.1.419

Papastergiou, M. (2009). Digital game-based learning in high school computer science education: Impact on educational effectiveness and student motivation. *Computers & Education*, *52*(1), 1–12. https://doi.org/10.1016/j.compedu.2008.06.004

Pearce, J. M., Ainley, M., & Howard, S. (2005). The ebb and flow of online learning. *Computers in Human Behavior*, *21*(5), 745–771. https://doi.org/10.1016/j.chb.2004.02.019

Pekrun, R., & Stephens, E. J. (2012). Academic emotions. In K. R. Harris, S. Graham, T. Urdan, J. M. Royer, & M. Zeidner (Eds.), *Individual differences and cultural and contextual factors: Vol. 2. APA educational psychology handbook* (pp. 3–31). Washington, DC: American Psychological Association.

Sancho, P., Torrente, J., & Fernandez-Manjon, B. (2009). Do multi-user virtual environments really enhance student's motivation in engineering education? In *Proceedings of the 39th IEEE International Conference: Frontiers in Education* (pp. 1–6). Seattle, WA: IEEE Computer Society. https://doi.org/10.1109/FIE.2009.5350863

Schrader, C., & Bastiaens, T. J. (2012). The influence of virtual presence: Effects on experienced cognitive load and learning outcomes in educational computer games. *Computers in Human Behavior*, *28*(2), 648–658. https://doi.org/10.1016/j.chb.2011.11.011

Skadberg, Y. X., & Kimmel, J. R. (2004). Visitors' flow experience while browsing a web site: its measurement, contributing factors, and consequences. *Computers in Human Behavior*, *20*(3), 403–422. https://doi.org/10.1016/S0747-5632(03)00050-5

Skulmowski, A., & Rey, G. D. (2017). Measuring cognitive load in embodied learning settings. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.01191

Sweller, J. (2010a). Element interactivity and intrinsic, extraneous and germane cognitive load. *Educational Psychology Review*, *22*, 123–128. https://doi.org/10.1007/s10648-010-9128-5

Sweller, J. (2010b). The redundancy principle in multimedia learning. In R. E. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp.159–182). New York, NY: Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.013

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. New York, NY: Springer.

Tamim, R. M., Bernard, R. M., Borokhovski, E., Abrami, P. C., & Schmid, R. F. (2011). What forty years of research says about the impact of technology on learning: A second order meta-analysis and validation study. *Review of Educational Research, 81*, 4–28. https://doi.org/10.3102/0034654310393361

Wu, J., Li, P., & Rao, S. (2008). Why they enjoy virtual game world? An empirical investigation. *Journal of Electronic Commerce Research, 9*(3), 219–230. https://www.researchgate.net/publication/228364678_Why_they_enjoy_virtual_game_worlds_An_empirical_investigation

Zheng, R., McAlack, M., Wilmes, B., Kohler-Evans, P., & Williamson, J. (2009). Effects of multimedia on cognitive load, self-efficacy, and multiple rule-based problem solving. British Journal of Educational Technology, 40(5), 790–803. https://doi.org/10.1111/j.1467-8535.2008.00859.x

Zumbach, J., & Mohraz, M. (2008). Cognitive load in hypermedia reading comprehension: Influence of text type and linearity. *Computers in Human Behavior, 24*(3), 875–887. https://doi.org/10.1016/j.chb.2007.02.015

Corresponding author: Chaoyun Liang, cliang@ntu.edu.tw

Please cite as: Chang, C.-C., Warden, C. A., Liang, C., & Lin, G.-Y. (2018). Effects of digital game-based learning on achievement, flow and overall cognitive load. *Australasian Journal of Educational Technology, 34*(4), 155-167. https://doi.org/10.14742/ajet.2961