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Digital Game-Based Learning Supports Student Motivation, Cognitive Success, and Performance Outcomes

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ABSTRACT

Traditional multimedia learning is primarily based on the cognitive load concept of information processing theory. Recent digital game-based learning (DGBL) studies have focused on exploring content support for learning motivation and related game characteristics. Motivation, volition, and performance (MVP) theory indicates that cognitive load and learning motivation simultaneously influence performance. To provide efficient management of learning effectiveness by understanding the latent relationship among cognitive load, motivation, and performance, this study investigated 63 university students using an online game entitled “Operating a Small Factory in Computer-Aided Manufacturing” for 8 weeks. We collected data based using an instructional materials motivation survey, a cognitive load scale, and performance (skill and cognitive) scales. The data analysis results showed that motivation and cognitive load exhibited a significant canonical correlation with performance. This preliminary finding suggests that when designing DGBL, designers should increase motivation and germane cognitive load to enhance learning effectiveness. In addition, the attention component must be compromised. However, relevance, satisfaction, and confidence do not conflict. This study proposes an application of game characteristics to the attention, relevance, satisfaction, and confidence model, and integrated multimedia effects in using DGBL design methods.

Keywords

DGBL; Motivation; Cognitive load; Performance; Computer-aided manufacturing

Introduction

Relevant studies have indicated that digital game-based learning (DGBL) possesses significant potential for increasing students’ learning motivation (Papastergiou, 2009; Huang, 2011) and enhancing their learning effectiveness (Yang, 2012; Wang & Chen, 2010). Higher education was the most frequently referenced research category (from 2001 to 2010) and has shown the highest growth in the number of DGBL studies (Hwang & Wu, 2012).

The attention, relevance, confidence, and satisfaction (ARCS) motivation model (Keller, 1987) has been widely applied to instructional designs to improve learning motivation (Liu & Chu, 2010; Karoulis & Demetriadis, 2005) and evaluate the performance of DGBL learners following motivation stimulation (Kebritchi, Hirumi, & Bai, 2010; Liu & Chu, 2010). Several studies suggest that games can enhance learning motivation because the game characteristics attract learners. Consequently, game characteristics have been systematically analyzed and summarized (Malone & Lepper, 1987; Garris, Ahlers, & Driskell, 2002; Prensky, 2007; Huang & Johnson, 2008). The relevant game software adopted by DGBL studies can be divided into the following two categories: (a) applications of existing commercial software (Kebritchi et al., 2010; Huang, 2011; Yang, 2012); and (b) designs and developments of new software (Papastergiou, 2009; Liu & Chu, 2010). Although both types stimulate learning motivation, new software designs and developments based on specific instructional objectives can better satisfy course demands. Nevertheless, how DGBL design methods can be employed to apply various game characteristics that match motivational strategy procedures remains unclear.

Although using DGBL can improve learning motivation, enhancing motivation in a multimedia learning environment, where stimulating external materials (Mayer, 2001) and interaction in a complex intrinsic game-based learning environment (GBLE) exist, requires considerable cognitive investment from learners to process environmental and social stimulation. This may lead to cognitive overload problems among learners. Improper learning process management can lead to early interruption or termination because of limited learner motivation and possible cognitive process overloads (Keller, 2008).

Various cognitive loads in learners' working memory, including intrinsic cognitive load, extraneous cognitive load, and germane cognitive load, are task-based mental loads induced by task characteristics, learners' performance, and mental effort invested (Paas, Tuovinen, Tabbers, & van Gerven, 2003). Because multimedia can process and display information using various methods, employing well-structured multimedia-based instructional designs can reduce learners' extraneous cognitive loads (Khalil, Paas, Johnson, & Payer, 2005). Furthermore, teaching material designs should enhance learners' learning motivation and germane cognitive load. Based on the dual-channel assumption, people use separate systems to process visual/pictorial and auditory/verbal representations of information. By combining limited capacity and active processing assumptions, Mayer (2001) developed a cognitive theory for multimedia learning; however, the limitation of this theory is its exclusion of motivational factors. The limitation of the ARCS macro model proposed by Keller (1987) is that it cannot explain how information processing elements are integrated with the learning process or how these elements interact with motivation. Deimann and Keller (2006) indicated that self-oriented multimedia-based learning environments use non-linear (i.e., nodes and hotlinks) and random information access characteristics (i.e., learners determine the sequence of information access), which empowers learners to control the learning process and results completely. Therefore, the cognitive theory of multimedia learning proposed by Mayer (2001) and learners' volition control have been included to explain the learning motivation process in multimedia-based learning environments. Keller's MVP model provides more comprehensive explanatory latent variables for the relationships among motivation, learning, and performance. The model also shows the influence that learning motivation and cognitive load during the learning process have on performance (Keller, 2008). However, the theoretical framework has not been practically developed or applied to DGBL environments, nor thoroughly investigated using empirical research.

Literature review

ARCS model

The ARCS model is a motivational model initially proposed for diagnosing motivational problems and providing strategic suggestions. Comprising the components of attention, relevance, confidence, and satisfaction, the ARCS model has been widely applied to instructional design processes, thereby connecting learning motivation with effectiveness (Keller, 1987). Experimental studies have confirmed that instructional designs of the ARCS model can significantly enhance learning motivation and effectiveness (Kebritchi et al., 2010; Liu, & Chu, 2010).

Game characteristics

From a pedagogical perspective, students' attraction to computer games has been considered to address student learning interests effectively (Thomas, Thomas, Mark, & Elizabeth, 2011). Moreover, game characteristics are what attract learners. Several researchers indicated different game characteristics (shown in table 1).

Table 1. Different game characteristics

researchers	Malone & Lepper (1987)	Prensky (2007)	Huang & Johnson (2008)	Garris et al. (2002)
categories	challenge, curiosity, fantasy, control	fun, play, rules, goals, interactive, adaptive, outcomes and feedback, win states, conflict/competition /challenge/opposition, problem solving, interaction, representation and story	challenges, competition, rules, goals, fantasy and changed reality, story or representation, engagement and curiosity, role-playing, control, multimodal presentation, tasks	control, rules/goals, challenges, sensory stimuli, mystery, fantasy

Activities should stimulate a portion of learners' sensory control; in other words, learning effectiveness or achievement is a feeling determined by learners' actions. Furthermore, learners can be prompted to participate in role-play activities or fantasy scenarios, and can experience imaginary situations and develop intrinsic motivation

(Malone & Lepper, 1987). Sensory stimuli should be appealing or novel visual and auditory stimuli (Garris et al., 2002). Games typically employ multimodal presentations to effectively increase interest and the instructional effects, and also integrate auditory, visual, and textual presentations to enrich players' experience (Huang & Johnson, 2008). Therefore, sensory stimuli are similar to multimodal presentations, which include representations or visual factors. Curiosity is a product of perceived discrepancies or knowledge inconsistencies (Garris et al., 2002). Incongruous information, complexity, novelty, surprise, and violations of expectations strengthen mystery (Berlyne, 1960). Therefore, mystery is similar to curiosity. In a multimedia environment with abundant stimuli, curiosity and achievement are positively correlated (Keller, 2008). Prensky (2007) indicated that adaptive characteristics enable learners to generate "flow." The learner is fully absorbed in the immediate activity of the game and does not rely on metacognitively induced strategies of self-regulation to remain on task (Keller, 2008). Players typically stop playing games because overly easy tasks bore them and tasks that are excessively difficult discourage them. Thus, appropriate challenges are essential for maintaining a "flow" state (Prensky, 2007) and fostering a sense of winning and challenge. Accordingly, adopting a suitable strategy can enable learners to exhibit superior performances (Wang & Chen, 2010).

In summary, game characteristics include fantasy, curiosity, control, role-playing, fun, play, rules, goals, interactive, adaptive, win states, conflict/competition/challenge/opposition, problem solving, interaction, multimodal presentation and story, task, and outcomes and feedback. The video "Dumb Ways to Die," which has a story and is fun, induces curiosity, and involves fantasy, has attracted more than 60 million views (http://www.youtube.com/watch?v=IJNR2EpS0jw&feature=youtu.be). A curious character pokes a bear with a stick. Another character is electrically shocked, becoming a fantasy skeleton. This reminds viewers to be safe around trains (Metro Trains Melbourne, 2012).

Digital game-based learning

Students use games to explore and ultimately construct concepts and relationships in authentic contexts. The concept of learning-by-doing comprises core constructivist principles that underlie game-based learning (Yang, 2012). Lenhert et al. (2008) found that 97% of Americans between the ages of 12 and 17 play digital games. Yang (2012) used commercially available games to assist students with understanding economic life and global issues. Kebritchi et al. (2010) examined the effects that a computer game had on students' mathematics achievements and motivation. Liu and Chu (2010) conducted a study investigating how ubiquitous games influence English learning achievements and motivation. Papastergiou (2009) assessed the learning effectiveness and motivational appeal of a computer game for computer science learning. The results show that DGBL can provide effective and motivating learning environments regardless of students' gender. Huang (2011) used the Trade Ruler game to introduce economic theory and found that it enhanced students' learning motivation. Therefore, DGBL can enhance learning motivation (Papastergiou, 2009; Kebritchi et al., 2010; Huang, 2011) and improve the learning effectiveness of students (Kebritchi et al., 2010; Liu & Chu, 2010; Yang, 2012). People acquire new knowledge and complex skills from game play (Federation of American Scientists, 2006). The games adopted by DGBL studies can be divided into two categories: (a) applications of existing commercial software (Kebritchi et al., 2010; Huang, 2011; Yang, 2012); and (b) designs and developments of new software (Papastergiou, 2009; Liu & Chu, 2010). Although both stimulate learning motivation, new software designs and developments based on specific instructional objectives can better satisfy course demands. Nevertheless, how DGBL design methods can be employed to apply various game characteristics appropriate for motivational strategy procedures remains unclear.

Reducing cognitive load in multimedia learning

The ideal teaching material format should integrate information from various sources to limit unnecessary mental integration by learners and reduce learners' extraneous cognitive load. Mayer (2001) indicated that in multimedia learning, active processing involves five cognitive procedures: selecting words, selecting images, organizing words, organizing images, and integrating. Cognitive requirements are divided into three types: essential processing, incidental processing, and representational holding. Essential processing refers to the cognitive processes necessary to comprehend teaching material, for which substantial cognitive capacity is used to select, organize, and integrate words and images. Incidental processing refers to cognitive processes that are not required to comprehend the presented materials but are primed by the learning task design. Finally, representational holding refers to the cognitive processes aimed at retaining a mental representation in working memory over time to support subsequent learning. When the total intended cognitive processing load exceeds the learner's cognitive capacity, cognitive overload occurs. The solution is to reduce the cognitive load by reallocating essential processing, reducing incidental processing, and/or decreasing representational holding. Mayer (2001) applied the results of multimedia research to propose various solutions (Fig. 1).

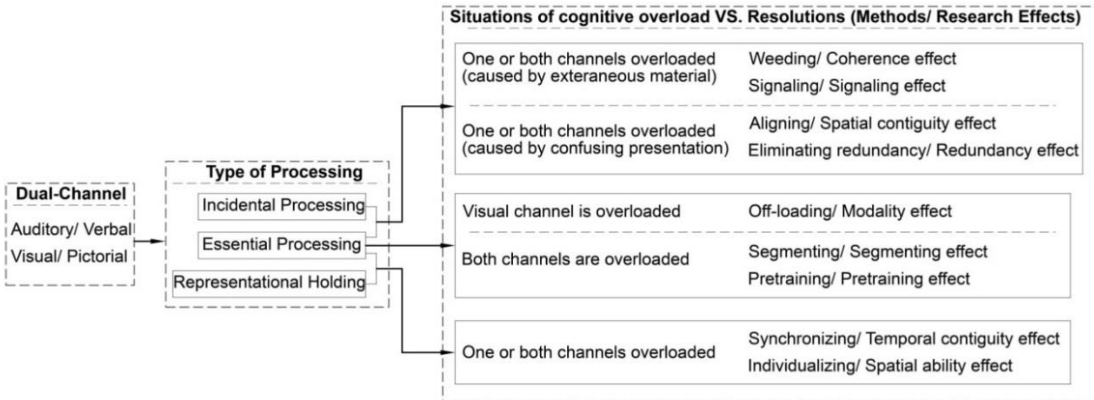


Figure 1. Cognitive load reduction methods for multimedia instruction (Mayer, 2001)

The MVP model for motivation, volition, and performance

Keller (2008) extended the ARCS model into an MVP model (Fig. 2), which represents the external input, psychological environment, and outputs. The external input of environmental conditions influences learners' psychological environments and processes, resulting in outputs of effort, learning and performance, and consequences influenced by contingency management and intrinsic reinforcement strategies. The psychological environment and relevant processes include motivation and volitional processing, motivation and information processing interfaces, information and psychomotor processing, and outcomes processing. Volition is included in motivation and volitional processing. Information processing elements and their interactions with motivation and volition can be explained using information and psychomotor processing and the motivation and information processing interface, respectively.

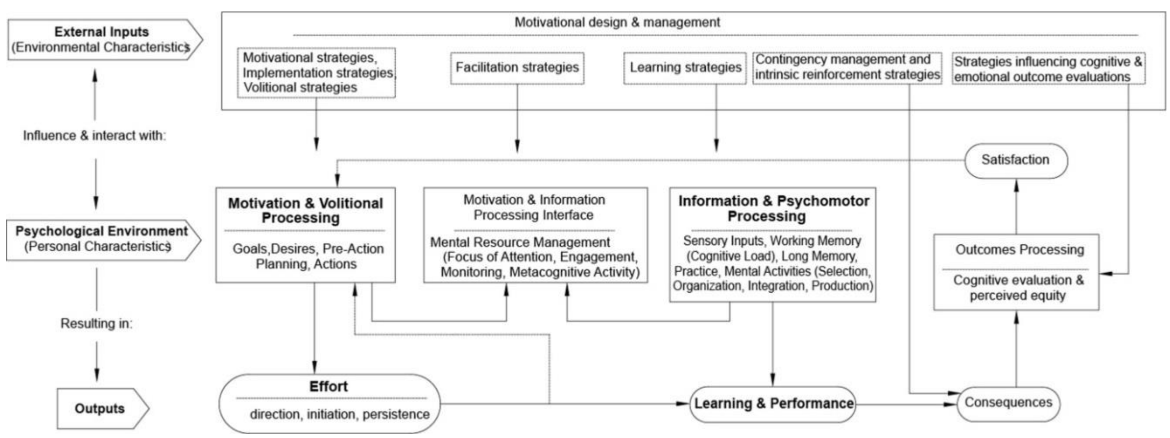


Figure 2. The MVP model developed by Keller (2008)

Kuhl (1985) defined volition as a mediating factor that "energizes the maintenance and enactment of intended actions." Gollwitzer (1996) investigated implementation intention and determined that it comprises the following three phases: (a) motivation (pre-decisional phase), (b) the beginning of volition (pre-actional phase), and (c) the implementation of volition (actional phase). Finally, the post-actional phase involves evaluating whether further goal pursuit is necessary and worthwhile, and then this evaluation provides feedback to motivation. In summary, volition can be considered a mediating factor of motivation, and the post-action phase is similar to the cognitive evaluation proposed in the ARCS model by Keller (1987). In addition, Astleitner and Wiesner (2004) indicated that in a multimedia environment, the instructional strategies proposed using the ARCS method can support self-regulated (Zimmerman, 1998) learners in various phases. However, multimedia elements can enhance the level of reality in the learning environment.

The limitation of the ARCS model developed by Keller (1987) is that it cannot describe how information processing elements are integrated into the learning process and how motivation interacts with information processing elements. Information processing theory and its applications (Mayer, 2001) also fail to consider motivational factors. Based on studies conducted by Keller (1987) and Mayer (2001), Astleitner and Wiesner (2004) proposed a model that integrates information processing and motivation, including motivational processing and elements of mental resource management. This model facilitates investigation of the interaction between cognitive and motivational elements in the learning process. The concept underlying information processing theory is cognitive load (Paas et al., 2003), which refers to the amount of information in working memory that a person is capable of processing. Cognitive load is comparatively more challenging to manage during multimedia-based instruction because various stimuli, such as hot links, Internet excursions, and problems such as "seductive details" and "lost in hyperspace," may occur in GBLEs (Deimann & Keller, 2006).

Researchers investigating cognitive loads must confirm the motivational influences of instructional conditions and verify strategies for maintaining student focus when using learning materials (Paas, Tuovinen, van Merrienboer, & Darabi, 2005). The MVP model in Fig. 2 shows that motivation and cognitive load are variables that influence learning and performance.

Research purposes

Based on the preceding discussion, this study aimed to address the following questions:
- What DGBL design method can be employed to apply various game characteristics that match the motivational strategy procedures?
- Do empirical relationships exist between motivation, cognition, and performance in DGBL, as suggested in Keller's MVP theory (Keller, 2008)?

Methods

Online DGBL (operating a small factory using computer-aided manufacturing (CAM; OSF-CAM)

Computer-aided design (CAD)/CAM has become the primary industrial production type and a leading course for mechanical and industrial design departments at universities. Dankwort, Weidlich, Guenther, and Blaurock (2004) indicated that students should acquire the ability to use CAD and CAM abilities when at university. Employing such techniques and technology facilitates the manufacturing of models designed by students of design education.

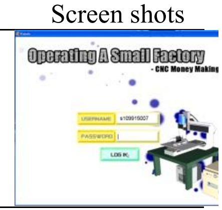
OSF-CAM design methods build on the game characteristics and ARCS model (Keller, 1987) to enhance student learning motivation using the systemized instructional strategies shown in Table 2 and the game characteristics employed in various design strategies, as shown in Table 3. Regarding the design procedure, three corresponding ARCS subcategories were first adopted, then matching game characteristics were analyzed (Table 2) and applied to DGBL design (Table 3). Finally, multimedia research effects (Mayer, 2001) were integrated. This process can reduce extraneous cognitive loads, enable learners to establish schema through assimilation and accommodation, and increase germane cognitive loads.

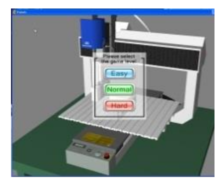
Table 2. Keller's ARCS vs. game characteristics

Categories	Subcategories	Game characteristics	Description
Attention	Perceptional arousal	Multimodal presentation and story, fantasy, and fun	Digital games are designed with effects such as rich pictorial and auditory variations and using multimedia characteristics to induce players' curiosity. In addition, the use of story contributes to various types of knowledge learning.

	Inquiry arousal	Problem solving, conflict/competition/ challenges/opposition, and role-playing	Games possess exploratory and experiential factors that correspond with constructive learning, assisting learners in resolving problems. Role-playing prompts participation (Huang & Johnson, 2008). Attempting to solve problems in the game and maintaining the level of conflict, competition, challenge, or opposition can balance the game.
	Variability	Fun, challenges, and curiosity	Including varying plots and tasks can increase the fun and challenge of the gaming process and incite learners' curiosity through learning contents to sustain their attention, thereby stimulating their motivation for continuous participation.
Relevance	Familiarity	None	This learning system adopts the following two strategies to compensate for the insufficiency of familiarity: (a) introduction of product model examples from the completed CAD course, and (b) designing objects in the game using 3D virtual machines for realistic simulation.
	Goal orientation	Tasks, goals	In the game tasks, including tasks that accumulate toward achieving game goals, learners are often required to undertake a series of tasks to complete the final goal of the game (Huang & Johnson, 2008).
	Motive matching	Goals, interaction, and sense of winning or achievement/win state	Goals give us motivation. Playing with others is fun and helps a player become involved in a community. Losing and winning have strong emotional and ego-gratification influences (Prensky, 2007).
Confidence	Learning requirements	Rules	Specific game rules and limitations show students criteria for achieving certain goals (Garris et al., 2002).
	Success opportunities	Adaptively, challenges, and competition	Providing various learning tasks with adequate difficulty levels while maintaining the challenge and competition of the game can arouse users' competitive intentions and guarantee success for everyone. DGBL can attain individualized learning goals (Deubel, 2006).
	Personal control	Control, play, interactive situations	Digital games constitute interactions between humans and machines, presenting players with a sense of performing actions. Play provides a strong and passionate sense of participation. Game actions also enhance a part of the learner's sensory control (Malone & Lepper, 1987).
Satisfaction	Natural consequences	Sense of winning or achievement/win state	When learners successfully complete tasks and accumulate scores, the sense of winning naturally induces a sense of achievement.
	Positive consequences	Outcomes and feedback	Designs where adequate feedback is obtained immediately following a key operation or decision can strengthen active interaction.
	Equity	Rules	Users must play the game using the same rules, and their scores for completing tasks must be identical.

Table 3. Game characteristics applied in various design strategies

Design strategies	Description	Game characteristics	Screen shots
Story-based gaming processes and goals	In the game, users act as a factory operator. Accumulating profits using the production model is the user's goal.	Goals, play, fun, and multimodal presentation and story	

Role-playing	Users can select the character they desire in the beginning of the game, and generating a sense of identification with the character they like.	Multimodal presentation and story, curiosity, and role-playing	
Learning task design	Game goals are presented using five tasks. The model style and difficulty required for each task varies. The virtual capital obtained when the model is completed increases with the difficulty level.	Problem solving, challenge, rules, and tasks	
Score accumulation design	Whenever a player completes a task, the player obtains profit corresponding to the task's difficulty. However, if an incorrect operation occurs during the completion of a task, the obtained profits decrease.	Competition, win state	
Real-time display design	Our system applied health points to show real-time profits. The reward or monetary amount obtained in each task is directly proportional to the number of correct operations.	Outcomes and feedback, challenges, and competition	
Time-limited game design	In the "aiming for the workpiece original point" phase, a timed game was designed to stimulate a sense of fun. The player operates the CNC platform to aim for the workpiece original within the time limits. Before playing the game, the player can select the difficulty level. Although harder levels possess shorter time limits, the profits for completing the game are more heavily weighted, thereby inducing the win state.	Control, challenges, outcomes and feedback, win state, adaptively, interactive, play, and fun	
Online updating design	The server side performs online updates, such as the percentage of correctly manufactured models and the number of completed models. In addition, the system shows the top five players that have earned the most capital, creating competition and interaction between players.	Outcomes and feedback, competition, win state, and interaction	
Humorous dialogue	Appropriate and timely feedback is presented with the character's humorous dialogue.	Fun, role-playing	
Exaggerated design	Feedback from the operating outcomes for height correction during the work piece original point phase is presented using sound effect and visual effect in dual models.	Fantasy, outcomes and feedback, and control	

Real contexts and scenarios	After the learner successfully completes all operations, the audiovisual record of a real CNC machining process for their model is presented online.	Interactive, outcomes and feedback, and win state	

The OSF-CAM game used in this study included a CAM game-based module (Fig. 3) and a CAM multimedia module (Fig. 4; Figs. 3 to 5 are screenshots). The CAM multimedia module enables users to understand background knowledge of CAM and its operating procedures, such as the effects of cheats, which can enhance game-based learning (Royle, 2008). OSF-CAM was designed according to multimedia cognitive load theory (Fig. 1) proposed by Mayer (2001) and the game characteristics applied in Keller's ARCS model (Tables 2 and 3). Strategies for reducing learners' cognitive loads include pretraining, signaling, segmenting, aligning, synchronizing, and weeding. For example (as shown in Fig. 5), the planning of machining cutting tools is performed using shot representation to increase the dynamic effects and sense of presence during operations in the predesigned interface. First, the lens was rotated left and zoomed in to present the complete installation of the first cutting tool (Step 1). Subsequently, Steps 2 (rotated right and zoomed out) and 3 (complete installation of tools) were performed. According to the principles of synchronizing and weeding, the designed operating interface was modified using a single perspective and appropriate zooming out techniques (to streamline the steps). The complete dynamic process of planning and installing all tools was fully demonstrated from this perspective, excluding the processing of presentational holdings. This operational practice enables learners to determine how to perform tool planning correctly, including the suitable sizes and types of cutting tools to select and the appropriate arrangements of the positions and sequences of the tools. Because the CAM course content involves complex learning, we introduced pretraining to help students understand the relevant background knowledge and technical terms before using the game-based learning module. In addition, bite-sized segments were adopted as the principle for presentation design (Mayer, 2001; Squire, 2005).

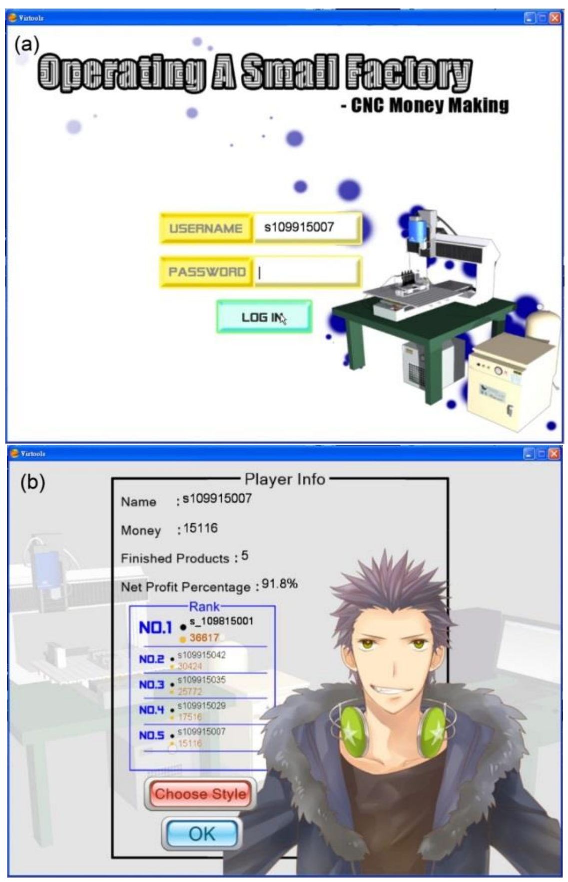


Figure 3. CAM game-based module: operating a small factory, (a) portal page of the online game, (b) player appearance and relevant information

Figure 4. CAM multimedia module, (a) CAM module, (b) CNC module

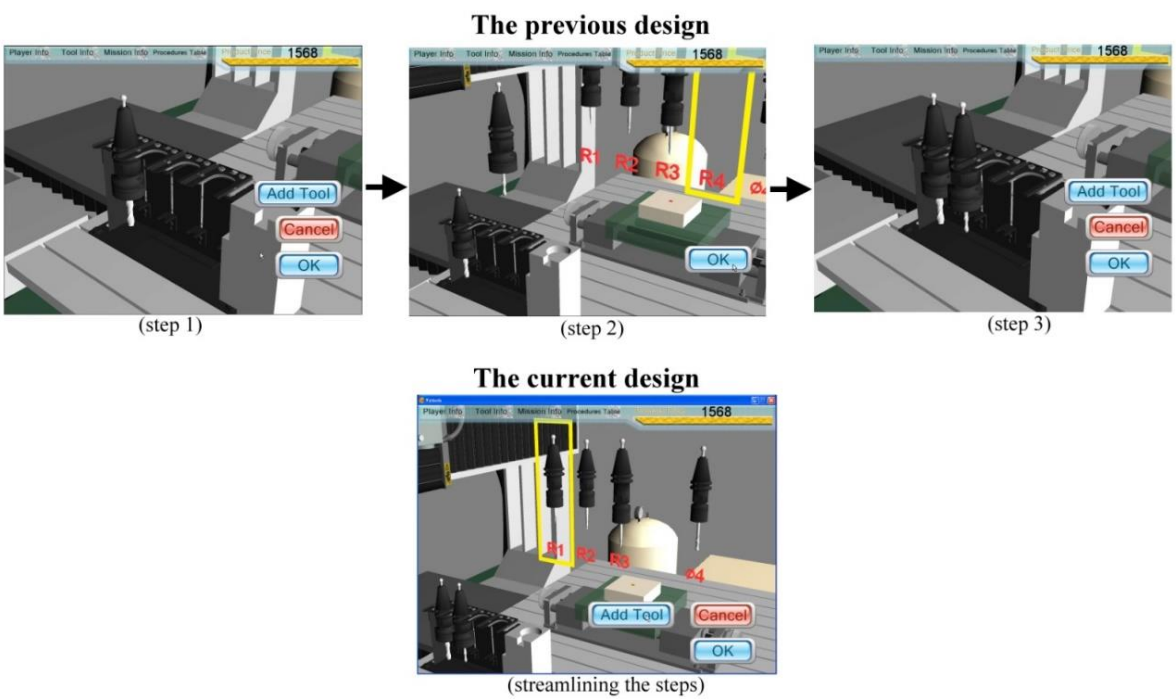


Figure 5. Application of the synchronizing and weeding principles

Users log into the game online through the webpage browser. Learners can examine the CAM multimedia module (Fig. 4) to learn the background knowledge and operating procedures relevant to CAM. Next, learners enter the

CAM game-based module, as shown in Fig. 3. When an authorized user logs into the game, the server mode is activated (this updates the use contexts and online scores and shows the score rankings). Learners can begin to play the game by manufacturing process simulation of easy or complex models, depending on their personal abilities.

Data collection

CAM course instruction was provided for 3 h every week. The participants were second-year university students of the Department of Art and Design. The study researcher lectured on course-related matters for 8 weeks and provided the OSF-CAM to guide learning. Student responses were measured after completing the game training. At the end of the course, 63 sets of valid responses (from 48 females and 15 males, aged between 19 and 21 years, mean = 20.12, standard deviation (SD) = 0.47) were employed for data analysis.

Motivation measurement

Measurements of learning motivation were based on the IMMS and comprised the subscales of attention, relevance, confidence, and satisfaction. A symmetric 9-point Likert scale containing 36 items was used, with 12 items for attention, 9 items for relevance, 9 items for confidence, and 6 items for satisfaction (Keller, 2010, pp. 283-284). Minor modifications were incorporated to accommodate the DGBL setting (i.e., replacing "this lesson/material" with "OSF-CAM"). The Cronbach's α for each subscale was .852, .819, .818, and .801, respectively, with 63 samples, and that for the overall survey was .914. All of the subscale Cronbach's α values exceeded .8, confirming the high reliability of the tests used in this study.

Measurement of cognitive loads

The sum of extraneous and germane cognitive loads is assumed to be equal to the total cognitive load deducted from the intrinsic cognitive load. Because intrinsic cognitive loads cannot be manipulated using instructional intervention approaches, the primary purpose of instructional designs is to construct the optimal combination of extraneous and germane cognitive loads (Huang, 2011). Inappropriate instructional designs generally generate relatively higher extraneous loads but, nevertheless, leave sufficient room for learners to individually decide how much germane load they want to invest (Cierniak, Scheiter, & Gerjets, 2009). The germane cognitive load is the effective cognitive load, which demonstrates the efforts that learners invest in learning (Kalyuga, 2009).

Salomon (1984) reported that students' perceived self-efficacy regarding learning material is significantly and positively correlated to their mental efforts and learning achievements. Because increased mental effort can enhance learning outcomes, mental effort appears to be correlated with germane cognitive load during the learning process. Both subjective and physiological measurements are non-interference measurements; however, mental effort measurements yield comparatively higher reliability and sensibility (Paas et al., 2003). Therefore, subjective mental effort measurements can be used as the main indicator for measuring learners' overall cognitive loads and evaluating their differing cognitive loads. In addition, concentration is considered active content, and can replace neutral "mental effort" learning conditions. Concentration in the learning process reflects the student's attention, is a cognitive ability required for various processes relevant to learning, and represents the schema for success (Cierniak et al., 2009). Consequently, the germane load scale is represented using the item "how much did you concentrate during learning?" Similar to the methods adopted by Ayres (2006) and Cierniak et al. (2009), the intrinsic load scale involves obtaining learners' self-evaluations regarding the perceived difficulty of the learning content by using the item "how difficult was the learning content for you?" Learning content with high difficulty may lead to low learning outcomes, and relatively higher concentration during the learning process may generate superior learning outcomes, which indicates a possible learning performance relationship. In this study, the use of germane and intrinsic load scales involved adopting symmetric 9-point Likert scales.

Performance measurements

The CAM cognitive scale

This study used six cognitive levels, specifically knowledge, comprehension, application, analysis, synthesis, and evaluation (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956), as the scope of the cognitive domain, and established a two-way specification table with which the pretest questionnaire items were determined. Subsequently, three CAM experts reviewed the items before completing the pretest questionnaire (35 items). We distributed the pretest questionnaires to 39 third-year university students of the Department of Art and Design who had completed a course in CAM. The item difficulties ranged from .2 to .8 with a discrimination of larger than .25 set as the criterion for selecting items. Subsequently, 24 items with a Kuder-Richardson reliability of .817 were retained. The completed scale is presented as Appendix A.

The CAM skill scale

The CAM skill scale was devised according to the course content and learning goals, and comprised items for (a) programming: planning suitable process types and cutting tools (including selecting suitable sizes and types of tools, and arranging the sequences of tools) and setting machining parameters (cutting-in amount, cutting interval, feed rate, etc.); (b) machining: setting up workpieces, machine settings, and machine operations. Three CAM experts reviewed the scale, and 5 third-year university students who had completed a CAM course implemented the model. The average time required to complete the model was 121.2 min (the working time included the programming and machining time), and the scale is presented as Appendix B.

Results and discussion

Learning motivation

Table 4 lists the students' responses regarding the ARCS motivation scale, for which the mean of the relevance subscale was the highest (6.37) and that of the attention subscale was the lowest (5.77). The means of the confidence and satisfaction subscales were 5.90 and 6.05, respectively. In addition, all of the motivational subscales attained standard deviations ranging from .67 to .78. The mean of overall learning motivation was 6.02. Although game characteristics, such as fun, fantasy, curiosity, and role-playing can attract learners' attention, they are not necessarily directly relevant to learning. Therefore, Royle (2008) indicated that although actual learning occurs in the game, a certain portion of the game content must be external to the course to maintain game value. Digital games that contain multimedia features can be designed to attract players' attention. However, Mayer (2001) contended that including appealing animation, which constitutes external materials, can increase learners' cognitive loads. Consequently, this study suggests using the weeding strategy to resolve this problem, which can lead to the coherence effect. When extraneous but interesting materials are excluded, students can interpret multimedia-based explanations more clearly. However, reducing the number of extraneous but interesting materials weakens learners' attention. This may be why attention received the lowest points among the four motivation subscales of the developed game. However, the attention value exceeded the median, primarily because the developed game retained the fun and curiosity designs attracting learners' attention to a considerable degree. Previous studies have indicated that certain forms of cognitive load are desirable for prompting and enriching the challenge of a game (Ang, Zaphiris, & Mahmood, 2007).

Regarding the lack of corresponding game characteristics for the relevance subscale, this game involved adopting the following two design strategies (as shown in Table 3): (a) familiarity with product model examples, and (b) realistic simulation. Multimedia elements can enhance the degree of reality in learning environments to increase the familiarity of the learning environment (Astleitner & Wiesner, 2004). Furthermore, the relevance of learning environments can be increased by integrating students' previous experiences. This may be the reason that the mean of the relevance subscale attained the highest score.

The mean of the confidence subscale (5.90) was only slightly higher than the value of the attention subscale. The reason may be, as indicated by Squire (2005), conventional school-based professional knowledge acquisition cannot be realized by successful students in a game-based learning environment. Such students do not believe that game-based learning can benefit their performance in college entrance examinations or university classrooms. The mean of the overall motivation scale was 6.02, indicating that OSF-CAM stimulates students' learning motivation.

Table 4. Descriptive statistics of motivation and all variables

Item	N	Mean	SD/(CV)
Attention	63	5.77	.67
Relevance	63	6.37	.70
Confidence	63	5.90	.78
Satisfaction	63	6.05	.72
Average of total ARCS	63	6.02	.55
Germane cognitive load	63	5.98	1.33
Intrinsic cognitive load	63	5.51	1.73
Cognition of CAM	63	60.98	15.58/(.26)
Working time (Completion times of operation)	63	111.84 (min.)	27.04/(.24)

Cognitive load

In the students' self-evaluated reports of cognitive load (shown in Table 4), the mean/SD of the germane and intrinsic cognitive loads were 5.98/1.33 and 5.51/1.73, respectively. The intrinsic cognitive load reported by the learners suggests that the CAM course is a learning domain with a slight to moderate level of difficulty for students, whereas the SD (1.73) shows that learners possess individual differences. The mean of the germane cognitive load was 5.98. Germane cognitive load increases learning effectiveness and creates relatively more profound learning experiences (Kalyuga, 2009), indicating that the proposed game-based learning design positively affects learning enhancement. However, the results were not sufficient in showing that the learners had learning experiences that were more significant in higher-order cognition and skills. Therefore, although games are an effective learning tool (Papastergiou, 2009), multiple researchers have contended that game-based learning is an instructional approach that complements only conventional methods (Royle, 2008).

Performance

The mean and coefficient of variation (CV) of students' cognitive performance were 60.98 and .26, respectively. The working time to complete model manufacturing represents the student's skill performance. The mean and CV of the student's skill performance were 111.84 min and .24, respectively. CV is independent of the unit. To compare data sets with differing units, the CV should be employed instead of the SD. Therefore, the CVs of cognitive performance and skill performance reflect the similarity in the degree of group dispersion. These performances are shown in Table 4.

Canonical correlation analysis of motivation, cognitive load, and performance

Table 5 lists the canonical correlation test results. In the DGBL of this study, motivation and cognitive load exhibited a significant canonical correlation with performance (Dimension 1, $p < .05$). Dimension 1 showed that the two sets of variables possessed a canonical correlation of .446, and that learning motivation and germane cognitive load positively influenced skill and cognitive performance (i.e., substantial learning motivation and germane cognitive load result in comparatively shorter working times and greater cognitive achievements). Intrinsic cognitive load negatively influenced cognitive performance and had a directly proportional influence on the working time. Table 6 lists the canonical correlation analysis results of this study; the first canonical variable χ_1 in Set X (canonical loadings -.446, -.263, and .776) explains 39.8% of the variance in motivation, germane cognitive load, and intrinsic cognitive load. The first canonical variable η_1 of Set Y (canonical loadings: -.638, .505) explains 76% of the variance in cognitive performance and skill performance. The independent variables of motivation, germane cognitive load, and intrinsic cognitive load in Set X can explain 15.1% of the variance in the dependent variables of cognitive performance and the skill learning performance in Set Y. A path diagram of the canonical correlation is shown in Fig. 6, in which motivation and germane cognitive load positively influenced skill and cognitive performance. This means that substantial motivation and germane cognitive load result in comparatively shorter working times (i.e., superior skill performance) and higher cognitive scores. Intrinsic cognitive load negatively influenced cognitive performance and had a directly proportional influence on the working time. This study verified that motivation and cognitive load are latent factors that influence performance in DGBL, as suggested in Keller's MVP theory.

Table 5. Test of canonical correlations

Dimension	Canonical correlation	Wilk's	Chi-sq	df	p-value
1	.446	.796	13.432	6	.037
2	.080	.994	.377	2	.828

Table 6. Canonical correlations

	Canonical loadings χ_1/η_1	
Independent variables (set X)		
Motivation	-.446	
Germane cognitive load	-.263	
Intrinsic cognitive load	.776	
Variance extracted		.398
Redundancy index		.079
Dependent variables (set Y)		
Cognitive performance	-.638	
Working time (skill performance)	.505	
Variance extracted		.760
Redundancy index		.151

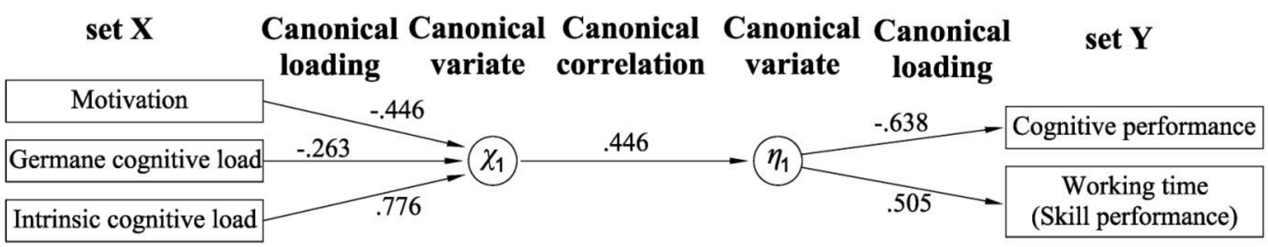


Figure 6. Path diagram of the **c**anonical correlation

Conclusions

OSF-CAM digital learning games were completed by applying game characteristics that matched the ARCS motivational strategies and integrating multimedia research effects (Mayer, 2001). The results verified that CAM skill and cognitive learning can cultivate learner motivation in the aspects of attention, relevance, confidence, and satisfaction, and can increase germane cognitive loads. In addition, a significant relationship exists in the first dimension of the canonical correlation analysis for motivation, germane cognitive load, and intrinsic cognitive load related to cognitive performance and skill performance. Motivation and the germane cognitive load are proportional to cognitive performance and skill performance (shorter working times), whereas the intrinsic cognitive load is inversely proportional.

In summary, this study proposes a systematic DGBL design method that applies game characteristics that match the ARCS motivation strategy and integrates Mayer's multimedia research effects. Based on the research results, when designing DGBL, designers should increase motivation and germane cognitive load to enhance learning effectiveness. In addition, the attention component must be compromised; however, relevance, satisfaction, and confidence do not conflict. For example, nonlinear presentations of textual information may increase learners' cognitive load (Zumbach & Mohraz, 2008), and animated instructional messages may necessitate additional cognitive processing capacity from learners (Ayres & Paas, 2007). Both nonlinear presentations of textual information and animated instructional messages commonly feature in GBLEs because they attract learners' attention and enhance their motivation; however, they also present ineffective cognitive loads. Furthermore, the experiment results confirmed that learners' learning motivation, cognitive load, and performance possess latent correlations in DGBL, as suggested in Keller's MVP theory. This is a case study for exploratory purposes. Future research with a larger sample size might be able to identify significant correlations in DGBL.

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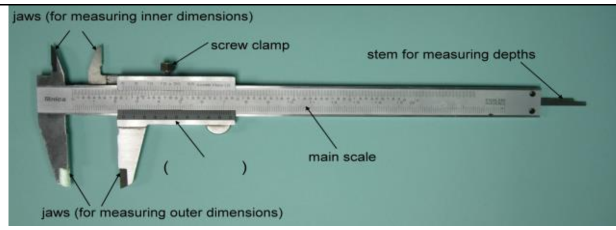
Appendix A. The CAM cognitive scale

items	content	categories
1	The feed rate is ① feed amount per revolution × revolutions per minute (rpm) ② feed amount per revolution ÷ rpm ③ cutting depth × feed amount per revolution ④ cutting depth ÷ feed amount per revolution.	C2
2	If the milling depth increases, the axial rpm should ① increase ② decrease ③ remain unchanged ④ increase proportionally.	C3
3	The common unit for the feed rate of a CNC mill is ① mm/min ② mm/rev ③ rps ④ rpm. 。	C2
4	Generally, the 3D modeling file format that can be loaded into computer-aided manufacturing (CAM) software for tool path planning is ① .igs ② .stl ③ both of the above ④ none of the above.	C3
5	During general roughing, the machining parameters must set the cutting-in amount, tool path cutting interval, and ① finish margin ② tool length ③ machining time ④ all of the above.	C2
6	The cutting speed of the milling should be reduced under the condition of ① finishing ② the blade being worn within an acceptable range ③ disregarding the life of the milling cutter ④ softer workpieces.	C6
7	When milling using an end mill, which of the following is not the reason for abnormal vibrations? ① overly long shank ② overly short shank ③ insufficient rigidity of the mill shank ④ overly thin shank.	C6
8	When milling, which of the following is not the reason for cutting vibrations? ① excessive milling depth ② unfixed workpiece ③ tool wear ④ insufficient feed.	C6
9	When milling workpieces using an end mill 50 mm in diameter at a milling speed of 30 m/min, the axial revolution speed should be ① 150 ② 170 ③ 190 ④ 210 rpm/min.	C4
10	Which of the following end milling conditions is wrong? ① The tool rotations decrease as the diameter increases ② The tool rotations increase as the diameter increases ③ The tool diameter increases with increased cutting depth ④ The tool rotations increase when the roughing changes to finishing.	C3
11	When clamping a workpiece using a mill clamp, we found that the workpiece moves upward and cannot adhere closely to the parallel block. Which of the following is improper? ① loosening the mill clamp and hammering the workpiece downward using a soft hammer ② clamping the workpiece using pressure wedges ③ hammering the workpiece downward using a sledge hammer ④ adjusting the chute clearance of the mill clamp moving jaw.	C6
12	When should the tool length be corrected again? ① after completing the model machining ② when resuming suspended machining ③ when replacing damaged cutting tools or maintaining the tools ④ all of the above.	C6
13	Regarding the CNC milling operation of a Roland MDX650, when implementing workpiece original point settings for a workpiece, what approach should be adopted to move cutting tools closer to the workpiece when they are already approaching the workpiece? ① moving button on the X and Y axes ② up and down moving button on the Z axis ③ hand wheel ④ all of the above.	C3
14	When performing the workpiece original point settings, the original point is ① set individually according to the model characteristic ② must be consistent with the workpiece original point set in the tool path of CAM software ③ can be set randomly ④ none of the above.	C2
15	To temporarily halt tool movement during program operations, we should press ① the emergency stop switch ② the reset button ③ the pause switch ④ the cutting feed rate adjustment button, adjusting to 0%.	C1
16	During milling, when the diameter of a cutting tool is small, the axial rpm should be ① higher ② lower ③ unchanged ④variable.	C3
17	If the cutting speed is 75 m/min, with a milling cutter diameter of 80 mm, the milling cutter rpm is ① 258 rpm ② 298 rpm ③ 358 rpm ④ 398 rpm.	C4

18	The common ψ10 end mill is not suitable for milling ① R4 rounds ② a level of 11 mm ③ groove widths of 12 mm ④ R4 fillets.	C5
19	Which of the following tool or cutting tool materials possesses a higher toughness? ① high speed steel ② tungsten carbide ③ ceramic ④ diamond.	C1
20	Take 19 mm from the main scale of the vernier caliper and divide it into 20 intervals on the vernier scale. The minimum reading of the vernier caliper is ① 0.01 ② 0.02 ③ 0.05 ④ 0.10 mm.	C4
21	 The graph above shows the name of each part of a vernier caliper. The name of the ( ) is ① sliding scale ② vernier scale ③ caliper ④ moving scale	C1
22	The parallel blocks used for the mill clamp generally comprise ① 1 ② 2 ③ 3 ④ 4 blocks in each set.	C1
23	When determining the margin of workpieces using a piece of thin oily paper, feeding is terminated immediately after the piece of thin paper is scratched off by the milling cutter. Which of the following actions should be conducted as the next priority? ① return this axis scale to zero ② eject the milling cutter from the workpiece ③ add cutting fluid to prepare for milling ④ cut off the power.	C5
24	When determining the workpiece margin using a thin paper 0.07 mm in thickness, if the drill bit diameter is 5 mm and the distance between the intended hole center and the margin is 20 mm, the table moving distance should be ① 22.57 ② 25.07 ③ 17.57 ④ 15.07 mm.	C5

C1/ knowledge, C2/ comprehension, C3/ application, C4/ analysis, C5/ synthesis, and C6/ evaluation

Appendix B. The CAM skill scale