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A constructionism framework for designing game-like learning systems: Its effect on different learners

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Abstract

Game-like learning systems such as simulation games and digital toys are increasingly being applied to foster higher-level abilities in educational contexts, as they may facilitate an active learning experience. However, the effect of such game-like learning systems is not guaranteed because students may only be interested in the fantasy interfaces and the elaborate scenarios, rather than in the learning tasks. In this vein, the study presented in this paper addresses this issue from the perspective of constructionism. A design framework based on constructionism, which highlights the principles of construction as the goal, low-threshold–high-ceiling and computer simulation is proposed for designing game-like learning systems. An evaluation was conducted to investigate the influence of the framework on the flow experiences and learning strategies of different students. The results of this study show that computer simulation is an integral component to promote exploratory learning activities. The results of this study also indicate that the framework was particularly helpful for those students with low background knowledge in balancing challenge and skill perceptions. For those students with middle and high level background knowledge, it also promoted the learning experience by either reducing the challenge perception or promoting the skill perception. Such findings suggest that the constructionism framework is a particularly important design guideline to engage students of different levels in active learning activities.

Introduction

Game-like learning systems, such as simulation games and digital toys, are now increasingly being applied to foster higher-level abilities in educational contexts (Kim, Park & Baek, 2009; Tan & Biswas, 2007). Such systems is applied to engage students in a joy emotion in which students are more likely to accept challenges and stretch their capacity through learning experiences until a successful outcome is reached (Fisher, 1998; Heywood, 2005). On the one hand, game-like learning systems can become an interactive question/answer platform to engage students in gaining basic knowledge. Many games are thus developed as a platform to motivate students to learn. For instance, the game Age of Computers (Sindre, Natvig & Jahre, 2009), which presents a rich set of problems of computer fundamentals with a game scenario, can be used to conduct question/answer activities to promote students' fundamental problem-solving knowledge. On the

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Practitioner Notes

What is already known about this topic

- Computer games are increasingly being applied to foster higher-level abilities in educational contexts.
- Learning with a game is sensitive to individual differences.

What this paper adds

- A game design framework based on constructionism is proposed to illustrate how low-threshold–high-ceiling principle and computer simulations may be used to help students of different levels learn with games.

Implications for practice and/or policy

- Computer simulation is an integral component to promote exploratory learning activities.
- The constructionism framework was mostly helpful for those students with low background knowledge in balancing challenge and skill perceptions.
- The low-threshold–high-ceiling principle is a particularly important design guideline to engage students of different levels in active learning activities.

other hand, game-like learning systems can serve as a tool to help students link abstract concepts to the concrete game experience. This is because the systems can provide students with an embodied problem context in which they can reflect on the learning tasks. For instance, the Leaping Frogs game (Lee & Chen, 2009) provides students with a visualized platform to help them exchange the positions of two arrays of objects (ie, the frogs). With such platforms, students can interactively apply and test problem-solving strategies to answer a given question. Such question/answer games provide interactive and fantasy interfaces for students to interact with knowledge, so that they can be attracted to gain the knowledge embedded in the systems.

Games may have multiple effects on learning. Kiili (2005) has argued that one of the prominent effects of games is that they can be a vehicle for engaging students in “flow” (Csikszentmihalyi, 1975, p. 36). Flow is considered as a useful construct for improving learning because a higher level of flow perceived by students is positively correlated with higher exploratory learning strategies (Trevino & Webster, 1992). For instance, the study by Liu, Cheng and Huang (2011) found that when students are in flow they are more likely to demonstrate in-depth learning strategies such as analytical reasoning and learning-by-example. However, the question/answer games have limitations in fostering both long-term motivation to learn and in-depth learning strategies. To facilitate students to learn in flow, Kiili (2005) argued that games must be designed based on a clear and challenging problem, and must provide facilities for students to reflectively observe the outcomes of actions performed to solve the problem. Such a loop of active actions and observation can lead to the construction of sophisticated knowledge structure, and enable the discovery of new and better solutions to the problem. Therefore, it has become imperative to understand how to integrate learning tasks into game-like learning systems to transform the learning activities into flow learning experiences.

In this vein, the study presented in this paper addresses the above design issue of game-like learning systems from the perspective of constructionism (Harel & Papert, 1991). Constructionism shares similar perspectives to constructivism. However, constructionism plays a distinct role in learning and instruction, and, as Papert pointed out that “*constructionism shares* *constructivism's connotation to learning as building knowledge structure irrespective of the circumstances of learning. It then adds the ideas that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity* (Harel & Papert, 1991)." Recently, constructionism has been increasingly applied to enhance problem-solving learning. For instance, many program development environments such as Scratch (Monroy-Hernández & Resnick, 2008), Alice (Dann, Cooper & Pausch, 2006), Tangible Programming Bricks (McNerney, 2004) and the Greenfoot system (Kulling & Henriksen, 2005), highlight several design principles, enabling them to construct applications by themselves. For instance, the low-threshold–high-ceiling principle addresses that the environments should enable novice students to easily participate in learning activities and allow them to work on increasingly complex products (Fischer, 2010). In addition, these environments also stress the importance of simulations in facilitating exploratory learning. Because constructionism adds several prominent learning and instruction principles to constructivism, this study investigates how these principles may be applied to design game-like learning systems and facilitate flow learning experience in game-based learning.

Previous study by Liu *et al* (2011) has investigated how a game-like learning system may influence flow experience. However, their analysis is mainly based on the specific system without a design framework that can inform how game-like learning system can be designed to enhance game-based learning experience. To this end, this study attempts to propose a design framework that stresses the importance of construction as the goal, low-threshold–high-ceiling, and computer simulations, for designing game-like learning systems. To understand the effectiveness of the framework, this study investigates how the proposed design framework may facilitate learning in terms of flow experience and learning strategies. In particular, learning with a game is sensitive to individual differences in various aspects (Cherney, 2008; Ke, 2008; Wang & Wang, 2008). Such differences may also affect the impact of game-based learning. Although the study by Liu *et al* (2011) has investigated how game-like learning systems may influence flow experiences, it is still not clear how they may influence the learning experience of different learners. This paper, thus, presents a follow-up study to investigate how the constructionism framework may influence the flow experience and learning strategies of students with different knowledge levels. More specifically, this study aims to answer the following research questions:

- How may the game-like learning system developed with the constructionism framework influence the challenge perception and skill perception of students with different background knowledge levels?
- How may the game-like learning system developed with the constructionism framework influence the motivation of students with different background knowledge levels?
- How do students with different background knowledge levels learn in the game-like learning system developed with the constructionism framework?

By answering the above questions, this study would explore how constructionism may be used to design game-like learning systems. In particular, this study would explore how three constructionism approaches, namely construction as the goal, low-threshold–high-ceiling and computer simulations, can be used as pedagogical guidelines in designing game-like learning systems.

The constructionism framework for educational game design

As mentioned in the previous section, game-like learning systems should be able to facilitate the application of in-depth learning strategies and foster long-term motivation. To address this issue, Garris, Ahlers and Driskell (2002) proposed a game-based learning model explicitly illustrating integral game features and game perceptions to enact active learning processes. This game-based learning model is widely used as a design framework for game-like learning systems (Belanich, Sibley & Orvis, 2004; Wilson *et al*, 2009) because it addresses both the motivation and process

Table 1: The design framework for game-like learning based on constructionism

Game design guideline	*Constructionism principle*	*Guideline for designing game-like learning systems/activities*
Enhancing motivation and persistent reengagement	Construction as the goal	Motivating students to learn by supporting them to build a product
Challenge and freedom	Low-threshold–high-ceiling activity	Enabling novice students to easily participate in, while allowing them to work on increasingly complex products
In-depth learning	Computer simulations	Supporting students to initiate and simulate ideas

aspects associated with games. According to this model, a game for learning should continuously present a motivating goal at an appropriate level of challenge where learners can have full control of their learning activity. Such a game can promote in-depth learning while interacting with it. Although the model of game-based learning exhibits critical antecedents of flow, how to address these integral guidelines in educational contexts is still not clear in the literature. Thus, this study extends the game-based learning model based on constructionism (Harel & Papert, 1991) as a framework to build game-like learning systems for supporting learning. The constructionism framework may promote the learning effect of games by enhancing the flow experience so that in-depth learning can be achieved. It is hoped that the game-like learning systems developed or applied based on the framework cannot only help students become immersed in the game scenario, but also engage them in active learning activities. The constructionism framework to promote flow experience in game-based learning is illustrated in Table 1.

Motivating students with a construction goal in game-like learning systems

In the game-based learning model proposed by Garris *et al* (2002), game-based learning is more effective when students consistently perceive it as interesting and are persistently motivated. This may be because students are more likely to experience flow when the game is of interest to them. Games that can promote such a flow perception can enhance persistent reengagement in which students "engage in target activities, they pursue those activities more vigorously, and they persist longer at those activities" (Garris *et al*, 2002). It is stressed in this model that a clear and challenging goal is an essential condition of games which enhance learning performance. This is because students who are given a clear goal in a game are more likely to be aware of the discrepancy between the goal and the current status so that their attention to and motivation for learning will be increased.

Constructionism may be applied to strengthen the above design guidelines by addressing construction as the goal. Harel and Papert (1991) advocated that learning is most effective in a context where students are to construct a product. Consequently, such a constructionism principle may be helpful in strengthening the educational effect of games by adopting a playing-to-construction design: players are to learn to build a product. With such a clear and specific goal, students are more likely to be motivated to regulate their learning process that can effectively achieve the goal in the game-like learning system.

Balancing challenge and skill perception via the low-threshold–high-ceiling principle

The game-based learning model proposed by Garris *et al* (2002) highlights the role of freedom, which refers to the ability to regulate, direct or command something, in promoting gamers' motivation and attention in the game. In addition, this model also addresses that a balance of perceived challenge and skill is an essential condition of flow by referring to flow theory (Csikszentmihalyi, 1975). In other words, game-like learning systems should afford students a high level of freedom so that they can regulate, direct or command their activity to achieve the challenging goal. This model suggests two guidelines for designing game-like learning systems. Firstly, game-like learning systems have to be an easy-to-participate-in activity so that students can freely carry out the learning activities. Secondly, the learning activity should afford a high level of freedom, with which the students can regulate their game-like learning process.

Constructionism principles may effectively address the above two guidelines, as it is argued that the learning activity should exhibit a low threshold but allow a high ceiling for developing complex abilities. Such a low-threshold–high-ceiling principle was initially coined to address the pedagogical guidelines for developing complex abilities (Burton, Brown & Fischer, 1984). More specifically, the low threshold of a learning activity enables novice students to easily participate in the activity, while the high ceiling allows them to work on increasingly complex products (Fischer, 2010). Previous studies have developed several innovative learning activities based on such a principle to engage users in learning with computers. For instance, manipulative robots have been proposed to address this issue. Logo (Turkle, 1995) and Tangible Avatars (Liu, Liu, Wang, Chen & Su, 2012), for example, provide facilities that simulate the actions that students may perform in the real world. With such facilities, novice students may intuitively understand the effect of their activities. As the students gradually build up sophisticated abilities, they can use the facilities to develop increasingly complex work. Due to the flexibility of such a principle, applying the low-threshold–high-ceiling principle in game-based learning activities may be helpful in balancing the perceived challenge and skill in a game-like learning system, and thus be more likely to promote a flow experience.

Facilitating in-depth learning with computer simulations

It is argued that games may facilitate in-depth learning when complicated events occur during gaming. For instance, the game-based learning model proposed by Garris *et al* (2002) considers debriefing as a critical learning activity of gaming experience. More specifically, while debriefing, students need to describe the events that occurred in the game, analyze why they occurred, and understand mistakes and corrective actions. Educators have indicated that computer simulations can facilitate in-depth learning as they support easy exploration, rapid experimentation and fortuitous combinations of ideas (de Jong, & van Joolingen, 1998). Constructionist's approach toward learning also utilizes such computer simulation as one of important means to enhancing in-depth learning while constructing a product (Shneiderman *et al*, 2006). As students can interactively initiate and test their ideas while constructing a product, they are more likely to be engaged in the learning activity. In the study by Liu *et al* (2011), they further found that students, with the support of computer simulations, are persistently motivated to apply trial-and-error, learning-by-example and analytical reasoning strategies to the construction of a system. Therefore, game-like learning systems should allow students to initiate and simulate ideas to persistently engage them in in-depth learning activities.

The above literature suggests that the constructionism principles may be helpful in enhancing game-like learning. On the one hand, they may be helpful in engaging students in flow in which they are in control of both the playing and the learning activities. On the other hand, they may also facilitate a discovery learning activity in which the students actively propose, test and self-reflect upon ideas to complete a product. Due to the aforementioned benefits, this study thus hypothesizes that the constructionism framework can enhance the game-based learning experience. An empirical study was conducted to confirm the hypothesis.

Method

Participants and the game-based learning activity

An empirical study was conducted to understand how students play and perceive a game-like learning system developed based on the constructionism framework. More specifically, this study explores the flow experience and the learning activities that they applied to build their product with the system. The participants were 117 first-year students from an engineering school in Taiwan. These students were enrolled in the "Introduction to Computer Sciences" course offered by the school. Among the 117 participants, 101 were male and 16 were female, because most students in engineering schools in Taiwan are male. The students used the system to learn basic algorithmic thinking skills such as conditions and iteration. After the teacher introduced the system, the students took part in developing a product with the system. The students had to apply algorithmic thinking skills to develop this product.

The learning activity lasted for 2 weeks. The students took part in the activity for 3 hours per week. Before the activity, the students had 1.5-month learning experience in traditional lectures during which the teacher lectured on algorithmic thinking skills and the students had to complete certain assignments. Therefore, their perceptions of learning in the traditional lecture and those associated with the system were compared. In particular, the students demonstrated significant variety in their background ability of programming in the traditional lectures. Therefore, this study explores how the students with different levels of algorithmic thinking skills perceived and learned with the system.

The game-like learning system

There are many types of game-like learning systems, and they may differ considerably from each other in their effect on learning. This study focuses on the design of game-like simulation learning environments. In such environments, "*the player discovers or forms goals within the simulation … . In order to reach these goals, the players must recognize problems and solve them from within the inside of the simulated world*" (Gee, 2005). Examples of such game-like simulation learning environments include SimCity where the players must plan, build, expand and manage a city within the simulation. Such environments may facilitate the achievement of educational objectives because they enable the players to test and analyze ideas. Therefore, this study developed a simulation environment, namely Train B&P (Train Build and Program it) based on the proposed design framework, in which students can construct a railway model with the simulation. This study then explored how the students played to learn with this environment.

Train B&P aims to help novice programmers learn algorithmic thinking skills including object-oriented concepts, conditions, iteration and object communication. Such skills have been highlighted as one of the critical contemporary competencies, because using computers to solve problems is becoming increasingly universal. (Borgman *et al*, 2008) The learning activity of Train B&P consists of two main parts. The first part is the model construction. The students can use several building blocks such as straight tracks, curved tracks, branch tracks and bridges to build a rail system, as displayed in Figure 1. They can freely drag these building blocks to create a railway model in a 3D environment. Such a model building activity resembles the railway model construction game that has been widely played and supported by many commercial toys such as Tomica and Hornby railway models. Secondly, the students can plan and build the behavior of the railway model by writing program code. For instance, they may make the train in Figure 1 go three rounds and stop where it set off. To achieve this goal, they need to write program code to control the behavior of the train. The exclamation marks attached to the objects in Figure 1 show that a student has written program code to govern the behavior of that object. For instance, program code in Figure 1 was attached to the track in (3) to signal a break command to the train if it has completed three rounds of the track.

Train B&P allows students to construct a railway model and design the transportation behaviors of the trains by using simple computational instructions. How the constructionism framework was applied to design the game is described below:

```
begin
int count=0;
while(true)
{
  if(TrainPassMe()){
count++;
print (count);
}
 if(count==3){
train0.Break(30);
print "Train0 Break[30]";
print("Train is
stopping");
}
}
```

The program governs the behavior of the track in (3)

Figure 1: The Train B&P design based on constructionism

- Construction as the goal: Previous study by Kafai (2006) has applied the constructionism principles to enhance game-based learning. More specifically, students in her study were provided with greater opportunities to construct their own games that help others learn a specific topic. To achieve this goal, students have to understand the knowledge associated with this topic. However, the study of this paper focuses on the framework that can be applied to design game-like learning systems in which students are to construct a product. In other words, the students involved in this study did not design a game. Instead, they used Train B&P to construct a rail model. The underlying model of the game-like learning system is that of a physical railway building game. In such games, students build a railway model. With such a clear goal in mind, they may be more likely to actively learn the algorithmic thinking skills and think scientifically for generating a railway model.
- Low threshold and high ceiling: Train B&P provides a manipulative interface in a 3D environment for students to design their rail systems. More specifically, the students can use several building blocks such as straight tracks, curved tracks, branch tracks and bridges to build a rail system. They can freely drag these building blocks to create a railway model in the 3D environment. Because such an interface resembles the manipulative building blocks of a physical toy, its threshold to construct is quite low. In addition, students can easily develop a railway model and then press the "g" key to start a train and see how it goes around the track. Therefore, novice players can easily design a simple railway model with the game. Meanwhile, the students may also use these building blocks and program code to build complex railways. The game supports a simple set of Jave-like program statements. More specifically, the statements include basic algorithmic constructs such as value assignment, looping, conditionals and object communications. With the environment, the students can build a complex railway model; for instance, one which includes multiple trains. In such a model, sophisticated programming is needed to avoid collisions between trains. Consequently, the game provides a high ceiling whereby the students may freely construct their own sophisticated railway system.
- Simulation of ideas: Train B&P allows students to program the transportation behaviors of the railway model. In particular, they can simulate the programs in the 3D environment because

> Train B&P was developed with a physics engine. The physics engine could simulate physics phenomena, such as gravity, speed, acceleration and friction, to simulate the behavior of railway systems in the real world. Therefore, the students have to program the transportation behavior of the railway model according to their experience in the real world. For instance, when encountering an ascent, they have to increase the power of the train in the program so that it can climb up the ascent. On the other hand, they have to lower the speed of the train when rounding a curve in the track to avoid derailing. Therefore, they may generate and test their new ideas in order to build a workable railway model.

The students in this study are novice programmers who have only limited knowledge of algorithmic thinking skills. They have to learn these skills to build the railway model. Therefore, Train B&P provides a tutorial to assist them in gaining these basic skills. The tutorial contains descriptions of basic algorithmic thinking skills and some examples of railway models which exemplify the application of the algorithmic thinking skills used in building a railway model. The students can refer to the tutorial at any time when they have problems in developing their railway models.

Perceptions of challenge, skill and motivation

One of the goals of this study is to understand the learning experience associated with the game-like simulation learning environment. In particular, this study explores the students' motivation and flow experiences in traditional lectures and while playing with game-like simulation learning environment. The Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich, Smith, Garcia & McKeachie, 1991) was used to evaluate the students' motivation because it is widely used in educational contexts. The MSLQ contains eight questions using a 5-point Likert scale concerning the extrinsic and intrinsic motivations associated with learning. Example questions within the MSLQ include "In a class like this, I prefer learning tasks that really challenge me so I can learn new things" and "Getting a good grade in this activity is the most satisfying thing for me right now." The former may reflect the students' intrinsic motivation, while the latter may reveal their extrinsic motivation.

Based on Csikszentmihalyi's (1975) initial notion, flow is more likely to occur when a learner perceives a balance between skills and challenges. Thus, perceptions of skills and challenges have been widely used as a theoretically meaningful reference for the presence or absence of flow (Massimini & Carli, 1988; Novak & Hoffman, 1997). This study thus evaluated the students' skill/challenge perceptions using the probe proposed by Pearce, Ainley and Howard (2005). The probe contains two question items using a 5-point Likert scale that asks the level of "perceived skill" and "perceived challenge" regarding the learning tasks. The perceived skill and challenge were used in their study as primary data for measures of flow during a sequence of learning tasks. According to Csikszentmihalyi's (1975) flow model, when a learner perceives a balance of challenge and skill, she or he may experience flow. A learner may be in an anxiety state when she or he perceives higher challenge with lower perceived skill. On the contrary, lower perceived challenge with higher perceived skill may imply a boredom state. By using this probe, we may understand the likelihood that the students experienced flow. The probe was used before and after the game activity to obtain the students' learning perceptions associated with the traditional lectures and with the Train B&P.

Data analysis

The students' background algorithmic thinking skills before the game-based learning activity were categorized into three levels according to their test scores in the traditional lectures. More specifically, 23 students who obtained a score higher than $M + SD$ were considered as the high background knowledge students (where M is the mean score of all students and SD is the standard deviation). Thirty-nine students were regarded as low background knowledge students.

They received a score lower than *M-SD*. The other 55 students, who obtained a score between *M* + *SD* and *M-SD*, were the middle background knowledge students. The perceptions of the three student groups (namely, the high background knowledge group, the middle background knowledge group and the low background knowledge group) of the Train B&P and their learning behaviors were analyzed. It should be noted that not all of the students completed the whole learning activity. Thus, the number of participants involved in the following analysis is less than the above number. It is hoped that the analysis can reveal the influence of the game-like learning system on different students.

Results

Challenge and skill perceptions

Figure 2 illustrates the challenge-skill chart in the two settings. The results in Figure 2 involve 21 high, 51 middle and 38 low background knowledge students. According to Csikszentmihalyi's (1975) flow notion , the upper-left area represents an anxiety state in which students perceive a higher level of challenge than that of skill. On the contrary, the lower-right area indicates a boredom state. The diagonal represents an optimal state in which the perceived challenge matches the perceived skill and a flow experience may occur. It is shown in Figure 2 that all three student groups perceived an anxiety state when they learned in the traditional lectures. However, when they were learning with the game-like simulation, the perceived challenge matched the perceived skill. In other words, the students were more likely to experience a flow state with the game-like simulation. Although the simulation had a positive influence on their learning, it played different roles for the three student groups. Its effect for different students is detailed as below:

- High background knowledge group: The students thought the game did not cause significant difference in the challenge of the learning task. More specifically, the perceived challenge associated with the game-like simulation ($M = 3.52$, $SD = .81$) was not significantly different from that of the traditional lectures ($M = 3.71$, $SD = .85$; $t = .75$, $p > .05$). However, they considered that they were more skillful in learning with the game-like simulation than they were in the traditional lectures. They perceived a higher level of skill with the simulation ($M = 3.52$, $SD = .87$) than they did in the traditional lectures ($M = 2.71$, $SD = .78$; $t = 3.78$, $p < .01$).
- Middle background knowledge group: The students thought the game-like simulation did not cause considerable difference in their algorithmic thinking skills. However, it significantly reduced the level of challenge required to learn the skills. The perceived challenge associated with the simulation ($M = 3.49$, $SD = .61$) is significantly lower than that associated with the traditional lectures ($M = 3.84$, $SD = .64$; $t = 3.07$, $p < .01$).
- Low background knowledge group: The perceived challenge of this group reduced significantly ($t = 2.74$, $\mathrm{t} < .05$) as their perceived skill increased profoundly ($t = 4.78$, $p < .01$). Such results indicate that the students thought learning algorithmic thinking skills with the game-like simulation was not as challenging ($M = 3.45$, $SD = .72$) as it was in traditional lectures ($M = 4.0$, $SD = .93$) and they considered themselves to be more skillful in learning the algorithmic thinking skills with the game-like simulation ($M = 2.95$, $SD = .73$) than they were in traditional lectures ($M = 2.21$, $SD = .88$). The effect of the game-like simulation is thus particularly evident for the low background knowledge group.

The above results show that the game-like simulation may balance the challenge and skill perceptions of the three groups of students, but it has different impacts on the students with different background knowledge. Because a balanced level of challenge and skill is a critical antecedent of flow (Kiili, 2005), such results show that the game-like simulation may be helpful in promoting the flow experience. To further understand the students' learning experience in the two settings, the students' motivation was evaluated with the MSLQ.

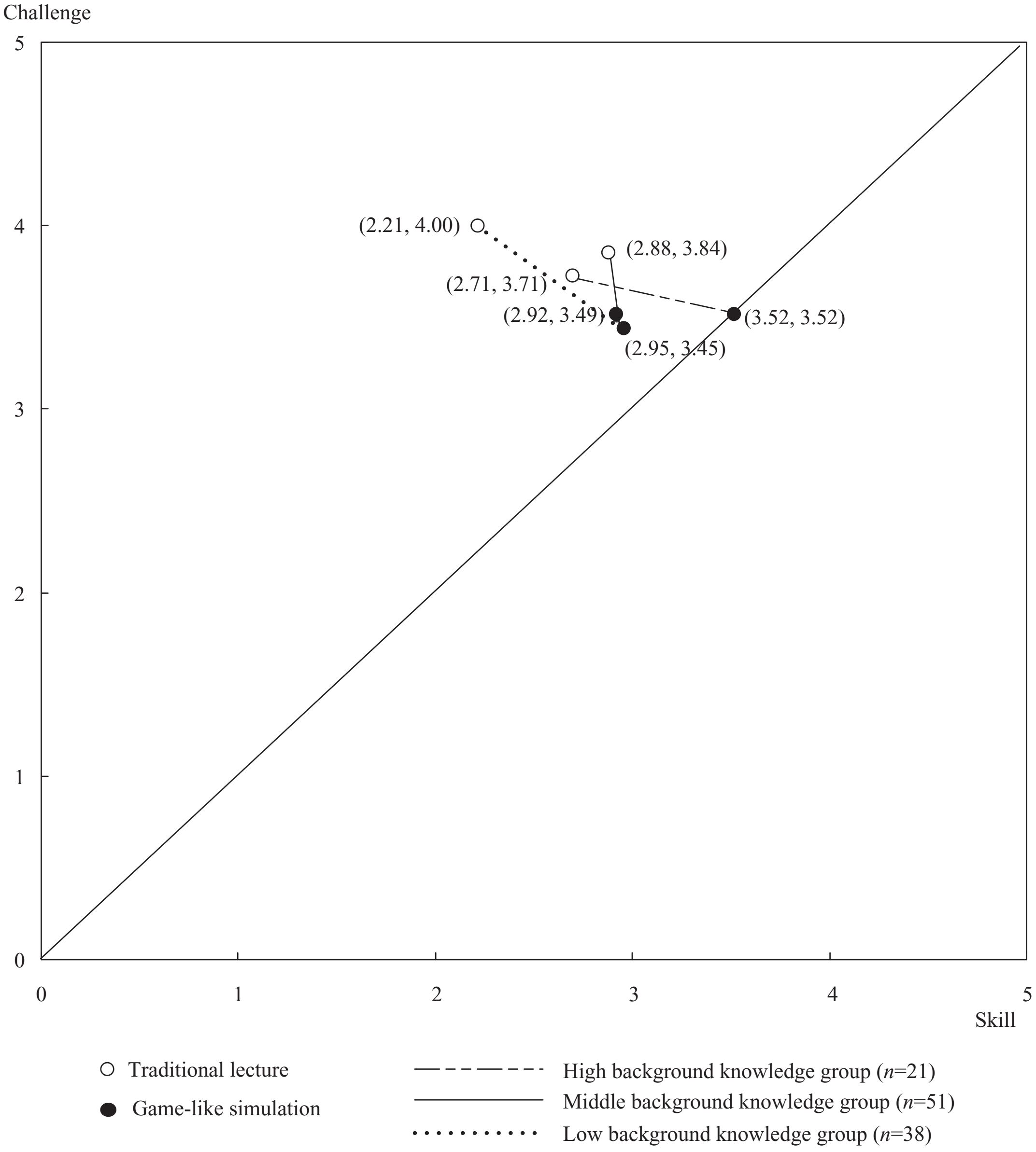

Figure 2: The flow states in the traditional and construction game settings

Motivations

Figures 3 and 4 show the students' motivations associated with learning with the game-like simulation and in the traditional lectures. The results involve 21 high, 49 middle and 31 low background knowledge students. The results show that the motivation of the three student groups increased when they learned with the game-like simulation after the traditional lecture. However, the enhancement is significant only for the students with low background knowledge ($t = -3.12$, $p < .01$). Their intrinsic motivation rose from 3.58 ($SD = .88$) to 4.02($SD = .56$). Such a finding may indicate that the game-like simulation helped this group of students learn in flow because flow experiences are positively correlated with motivation (Kowal & Fortier, 2000). More

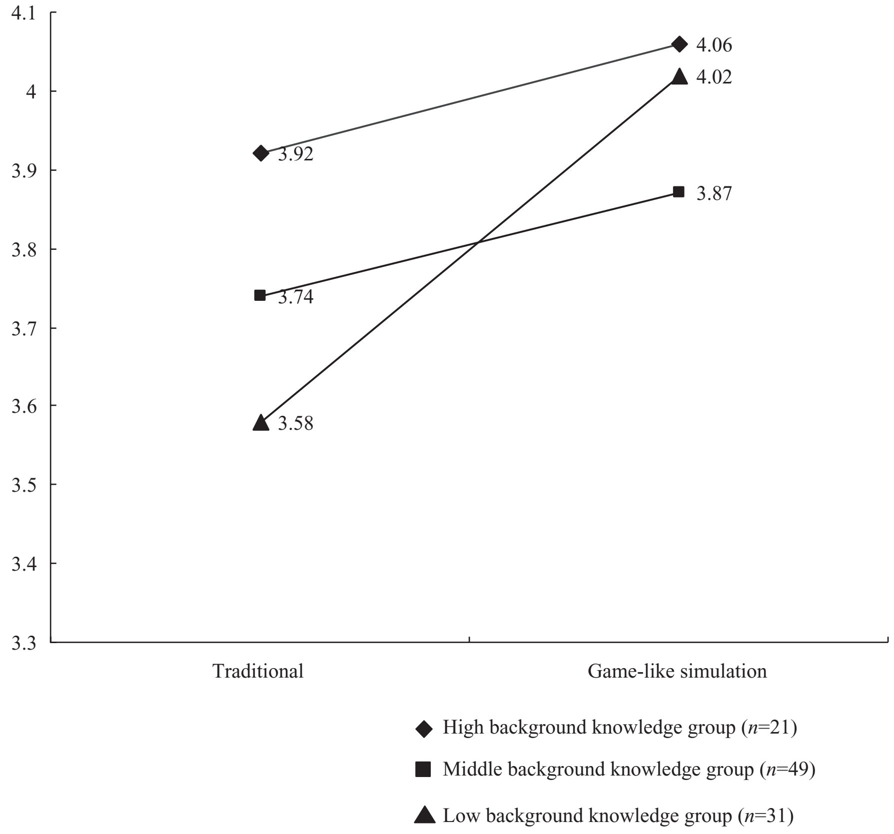

Figure 3: The students' intrinsic motivation in the traditional lectures and in the construction game

specifically, because the game-like simulation profoundly improved the flow experience of the low background knowledge group in terms of perceived challenge and perceived skill, the students were more likely to be motivated to learn with the simulation.

Figure 4 shows the extrinsic motivation of the three student groups. It is shown that the game-like simulation had different influences on the extrinsic motivation of the three groups. The extrinsic motivation of the high and middle background knowledge group associated with the simulation was lower than in the traditional lectures. This difference is particularly significant for the middle background knowledge group ($t = 2.695$, $p = .01$). Their extrinsic motivation reduced from 3.63 ($SD = .57$) to 3.42 ($SD = .55$). Such results are consistent with the findings of the study by Lepper and Henderlong (2000), indicating that intrinsic and extrinsic motivation can be in conflict. Therefore, this finding supports that the game-like simulation is helpful in transforming the learning of algorithmic thinking skills via an active learning experience. However, such an effect is not evident for the low background knowledge group. Their extrinsic motivation associated with the game-like simulation ($M = 3.5$, $SD = .63$) was slightly higher than that associated with the traditional lectures ($M = 3.42$, $SD = .89$) ($t = .63$, $p > .05$). This might be because the students were not so skillful that they could use their algorithmic thinking skills to construct their work. However, their extrinsic motivation associated with the game-like simulation was similar to that of the high and middle background knowledge groups. Such results support that the game-like simulation is helpful in engaging students in an active and immersion learning experience.

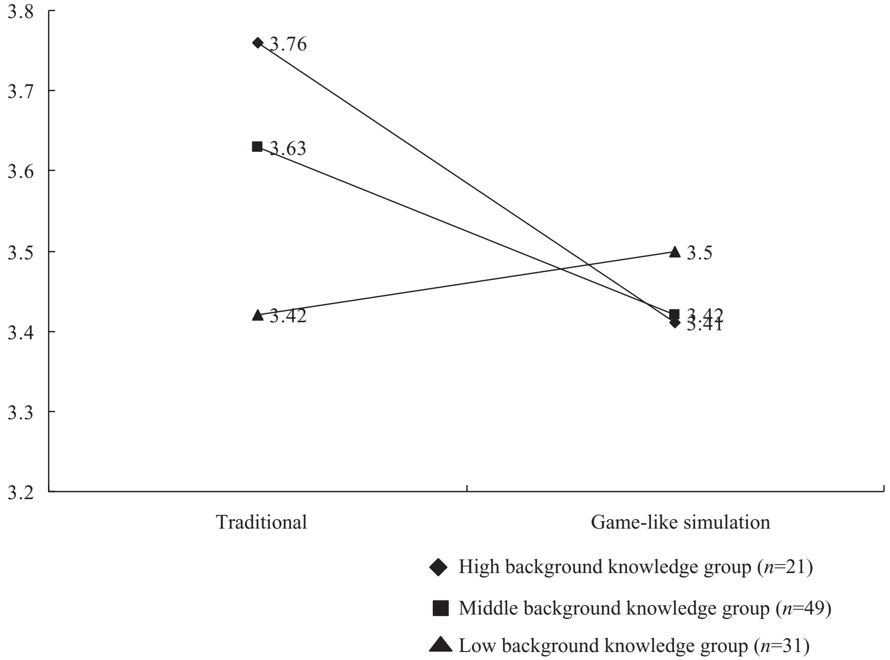

Figure 4: The students' extrinsic motivation in the traditional lectures and in the construction game

Learning behavior analysis

The learning behaviors of the three student groups were logged and analyzed to reveal how they learned with the game-like simulation. The students' behaviors were logged using a form of web logs and transformed to comprehensive records. More specifically, the students' behaviors included:

- Document review: a student reads the tutorial.
- Copying related examples: a student copies a segment of code from the tutorial and pastes it to the simulation.
- Experiment: a student presses the "Run Program" button to simulate the program they have built.
- Typing code: a student types code for the simulation.
- Self-Review: a student reviews the code they have developed.

To achieve a better understanding of how the students learned with the system, this study applied behavioral pattern analysis (Liu, Fan Chiang, Chou & Chen, 2010; Yamauchi, Yokozawa, Shinohara & Ishida, 2000) to investigate the behavioral patterns that the students exhibited in developing the rail model. More specifically, the series of behaviors of a student were coded into sequences according to the time order in which the behaviors were performed. The transition probability from behavior a to behavior b (a- > b) was calculated based on the percentage of transition a- > b among all transitions to b. The probability of the transition a- > b reflects the tendency of performing behavior b after behavior a. Among these transitions, the transition with small probabilities (transition probability <1/5, the random probability between any two of the five learning behaviors under uniform distribution) was eliminated so that only frequent transitions were displayed to illustrate only main behavioral patterns. The transition probability was then represented as the value attached to an arc between two behaviors in a transition diagram.

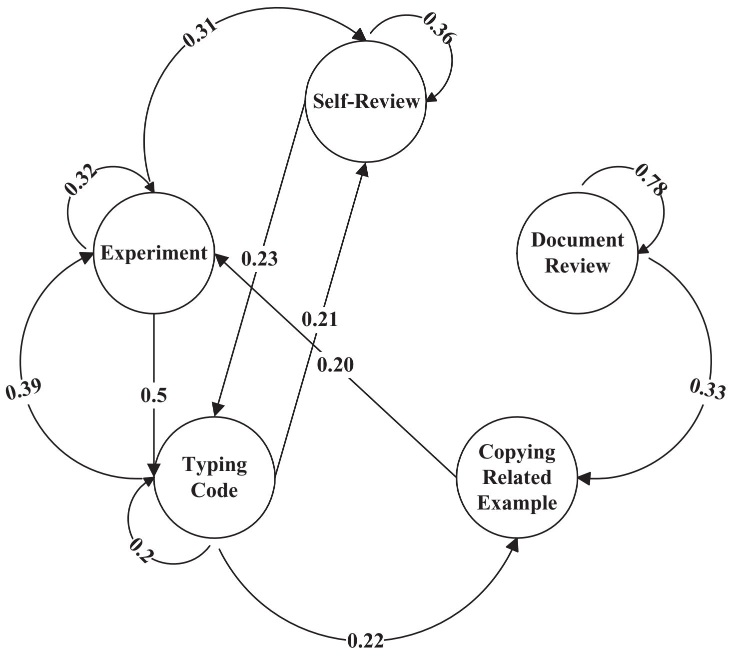

Figure 5: The behavioral pattern associated with the learning in the game-like simulation

The behaviors of the three student groups were analyzed independently so that we can understand the behavioral pattern of each group. However, the results of the behavioral patterns of the three groups are similar. More specifically, the three groups demonstrated an identical set of frequent transitions. Such results show that no individual group showed a significantly different pattern from the other two groups. This study thus merged all the behavior records of the three groups to obtain a general behavioral pattern in the game-like simulation. Figure 5 shows the behavioral patterns of the three student groups. The results were obtained from the behavior logs of all the 117 students. The students, as shown in Figure 5, may have applied several strategies to learn with the game. They seemed to start with learning by reading the tutorial (Document Review). They then selected some examples from the tutorials (Copying-Related-Example) and tested these examples to understand their effect (Experiment). Such a pattern reveals that with the simulation function, the game-like simulation is helpful in facilitating a learning-by-example strategy with which the students quickly understood the effect of some algorithmic thinking skills.

The behavioral patterns in Figure 5 also demonstrate that Experiment plays a central role in the game-based learning activity. In other words, the students relied heavily on the simulation function of the system. With this function, they quickly and frequently tested their ideas while constructing their models. This can be shown in the cyclical pattern Typing Code- > Experiment- > Typing Code. In other words, the students applied the simulation function to test their ideas and then modified their ideas based on the results of the simulations. Such an effect of the simulation of the system can also be shown from the cyclical behavioral pattern Typing Code- > Experiment- > Self-Review- > Typing Code. The behavioral patterns reveal that the simulation could help the students analyze their solutions and, thus, gradually improve their solutions. In other words, the students iteratively developed, simulated and analyzed their solutions to refine their products. Such findings support that game-like learning systems or activities should provide students with opportunities for iterative practices within the learning experience when they come to facilitating analytical reasoning.

Conclusion and implications

As simulation games and digital toys are increasingly being applied in educational contexts, how to integrate the design guidelines of these game-like learning systems and pedagogical principles is becoming imperative. Game-like learning systems should address pedagogical principles in their design. To achieve this goal, this study proposes a design framework based on constructionism. Such a framework consists of three elements, namely construction as the goal, low-threshold–high-ceiling activities and computer simulations, to address educational principles in the learning system. It was found that the game-like simulation environment developed with such a constructionism framework significantly improved the balance between the students' perceptions of skill and challenge, and was helpful in engaging the students in an active learning experience.

The influence of the constructionism framework on the skill and challenge perceptions

This study further evaluated the influence of such a design framework on different students. The results indicate that such a framework was particularly helpful for those students with low background knowledge. More specifically, the design profoundly enhanced the students' flow experience during learning in terms of perception of skills and challenge. This might be because the system is designed based on a simulated construction task, and thereby presents an embodied context. The students thus felt that learning with the learning was not as challenging as it was in traditional lectures, as they could associate their prior experience of learning algorithmic thinking skills in an embodied context. On the other hand, the system presents a low-threshold activity, whereby those students with low background knowledge could easily manipulate it. Thus the students perceived a significantly higher level of skill than they did in the traditional lectures.

The constructionism framework demonstrates a different impact on the students with high and middle levels of background knowledge from those with low background knowledge. More specifically, the system developed with the proposed framework can reduce the level of challenge for those students with low and middle level background knowledge. However, such an effect is not significant for the students with a high level of background knowledge. This might be because the construction task and the simulation presented an embodied and visualized context. Such context might be particularly helpful for low and middle level background knowledge to understand the conceptual algorithmic constructs such as looping and condition. However, the levels of their challenge perceptions were still higher than those of their skill perceptions. On the contrary, the students with a high level of background knowledge perceived a balanced level of skill and challenge while learning with the game-like system. The framework significantly increased their skill perceptions. This might be because such a system provides a high ceiling so that they may feel it is more skillful if they can freely apply algorithmic thinking skills to build their own work. Such results indicate that the low-threshold–high-ceiling principle can help the students with a sufficient level of background knowledge to experience flow. The above findings support that the low-threshold–high-ceiling principle is particularly important for designing game-like learning systems or activities, as students' background knowledge may vary extensively.

The influence of the constructionism framework on the motivation

Although the system had a different influence on the three student groups regarding their perceptions of skill and challenge, the results of the MSLQ show that all three student groups demonstrated an immersive and active learning experience. In other words, all three groups of students were highly motivated by the system. This might be because the system considered construction as the main goal. With such a clear goal in mind, all three student groups felt intrinsically motivated and perceived a similarly low level of extrinsic motivation. Such a finding suggests that the design framework is helpful in facilitating an active learning experience. Furthermore, it is found in this study that the extrinsic motivation of the middle and high background knowledge students' extrinsic motivation reduced substantially when using the game-like system, while their intrinsic motivation increased only slightly. On the contrary, both the intrinsic and extrinsic motivation of the low background knowledge students increased when using the system. It may be that intrinsic motivation might not be so important to middle and high background knowledge students in the game-like simulation setting because their high levels of computational thinking skills may be sufficient to ensure a high level of engagement in their learning. Such results may imply that learning strategies involving the use of game-like learning systems like Train B&P might be most suitable for low background students.

The influence of the constructionism framework on the learning behaviors

The learning behavior analysis found that the behavioral patterns of the three groups in the game-like learning system were similar. More specifically, all three student groups demonstrated rich exploratory learning behaviors as their intrinsic motivation were increased. Such results are consistent with the findings of the studies by Trevino and Webster (1992), indicating that students are more likely to demonstrate exploratory behaviors when they are intrinsically motivated. For instance, the students frequently applied the learning-by-example strategy to understand the effect of some algorithmic thinking skills. Moreover, they also demonstrated analytical reasoning behaviors to refine their learning. Such learning behaviors support the argument that game-like learning systems should support sophisticated simulation functions so that students can take an exploratory approach to learning in the system.

This study proposes a constructionism framework for designing game-like learning systems. The evaluation was conducted in the learning context of algorithmic thinking skills. However, this study mainly focuses on the influence of the proposed framework on different learners. It would be interesting to investigate how students with different knowledge levels may interact with each other when playing with the game-like learning system like Train B&P. In addition, this study only analyzed the students' motivations and challenge/skill perceptions to understand the effect of the design framework on flow experience. It would be worthwhile to apply other instruments to understand the flow experience associated with the system. For instance, the scale developed by Trevino and Webster (1992) may be helpful to understand the effect of the system on other flow components such as attention focus and curiosity. Moreover, it should be noted that most of the students in this study were male. The findings may not therefore be generalized beyond this particular study, especially as interest in building railway tracks may be gender specific. The type of construction task largely affects the influence of the constructionism framework. Female students may be more likely to be engaged in construction tasks such as building fashion and textile artifacts (Buechley, Eisenberg, Catchen & Crockett, 2008). Future studies are necessary to understand the relationship between gender differences and flow experiences. Gathering information on these issues through further work can help clarify the findings of the present study. In addition, the results of such studies could be integrated to build sophisticated learning environments to engage both female and male students in flow experience.

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References

Belanich, J., Sibley, E. D. E. & Orvis, L. K. (2004). Instructional Characteristics and Motivational Features of a PC-based Game. Research Report 1822, U.S. Army Research Institute for the Behavioral and Social Sciences.

Borgman, C. L., Abelson, H., Dirks, L., Johnson, R., Koedinger, K. R., Linn, M. C. *et al* (2008). *Fostering learning in the networked world: the cyberlearning opportunity and challenge*. A 21st Century Agenda for the National Science Foundation, Report of the NSF Task Force on Cyberlearning.

Buechley, L., Eisenberg, M., Catchen, J. & Crockett, A. (2008). The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. Proceedings of ACM Conference on Human Factors in Computing Systems, 423–432.

Burton, R. R., Brown, J. S. & Fischer, G. (1984). Skiing as a model of instruction. In B. Rogoff & J. Lave (Eds), *Everyday cognition: its development in social context* (pp. 139–150). Cambridge, MA and London: Harvard University Press.

Cherney, D. I. (2008). Mom, let me play more computer games: they improve my mental rotation skills. *Sex Roles*, *59*, 776–786.

Csikszentmihalyi, M. (1975). *Beyond boredom and anxiety*. San Francisco, CA: Jossey-Bass.

Dann, W., Cooper, S. & Pausch, R. (2006). *Learning to program with Alice*. Upper Saddle River, NJ: Prentice Hall.

de Jong, T. & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68*, 2, 179–201.

Fischer, G. (2010). Extending boundaries with meta-design and cultures of participation. Proceedings of the 6th Nordic Conference on Human -Computer Interaction, 168–177.

Fisher, B. (1998). *Joyful learning in kindergarten*. Portsmouth, NH: Heinemann.

Garris, R., Ahlers, R. & Driskell, E. J. (2002). Games, motivation, and learning: a research and practice model. *Simulation & Gaming*, *33*, 4, 441–467.

Gee, J. P. (2005). *Why are video games good for learning?* Retrieved June 3, 2010, from http://academiccolab.org/resources/documents/MacArthur.pdf.

Harel, I. & Papert, S. (1991). *Constructionism*. Norwood, NY: Ablex Publishing Corporation.

Heywood, P. (2005). Learning joyfully: an emotional and transformative experience. *Melbourne Studies in Education*, *46*, 1, 33–44.

Kafai, Y. (2006). Playing and making games for learning: instructionist and constructionist perspectives for game studies. *Games and Culture*, *1*, 1, 36–40.

Ke, F. F. (2008). Alternative goal structures for computer game-based learning. *International Journal of Computer-Supported Collaborative Learning*, *3*, 4, 429–445.

Kiili, K. (2005). Digital game-based learning: towards an experiential gaming model. *Internet and Higher Education*, *8*, 1, 12–24.

Kim, B., Park, H. & Baek, Y. (2009). Not just fun, but serious strategies: using meta-cognitive strategies in game-based learning. *Computers & Education*, *52*, 4, 800–810.

Kowal, J. & Fortier, M. S. (2000). Testing relationships from the hierarchical model of intrinsic and extrinsic motivation using flow as a motivational consequence. *Research Quarterly for Exercise & Sport*, *71*, 171–181.

Kulling, M. & Henriksen, P. (2005). Game programming in introductory courses with direct state manipulation. Proceedings of the 10th Annual SIGCSE Conference on Innovation and Technology in Computer Science Education, 59–63.

Lee, C. Y. & Chen, M. P. (2009). A computer game as a context for non-routine mathematical problem solving: the effects of type of question prompt and level of prior knowledge. *Computers & Education*, *52*, 3, 530–542.

Lepper, M. R. & Henderlong, J. (2000). Turning "play" into "work" and "work" into "play": 25 years of research on intrinsic versus extrinsic motivation. In C. Sansone & J. M. Harackiewicz (Eds), *Intrinsic and extrinsic motivation: the search for optimal motivation and performance* (pp. 257–307). San Diego, CA: Academic Press.

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.

Liu, C. C., Fan Chiang, S. H., Chou, C. Y. & Chen, S. Y. (2010). Knowledge exploration with concept association techniques. *Online Information Review*, *34*, 5, 786–805.

Liu, C. C., Liu, K. P., Wang, B. H., Chen, G. D. & Su, M. C. (2012). Applying tangible story avatars to enhance children's collaborative storytelling. *British Journal of Educational Technology*, *43*, 1, 39–51.

Massimini, F. & Carli, M. (1988). The systematic assessment of flow in daily experience. In M. Csikszentmihalyi & I. S. Csikszentmihalyi (Eds), *Optimal experience: psychological studies of flow in consciousness* (pp. 266–287). Cambridge, New York: Cambridge University Press.

McNerney, T. (2004). From turtles to tangible programming bricks. *Personal and Ubiquitous Computing*, *8*, 5, 326–337.

Monroy-Hernández, A. & Resnick, M. (2008). FEATURE: empowering kids to create and share programmable media. *Interactions*, *15*, 2, 50–53.

Novak, T. P. & Hoffman, D. L. (1997). *Measuring the flow experience among web users*. Paper presented at the Interval Research Corporation.

Pearce, J. M., Ainley, M. & Howard, S. (2005). The ebb and flow of online learning. *Computers in Human Behavior*, *21*, 5, 745–771.

Pintrich, P. R., Smith, D., Garcia, T. & McKeachie, W. J. (1991). *A manual for the use of the motivated strategies for learning questionnaire (MSLQ)*. Ann Arbor, MI: The University of Michigan.

Shneiderman, B., Fischer, G., Czerwinski, M., Resnick, M., Myers, B., Candy, L. *et al* (2006). Creativity support tools: report from a US National Science Foundation sponsored workshop. *International Journal of Human-Computer Interaction*, *20*, 2, 61–77.

Sindre, G., Natvig, L. & Jahre, M. (2009). Experimental validation of the learning effect for a pedagogical game on computer fundamentals. *IEEE Transactions on Education*, *52*, 1, 10–18.

Tan, J. & Biswas, G. (2007). Simulation-based game learning environments: building and sustaining a fish tank. Proceedings of The First IEEE International Workshop on Digital Game and Intelligent Toy Enhanced Learning, 73–80.

Trevino, L. K. & Webster, J. (1992). Flow in computer-mediated communication: electronic mail and voice mail evaluation and impacts. *Communication Research*, *19*, 5, 539–573.

Turkle, S. (1995). *Life on the screen: identity in the age of the internet*. New York: Simon & Schuster.

Wang, H. Y. & Wang, Y. S. (2008). Gender differences in the perception and acceptance of online games. *British Journal of Educational Technology*, *39*, 5, 787–806.

Wilson, K. A., Bedwell, W. L., Lazzara, E. H., Salas, E., Burke, C. S., Estock, J. L. *et al* (2009). Relationships between game attributes and learning outcomes. *Simulation & Gaming*, *40*, 217–266.

Yamauchi, Y., Yokozawa, M., Shinohara, T. & Ishida, T. (2000). Collaboration with lean media: how open-source software succeeds. Proceedings of Computer Supported Cooperative Work Conference, 329–338.