Chen, C.-H., Liu, J.-H., & Shou, W.-C. (2018). How Competition in a Game-based Science Learning Environment Influences Students' Learning Achievement, Flow Experience, and Learning Behavioral Patterns. *Educational Technology & Society, 21* (2), 164–176.

How Competition in a Game-based Science Learning Environment Influences Students' Learning Achievement, Flow Experience, and Learning Behavioral Patterns

Ching-Huei Chen*, Jun-Han Liu and Wen-Chuan Shou

Department of Industrial Education and Technology, National Changhua University of Education, Taiwan, R.O.C. // chhchen@cc.ncue.edu.tw // junhan657@gmail.com // wen01306132@gmail.com

*Corresponding author

ABSTRACT

Although educational games have become prevalent in recent research, only a limited number of studies have considered learners' learning behaviors while playing a science problem-solving game. Introducing a competitive element to game-based learning is promising; however, research has produced ambiguous results, indicating that more studies should investigate its pros and cons of competition. A total of 57 seventh-grade students participated in the study and were assigned to two conditions: competition or non-competition. Results revealed that students in the non-competition condition performed significantly better on the learning achievement test than those in the competition condition. With regard to the flow experience, no significant differences were found between the two conditions. The results of learning behavioral analyses revealed that, while both conditions resulted in students acquiring through means-ends strategies, students in the non-competition condition tended to read the instructions carefully and repeatedly sought additional supports to help themselves advance their conceptual understanding. These findings, when examined in light of previous research, call into question other types of competition in promoting engagement and supporting learning.

Keywords

Game-based science learning, Competition, Learning performance, Flow experience, Learning behavioral patterns

Introduction

In general, a game is organized play with a set of rules and obstacle apparatuses (e.g., Ke, 2016; Klopfer et al., 2009). Characteristics of a game often include interactivity, rules and constraints, goal(s), competition, and feedback (Wouters & van Oostendorp, 2013). In the last decades, game-based learning (GBL) has become a prevalent instructional approach across various disciplines. Moreover, GBL is situated in an interactive environment based on a set of agreed-upon directions and constraints (Garris, Ahlers, & Driskell, 2002) and is aimed at solving a clear goal that is often set by a challenge (Malone & Lepper, 1987). GBL provides constant feedback, either as a score or as changes in the game world, to enable players to monitor their progress toward the goal (Prensky, 2001). While many efforts have been pouring into the study of GBL, evidence of its effectiveness on learning has yet to reach consensus across the different disciplines. Mayer (2011) suggested that game research should take further approaches in value-added and cognitive consequences to understand how specific game feature fosters learning and motivation as well as to determine what students learn from games.

Therefore, in this study, we focused on the distinct features that constitute an educational game in order to define its effectiveness (Aldrich, 2005; Vandercruysse et al., 2012). Competition, one of the dispensable game features, has attracted the attention of many researchers because it is so multifaceted in nature and diverse in form. Some researchers have considered competition a motivational trigger in a game because it stimulates student engagement and persistence in the learning activity (Kollöffel & De Jong, 2016; Malone & Lepper, 1987). Yet others warn that overemphasizing the competition aspect may induce negative emotional effects and ultimately distract students from learning content and seeking support (Cheng, Wu, Liao, & Chan, 2009; Van Eck & Dempsey, 2002). In light of this, the competition element in GBL has inconsistent findings, and contextual considerations require further investigation. In this study, we set out to examine the effect of competition in a game-based science learning (GBSL) environment and to determine the differences in student learning behavioral patterns when competition as an element. This study specifically attempted to answer the following research questions:

- Does the competition mode in GBSL affect students' learning achievement when compared to the non-competition mode?
- Does the competition mode in GBSL affect students' flow experience when compared to the non-competition mode?
- Does engaging in the competition mode in GBSL affect students' learning behavioral patterns differently than those who engage in the non-competition mode?

Review of relevant literature

Game-based science learning (GBSL)

Consensus is growing among science educators and practitioners regarding the importance of designing personally relevant experiences to foster lifelong learning in science (Eylon, 2000). Studies have shown that GBL provides a learner-centered context that enhances learning (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012). Particularly, indulgence in GBL presents a unique opportunity for science learning since the subject of science is universally acknowledged to be complicated and challenging. Cheng and her colleagues (2016) found that GBL (learning by gaming) facilitated student science learning achievement. Moreover, GBL is often believed to have the potential to facilitate both the cognitive and affective/motivational processes of learning (Ke, 2016; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013). A meta-analytic examination on the instructional effectiveness of GBL also found a significant improvement in learning achievement (Sitzmann, 2011). While GBL offers many educational advantages that can address learning needs, meta-analyses of GBL have not reached consistent findings about the impact of GBL in the context of science education. Some studies have found that games have a significant impact on science learning, while others identified insignificant relationships between the two (Vogel et al., 2006; Wouters & van Oostendorp, 2013). Additionally, several researchers have suggested that different elements of the GBL environment should be separately examined before a conclusion on the effectiveness of an educational game is reached (e.g., Young et al., 2012). Competition, amongst various elements that could have affected learning behaviors and flow experience, is multifaceted in nature and diverse in form. Next, we summarize the literature on the competition element in GBL.

Competition in GBL

Competition is an important ingredient of GBL. Game developers have always maintained that competition allows for GBL activities that are intrinsically game-like (e.g., Prensky, 2001). Of course, there have been fluctuations in emphasis, and much has changed through the years. Ideally, when competing with others, learners must work harder; as a result, all students improve their knowledge, allowing the group to progress. Without competition, only the best of the class would improve his or her knowledge. In GBL, Cheng and his colleagues (2009) considered competition a well-structured learning activity with the potential to increase learners' attention and generate excitement. As a result, researchers have regarded competition as a useful technique to motivate individuals to learn (Burguillo, 2010; Julian & Perry, 1967; Malone & Lepper, 1987; Nemerow, 1996). For instance, van Eck and Dempsey (2002) reported that competition may motivate students extrinsically, resulting in students putting forth more effort on current tasks. Many studies have found positive effects of competition in GBL such as enhanced learning and motivation, a higher tendency to make risky plays, and decreased cognitive load (Admiraal, Huizenga, Akkerman, & Dam, 2011; Cagiltay, Ozcelik, & Ozcelik, 2015; Foo et al., 2017; Hwang & Chang, 2015).

However, competition may not always be prominent in GBL. Vandercruysse, Vandewaetere, Cornillie, and Clarebout (2013) found that competition had no effect on learning outcomes and/or motivation. Furthermore, competition may weaken a student's intrinsic motivation to learn the educational content because of the focus on winning (Van Eck & Dempsey, 2002). In line with Van Eck and Dempsey's (2002) argument, competition may increase hostility between students, and such social comparison can negatively affect a student's self-efficacy beliefs, motivation, and performance (Bandura & Locke, 2003). The abovementioned studies have generally shown that competition may inhibit metacognitive skills, attention, and elaboration and may also create an affective state of anxiety that may be detrimental to learning.

After reviewing these studies, we concluded that the inconsistent findings regarding competition in GBL may be due to differences in the forms of competition and the learning content itself. Competition in GBL takes many forms; for example, players may compete with themselves, with the game system, with other individual players, with other teams, or a combination of these to achieve game objectives (Alessi & Trollip, 2001; Fisher, 1976; Yu, 2003). In this study, we operationalized competition by allowing students to compare their own performance in GBL against that of their counterparts. Their learning content was science, which has a history of competition in traditional science fairs. Cheng and her colleagues (2009) pointed out that less-able students in science may be discouraged by the persistent winning of more-able students and thus, reduce their own effort. In other words, the same competition may result in different levels of engagement among different students. While the competition is assumed to be the key element in a game to foster motivation, there is limited research that addresses the empirical effectiveness of competition on learners' affections. Considering the multifaceted nature of competition, this study intended to investigate whether competition as an element in a GBL environment affects a student's flow experience and triggers different learning behaviors when compared to a non-competitive environment.

Flow experiences in GBL

Over the past decades, researchers have been increasingly interested in understanding student motivation and finding ways to predict and improve it. According to self-determination theory, motivation can be affected by levels of control (Ryan et al., 2006), which implies that when learners make their own decisions in the learning process, they are more likely to be motivated. In the context of GBL, researchers have often considered motivation a key variable that can affect a learner's motivational appeal (Garris et al., 2002; Malone, 1981). Ke (2009) claimed that, generally, instructional computer games seem to facilitate motivation across different learner groups and learning situations. Therefore, in this study, we examined one of the key characteristics of motivation, flow, which has been found to significantly predict perceived learning and enjoyment (Barzilai & Blau, 2014).

Flow is a state of mind in which a person is completely involved in an activity for its own sake. Many researchers have explored student flow experience in the context of GBL (e.g., Kiili, 2005; Sun, Kuo, Hou, & Lin, 2017). Admiraal, Huizenga, Akkerman, and Dam (2011) found that when experience flow in their game activities, that it has an effect on their game performance, but not on their learning outcome. Admiraal et al. (2011) found that distractive activities and being occupied with competition between teams affected the learning outcome of students. Their results revealed that the less students were distracted from the game and the more they were engaged in group competition, the more they learned about the medieval history of Amsterdam (Admiraal et al., 2011). Csikszentmihalyi (1991) stated that educators create flow by screening out distractions and making concentration possible. While game elements, such as challenge and complexity in GBL environment, were found to affect flow experiences of the students (Inal & Cagiltay, 2007), research addressing the effect of competition on the flow experience seems scarce. Presumably, while competition increases learners' engagement (e.g., Malone & Lepper, 1987), there can also be cases where learners may be distracted or lack engagement when witnessing the persistent winning of other students (Cheng, Wu, Liao, & Chan, 2009). Therefore, in this study, flow is measured as an outcome variable that plays a motivational role in the learning process.

Methodology

Design and participants

A quasi-experimental study, supplemented by behavioral logs, was employed to investigate the three research questions. This study applied both quantitative and qualitative methods for the purpose of seeking triangulation of the results from different data sources and examining overlapping and different facets of a phenomenon. Participants in this study were 57 students (13-14 years old) who were recruited from two seventh-grade classes at a junior high school in Taiwan. One class, with 29 students (13 males and 16 females), was in the competition mode of GBL ("the competition condition"), while the other class, with 28 students (15 males and 13 females), was in the control group ("the non-competition condition"). A knowledge pre-test was administered and showed no differences among participants in terms of what they would be learning. Further, students reported equivalent experiences in learning through game playing.

Game-based science learning environment (*SumMagic*)

A central component of our study was a game called *SumMagic*, which was developed based on the theories of how we learn (e.g., Bransford, Brown, & Cocking, 2000). The topics for the learning subject were primarily in science, specifically, time, distance, position, and velocity. Learning objectives included: (a) to observe the timeline of an object's movement, (b) to identify an object's moving distance, (c) to define speed as a scalar quantity that involves a magnitude, and (d) to calculate an object's speed from its moving distance and time data.

Students in *SumMagic* are required to learn independently using observable variables to analyze, operate, and finally rationalize the phenomenon and conclude the findings. The main functions covered in the game can be classified into four main components: (1) sources of game problem, (2) manipulative tools, (3) observable interpretation, and (4) report results. Sources of game problem reflected the problem representation, in which students needed to utilize manipulative tools for clarifying the problem and the means to solve it. Based on prior problem-solving research (Bransford & Stein, 1984; Chi & Glaser, 1985), the representation of a problem consists of the solver's interpretation of the problem, which, follows the connection of existing knowledge to form an integrated representation. During the learning process, students were required to interpret information about the problem by constructing the problem space and actively manipulating and testing before triggering particular solution processes. According to information-processing theories, if appropriate schema cannot be activated, the solver goes back to an earlier stage and redefines the problem or uses another method to solve the problem, so called means-ends analysis (Gick, 1986). Figure 1 provides the scenarios for *SumMagic*. This study evaluated competition as a specific game element. As shown in Figure 2, after the gameplay, students in the competition condition could see a ranking board that showed their own ranking as well as their counterpart's ranking in score and time spent on completing the game. Conversely, students in the non-competition condition did not have access to the ranking board.

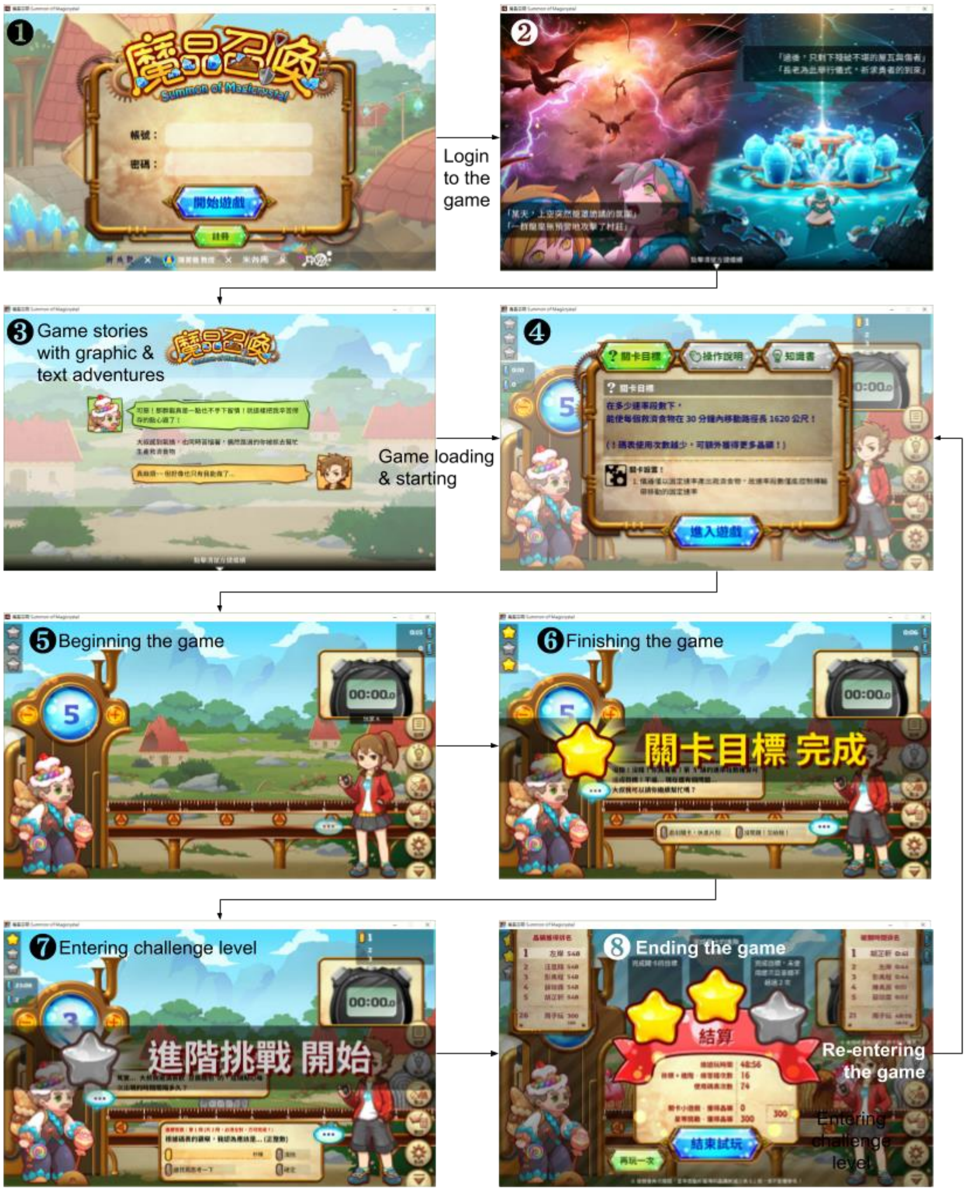

Figure 1. Game scenarios for *SumMagic*

Figure 2. Screenshot of game interface (showing the ranking board for the competition group)

Instruments

The data gathered for subsequent data analyses were learning achievement tests regarding time, distance, position, and velocity; surveys on flow experience; and learning behavioral logs. The learning achievement test was designed to assess the participants' topic-specific knowledge. It consisted of 10 multiple-choice questions. The test was developed and validated by two experienced teachers who determined that the questions were well-represented and aligned with the content being taught. The reliability of the learning achievement test was .87.

The flow experience measurement was adopted from Killi (2006) and measured four key flow dimensions: concentration, loss of self-consciousness, transformation of time, and autotelic experience (Csikszentmihalyi, 1991). Previously, a Chinese version of Killi's approach was used by Hou and Li (2014) and found to obtain reasonable reliability levels. Respondents completed a total of 12 questions using a 5-point Likert-type response format (5 = agree, 1 = disagree). Samples of questions were "My attention was focused entirely on playing the game" and "I really enjoyed the playing experience." There were two additional open-ended questions that enabled students to describe whether they had experienced flow before and the factors that may interrupt their flow experiences. The reliability of flow experience measurement for this study was .92.

Table 1. Examples of learning behavioral codes and definitions

Code	Learning behavioral dimension	Definition
SC	Speed change	Learners can change the speed level to complete the learning goals.
TC	Timer control	Learners can click on the timer to observe the changes in time while the objects move in distance and time.
RV	Ruler view	When scrolling over the moving object, students can use the ruler to observe its exact position.
BR	Board reading	Information about the goal, operation, and factual knowledge for completing the game.
RC	Role click	Learners can click on the non-player character (NPC) and answer the NPC's questions.
NU	Note using	Learners can use the provided painter to take notes or use the calculator tool.
HU	Hint using	A list of prompts is provided for learners to guide their problem-solving processes.
GP	Game process	When learners complete the learning goals, the game will direct them to the next (more advanced) level of the game.

In addition to learning achievement tests and flow experience surveys, this study collected students' gaming behavioral logs. The game automatically stored each student progressive game behaviors in the database. The content experts first reviewed the game and identified eight behavioral dimensions, which are defined in Table 1.

These behavioral dimensions provided a comprehensive view of how students performed and progressed within the game environment. These dimensions were also keys to solving the game problem and gaining important conceptual knowledge. For example, in order to understand the relationship between time, distance, and velocity, students needed to manipulate the time control (TC) and observe position change (RV) to experience the changes in velocity (SC). If the obtained velocity did not meet the requirements (RC), students then continually switched to other segments. Figures 3–7 exemplify how different dimensions were presented in the game.

Figure 3. Screenshot of Board Reading (BR) interface

Figure 4. Screenshot of game interface (including SC, RV, and TC)

Figure 5. Screenshot of game interface (including HU and RC)

Figure 6. Screenshot of game interface (including NU)

Figure 7. Screenshot of game interface (including GP)

Procedure

The final analysis included only those students who were present for all phases of the study and for whom completed data were obtained. The study took place in the computer classroom with a teacher and two researchers present throughout. On the day of the study, the participants arriving in the computer classroom were seated in front of computers, introduced to the research team, informed of the general purpose of the study, and given a description of the procedures. After this orientation, students had approximately 20 minutes to individually complete an online pre-test on learning achievement. Upon completion of the pre-test, students were instructed to login to the game using a pre-assigned username and password. Students individually played the game at their own pace for approximately 40 minutes, and their gaming behaviors were logged and coded automatically through the computer system. The game ended once the students completed the challenges successfully. Upon the completion of the game play, students were instructed to complete a post-test and a flow experience survey.

Data analysis

To assess learning achievement, analysis of covariance (ANCOVA) was conducted, and a significance level of p < 0.05 was adopted. The assessment of flow experience was followed using *t*-test. All the analyses were done with the Statistical Package for the Social Sciences (SPSS 11.0 for Windows). The lag sequential analysis of student behavioral patterns was performed because it enables researchers to find significant behavioral patterns and determine whether the sequential relationships between each behavior pattern reached statistical significance (Bakeman & Gottman, 1997).

Results

Learning achievement

One of the objectives of this study was to examine whether the competition or the non-competition mode in GBSL influenced students’ learning achievement tests. ANCOVA was carried out to exclude the difference between the prior knowledge of the two groups by using the pre-test scores as the covariate and the post-test scores as dependent variables. The homogeneity test result showed that the post-test scores of the two groups were homogeneous ($F = 0.40$, $p = 8.42 > 0.05$), implying that ANCOVA could be applied. Table 2 summarizes the ANCOVA results in which the adjusted mean values of the post-test achievement scores were 8.57 for the competition group and 9.40 for the non-competition group; moreover, a significant difference was found between the two groups ($F = 7.40$, $p < 0.05$, ES = .12, observed power = .90), implying that there was a significant difference in the learning achievements of the competition and non-competition conditions.

Table 2. Descriptive statistics for the learning achievement post-test results

Conditions	*N*	Mean	*SD*	Adjusted mean	Std. error	*F*
Competition	29	8.66	1.82	8.57	.21	7.42^{*}
Non-competition	28	9.32	0.77	9.40	.22	

Note. $^{*}p < .05$.

Flow experience

Table 3 shows the *t*-test result of the flow experience ratings of the two conditions. The means and standard deviations were 3.62 and 0.75 for the competition condition, and 3.48 and 0.79 for the non-competition condition. The *t*-test result showed no significant difference between the two groups (t = -.71, $p > .05$), indicating that the two groups of students reported equivalent flow experience after participating in the learning activity.

Table 3. t-test result of the flow experience for the two groups

Conditions	*N*	Mean	*SD*	*t*
Competition	29	3.62	0.75	-.71
Non-competition	28	3.48	0.79	

Learning behavioral patterns in different conditions

We collected a total of 13,921 behavioral codes (competition condition: 6,879, non-competition condition: 7,042). In terms of dimensional difference, Table 4 shows the frequency distribution of their learning behaviors across various dimensions.

Table 4. Summary of learner behaviors by frequency

Conditions	BR	RC	GP	TC	RV	NU	SC	HU	Total
Competition	115 (2%)	563 (8%)	21 (1%)	1549 (22%)	2750 (39%)	87 (2%)	1654 (24%)	140 (2%)	6879
Non-competition	110 (2%)	408 (6%)	22 (1%)	1441 (20%)	2944 (41%)	56 (1%)	1664 (23%)	397 (6%)	7042

We first performed sequential analysis on the competition condition and adjusted the residual table on the dimensions and found that the significant sequences for $p < .05$ were RV → RV ($z = 8.38$), SC → SC ($z = 4.262$), SC → TC ($z = 10.75$), TC → SC ($z = 6.188$), RC → RC ($z = 7.34$), and RC → NU ($z = 1.92$). Figure 8 shows the learning behavioral patterns chart, and the thickness of the lines represents the closeness of the sequential relations. The competition condition had the following characteristics: (a) students preferred repeatedly using the ruler view (RV) to make observations when achieving their learning goals; (b) students tended to click on speed change (SC) many times, indicating they were likely to use means-ends and guessing strategies to answer their learning goals; (c) when the selected speed change (SC) was incorrect, students tended to work backward to click on the timer control (TC) to start over; (d) students preferred to interact or seek help from a role click (RC) to proceed; and (e) students liked to take or leave notes (NU) after seeking help from the NPC.

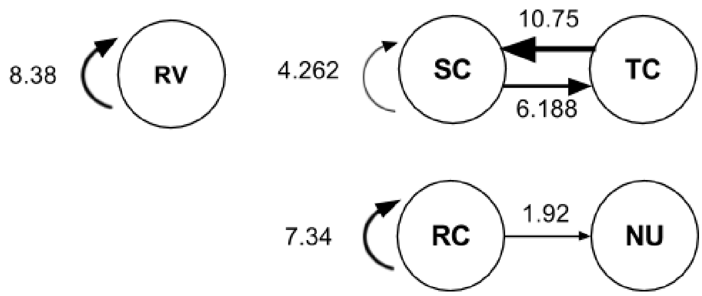

Figure 8. The dimensional behavioral patterns chart of the competition condition

We then adjusted the residual table based on the dimensions of the non-competition condition, we discovered that the significant sequences for $p < .05$ were SC → TC ($z = 7.604$), TC → SC ($z = 13.453$), RV → RV ($z = 9.588$), RV → RC ($z = 2.157$), RC → RV ($z = 2.447$), BR → RC ($z = 3.422$), RC → HU ($z = 4.001$), RC → GP ($z = 3.8$), and HU → HU ($z = 9.563$). The non-competition group's learning behavioral patterns chart is shown in Figure 9. The learning behaviors of the non-competition condition exhibited the following characteristics: (a) students tended to click on speed change (SC), indicating that students were likely to use means-ends and guessing strategies to answer their learning goals; (b) students preferred repeatedly using ruler view (RV) to make observations while also seeking help from the NPC (RC), which likely completed the learning goals and advanced them to the more difficult level of the game; (c) after interacting with the NPC, students also clicked on hint using (HU) repeatedly to seek additional support from the game itself; and (d) students preferred to engage in board reading (BR) before making observations.

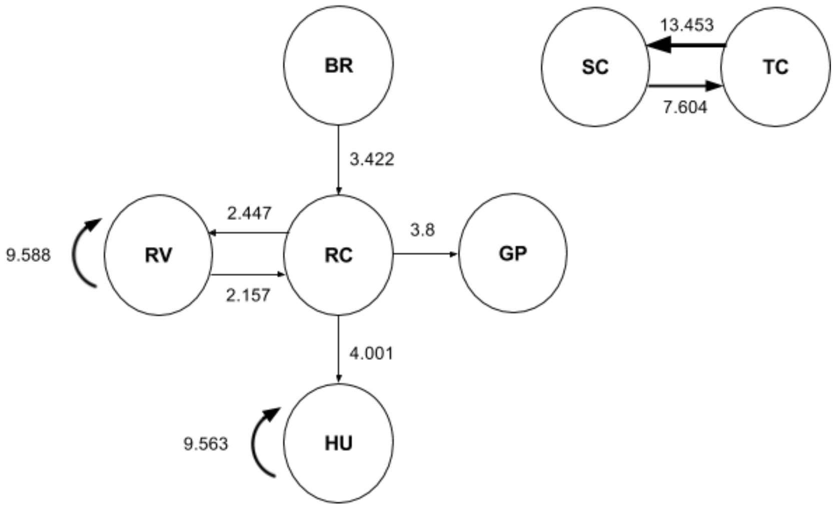

Figure 9. The dimensional behavioral patterns chart of the non-competition condition

Discussion

The purpose of this study was to examine whether the presence of competition in GBSL made any differences on student learning achievement, flow experience, and learning behavioral patterns. The results confirmed the expectation that secondary students can benefit from a GBSL (e.g., Cheng et al., 2016). When comparing students' performance tests, this study found the main effect of non-competition on GBL was in line with previous findings from studies on the use of competition in GBL (e.g., Vandercruysse et al., 2013). Specifically, this study compared the competition versus non-competition aspect of the game. The learning achievement tests showed that students in the non-competition condition performed significantly better than those in the competition condition. There might be several explanations for the results, including peer pressure and time constraints. The absence of peer pressure allowed students to continually work on the game challenges. From the field observations, we found that students in the non-competition condition spent most of the time exploring the problem space and solutions, and that they utilized the support tools provided in the game environment.

Regarding the flow experience as the result of gameplay, no significant difference was found between the competition and non-competition conditions. The insignificance may be due to several reasons. First, to experience flow, students should be immersed in the task for a longer or extended period of time. Second, to experience flow, extraneous distractions should be diminished so that concentration can be facilitated (Cheng, Wu, Liao, & Chan, 2009; ter Vrugte, de Jong, Vandercruysse, Wouters, van Oostendorp, & Elen, 2015). Last, challenge and complexity elements may have further impacted the flow experience (Inal & Cagiltay, 2007).

While most GBL studies examining the cognitive benefits of GBL have focused on learning outcomes at the completion of gameplay (e.g., Hwang, Wu, & Chen, 2012), they have largely ignored learning behaviors, except for a limited number of studies (e.g., Admiraal et al., 2011; Nietfeld, Shores, & Hoffmann, 2014). With the advancement of technology, learning behaviors can often be tracked and analyzed to provide valuable insight into GBL *processes* that lead to eventual learning outcomes (Cheng, Lin, & She, 2015). Accordingly, one purpose of the current study was to take into consideration learners' learning behaviors while playing a science problem-solving game. Therefore, learners' learning behavioral patterns in both conditions were analyzed and compared. We found that both conditions were similar in the way students frequently used means-ends and guessing strategies and actively sought help from the NPC. The differences were students in the non-competition condition tended to not only interact with the NPC, but to repeatedly seek additional support. These students also preferred to read instructions before making observations in the game, whereas students in the competition condition mainly relied on surface learning that included trying different variables and observing the effects; furthermore, they seldom sought help because they would have had to spend additional time reading and following the instructional supports. Basically, student behavioral patterns in the competition condition were more focused on necessary movement, and they were less likely to explore other functions provided within the game environment. The reason for these behavioral differences may be due to the design of the competition and the various types of learners. In the competition condition, the students' attentions were drawn to the in-game performance and the comparison of scores with their peers; the scoreboard showed the ranking and time spent on completing the game. Such competition may make students focus their attention on the scores and make them less engaged in the additional learning materials provided in the game. In this study, adding the ranking or competing scores may have subverted learning improvement. Additionally, differences in the student's self-efficacy beliefs may have influenced their game learning behavior. Previous research stated that failure in a competition debilitated the greater efforts in learning for students with low self-efficacy beliefs (Bandura & Locke, 2003). These findings add to the existing literature that has explained how competition may harm the learning process by turning a project into a race to the finish line where understanding and internalizing concepts and knowledge becomes unimportant compared to winning. In GBSL, learners move from engagement in the form of making sense of the elements of the process to attempting to interpret and make a quality effort to efficiency, speed, and the outcome relative to others. The emphasis on the mode of competition, where a player sees his or her game performance as a contest, leads to a helpless pattern. This may further bring negative effects on student's self-efficacy beliefs, motivation, and performance (Bandura & Locke, 2003; Van Eck & Dempsey, 2002). On the other hand, students in the non-competition condition played the game without any time constraints or peer pressure. Consequently, viewing a score without any comparisons may increase game involvement and may strengthen beliefs that putting effort in the game is worthwhile.

Conclusions and implications for future study

The role of competition in GBL has received increasing attention. However, the literature has overlooked how the level of competition in GBL grows abruptly. The results of this study provided new insights into the complex relationship between the inclusion of competition in a GBL environment and its effects on student learning achievement, flow experience, and learning behavioral patterns. Students in the non-competition condition showed significantly better learning achievement than those in the competition condition, while no significant difference was found in their flow experience. The results of the learning behavioral analyses revealed that, while both conditions resulted in students' utilizing means-ends strategies, students in the non-competition condition tended to read the instructions carefully and repeatedly sought additional support to help themselves advance their conceptual understanding.

The results of this study offer several implications for game researchers, practitioners and designers. First, while competition condition of this study did not have significant positive effects, we recommend further investigation into other types of competition. For example, Chen, Law, and Chen (2018) suggested students might benefit more from the inclusion of anonymous competition. In our opinion, this could better promote learning, induce positive motivational outcomes, and facilitate meaningful cognitive engagement. Second, other possible effects of competition can be further examined, for example, the effects on interest, self-efficacy beliefs, or frustration. Third, the design of the game can explore the inclusion of intergroup competition on student learning achievement or learning behavioral patterns. For example, team-based competitive approaches may be especially effective in making instructional materials more enjoyable and engaging. Competition between groups may increase cooperation within groups because students are unified in working toward a common goal.

Acknowledgements

This research was supported by the Ministry of Science and Technology in Taiwan through the contract number MOST 105-2628-S-018-001-MY3. The authors would like to acknowledge the contributions of Yu-Kai Zhang, Migema Design Co., Ltd, and Jhih-Ping Jiang who supported the game development and research study.

References

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

Aldrich, C. (2005). *Learning by doing: The Comprehensive guide to simulations, computer games, and pedagogy in e-learning and other educational experiences*. San Francisco, CA: Pfeiffer.

Alessi, S. M., & Trollip, S. R. (2001). *Multimedia for learning* (3rd ed.). Needham Heights, MA: Allyn and Bacon.

Bakeman, R., & Gottman, J. M. (1997). *Observing interaction: An Introduction to sequential analysis* (2nd ed.). Cambridge, UK: Cambridge University Press.

Bandura, A., & Locke, E. A. (2003). Negative self-efficacy and goals effects revisited. *Journal of Applied Psychology, 88*, 87-99.

Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computers & Education, 70*, 65-79. doi:10.1016/j.compedu.2013.08.003

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press.

Bransford, J. D., & Stein, B. S. (1984). *The IDEAL problem solver: A Guide for improving thinking, learning, and creativity.* New York, NY: W. H. Freeman and Company.

Burguillo, J. C. (2010). Using game theory and competition-based learning to stimulate student motivation and performance. *Computers & Education, 55*, 566-575.

Cagiltay, N. E., Ozcelik, E., & Ozcelik, N. S. (2015). The Effect of competition on learning in games. *Computers & Education, 87*, 35-41.

Chen, C.-H., Law, V., & Chen, W.-Y. (2018). The Effects of peer competition-based science learning game on secondary students' performance, achievement goals, and perceived ability. *Interactive Learning Environments, 26*(2), 235-244. doi:10.1080/10494820.2017.1300776

Cheng, H. N. H., Wu, W. M. C., Liao, C. C. Y., & Chan, T. W. (2009). Equal opportunity tactic: Redesigning and applying competition games in classrooms. *Computers & Education, 53*(3), 866-876. doi:10.1016/j.compedu.2009.05.006

Cheng, M.-T., Lin, Y.-W., She, H. C., & Kuo, P. C. (2016). Is immersion of any value? Whether, and to what extent, game immersion experience during serious gaming effects science learning. *British Journal of Educational Technology, 48*(2), 246-263.

Cheng, M.-T., Lin, Y.-W., & She, H. C. (2015). Learning through playing Virtual Age: Exploring the interactions among student concept learning, gaming performance, in-game behaviors, and the use of in-game characters. *Computers and Education, 86*, 18-29.

Chi, M. T. H., & Glaser, R. (1985). Problem-solving ability. In R. J. Sternberg (Ed.), *Human abilities: An information-processing approach.* (pp. 227-250). New York, NY: W. H. Freeman and Company.

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A Systematic literature review of empirical evidence on computer games and serious games. *Computers & Education, 59*, 661-686.

Csikszentmihalyi, M. (1991). *Flow: The Psychology of optimal experience.* New York, NY: Harper Perennial.

Eylon, B.-S. (2000). Designing powerful learning environments and practical theories: The Knowledge integration environment. *International Journal of Science Education, 22*(8), 885-890.

Fisher, J. E. (1976). Competition and gaming: An Experimental study. *Simulation & Gaming, 7*(3), 321-328.

Foo, J. C., Nagase, K., Naramura-Ohno, S., Yoshiuchi, K., Yamamoto, Y., & Morita, K. (2017). Rank among peers during game competition affects the tendency to make risky choices in adolescent males. *Frontiers in Psychology, 8*, 16. doi:10.3389/fpsyg.2017.00016

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

Gick, M. L. (1986). Problem-solving strategies. *Educational Psychologist, 21*(1&2), 99-120.

Hou, H. T. & Li, M. C. (2014). Evaluating multiple aspects of a digital educational problem-solving-based adventure game. *Computers in Human Behavior, 30*, 29-38

Hwang, G. J., & Chang, S. C. (2015). Effects of a peer competition-based mobile learning approach on students' affective domain exhibition in social studies courses. *British Journal of Educational Technology*. doi:10.1111/bjet.12303

Hwang, G. J., Wu, P. H., & Chen, C. C. (2012). An online game approach for improving students' learning performance in web-based problem-solving activities. *Computers & Education, 59*(4), 1246-1256.

Inal, Y., & Cagiltay, K. (2007). Flow experiences of children in an interactive social game environment. *British Journal of Educational Technology, 38*(3), 455-464. doi:10.1111/j.1467-8535.2007.00709.x

Julian, J. W., & Perry, F. A. (1967). Cooperation contrasted with intra-group and inter-group competition. *Sociometry, 30*(1), 79-90.

Ke, F. (2016). Designing and integrating purposeful learning in game play: A Systematic review. *Educational Technology Research & Development, 64*(2), 219-244. doi:10.1007/s11423-015-9418-1

Kiili, K. (2005). Content creation challenges and flow experience in educational games: The IT-emperor case. *The Internet and Higher Education, 8*(3), 183-198. doi:10.1016/j.iheduc.2005.06.001

Klopfer, E., Osterweil, S., & Salen, K. (2009). *Moving learning games forward*. Cambridge, MA: The Education Arcade.

Kollöffel, B., & De Jong, T. (2016). Can performance feedback during instruction boost knowledge acquisition? Contrasting criterion-based and social comparison feedback. *Interactive Learning Environment, 24*(7), 1428-1438. doi:10.1080/10494820.2015.1016535

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science, 5*(4), 333-369. doi:10.1207/s15516709cog0504_2

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A Taxonomy of intrinsic motivations for learning. In R. E. Snow & M. J. Farr (Eds.), *Aptitude, learning, and instruction* (Vol. 3, pp. 223-253). Hillsdale, NJ: Erlbaum.

Mayer, R. E. (Ed.). (2011). *Multimedia learning and games*. Charlotte, NC: Information Age.

Nemerow, L. G. (1996). Do classroom games improve motivation and learning? *Teaching and Change, 3*(4), 356-366.

Nietfeld, J. L., Shores, L. R., & Hoffmann, K. F. (2014). Self-regulation and gender within a game-based learning environment. *Journal of Educational Psychology, 106*(4), 961-973.

Prensky, M. (2001). *Digital game-based learning*. New York, NY: McGraw-Hill.

Ryan, R., Rigby, C. S., & Przybylski, A. (2006). The motivational pull of video games: A self-determination theory approach. *Motivation and Emotion, 30*(4), 344-360. doi:10.1007/s11031-006-9051-8

Van Eck, R., & Dempsey, J. V. (2002). The Effect of competition and contextualized advisement on the transfer of mathematics skills in a computer-based instructional simulation game. *Educational Technology Research & Development, 50*(3), 23-41. doi:10.1007/BF02505023

Vandercruysse, S., Vandewaetere, M., & Clarebout, G. (2012). Game-based learning: A Review on the effectiveness of educational games. In M. M. Cruz-Cunha (Ed.), *Handbook of research on serious games as educational, business and research tools: Development and design* (pp. 628-647). Hershey, PA: IGI Global.

Vandercruysse, S., Vandewaetere, M., Cornillie, F., & Clarebout, G. (2013). Competition and students' perceptions in a game-based language learning environment. *Educational Technology Research and Development, 61*(6), 927-950. doi:10.1007/s11423-013-9314-5

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A Meta-analysis. *Journal of Educational Computing Research, 34*, 229-243.

Sitzmann, T. (2011). A Meta-analytic examination of the instructional effectiveness of computer-based simulation games. *Personnel Psychology, 64*, 489–528. doi:10.1111/j.1744-6570.2011.01190.x

Sun, C.-Y., Kuo, C.-Y., Hou, H.-T., & Lin, Y.-Y. (2017). Exploring learners' sequential behavioral patterns, flow experience, and learning performance in an anti-phishing educational game. *Educational Technology & Society, 20*(1), 45-60.

ter Vrugte, J., de Jong, T., Vandercruysse, S., Wouters, P., van Oostendorp, H., & Elen, J. (2015). How competition and heterogeneous collaboration interact in prevocational game-based mathematics education. *Computers and Education, 89*, 42-52.

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A Meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology, 105*(2), 249-265.

Wouters, P., & van Oostendorp, H. (2013). A Meta-analysis review of the role of instructional support in game-based learning. *Computers & Education, 60*, 412-425.

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., Simeoni, Z., Tran, M., & Yukhymenko, M. (2012). Our princess is in another castle: A Review of trends in serious gaming for education. *Review of Educational Research, 82*(1), 61-89.

Yu, F. Y. (2003). The Mediating effects of anonymity and proximity in an online synchronized competitive learning environment. *Journal of Educational Computing Research, 29*(2), 153-167.