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The interactivity of video and collaboration for learning achievement, intrinsic motivation, cognitive load, and behavior patterns in a digital game-based learning environment

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ABSTRACT

This study investigated how the use of an instructional video and collaboration influenced the learning achievement, intrinsic motivation, cognitive load, and learning behaviors of students learning Newtonian mechanics within a digital game-based learning (DGBL) environment. The participants were 109 seventh-grade students who were randomly assigned to one of four experimental groups, forming a 2 × 2 factorial design, with the presence or absence of an instructional video as one factor and collaboration as the other. With regard to learning achievement, the findings revealed a significant main interaction effect between the use of an instructional video and collaboration. While collaborative DGBL promoted intrinsic motivation, the results for cognitive load showed that the use of an instructional video in collaborative DGBL significantly reduced both intrinsic and extraneous cognitive loads. The implications for designing game-based science learning are discussed.

1. Introduction

Digital game-based learning (DGBL) has become a prevalent instructional approach in both formal and informal educational settings. DGBL provides students with opportunities to take the initiative in their learning by analyzing, synthesizing, evaluating, and performing higher-order thinking skills, such as critical thinking and problem-solving (Dindar, 2018; Yang, 2015). DGBL has the power to promote learning due to the attributes and affordances that are built into games; nevertheless, evidence-based direction regarding the most suitable conditions under which to integrate games into formal settings is needed before the full potential of DGBL can be realized (Van Eck, 2015).

A substantial amount of research supports the use of instructional videos to convey settings, characters, and action in an interesting way and to help learners easily understand and remember content in comparison with the use of expository materials (Jonassen, Peck, & Wilson, 1999). In the popular flipped learning approach, teachers provide instructional videos that students can access on their own to learn subject knowledge and key concepts, thereby freeing up class time for collaboration and problem-solving activities (Bergmann & Sams, 2012). When used in this way, instructional videos can prepare students for knowledge acquisition, set the stage for their interpersonal interaction, and increase the potential for their knowledge building (DeLozier & Rhodes, 2017). While the use of instructional videos and collaboration have been studied in conjunction with one another, they have been examined only minimally in the game-based research literature. Presumably, instructional videos that are intended to support knowledge building should help to streamline learners' cognitive processes and facilitate their schema construction. However, the existing

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research on the effects of using instructional videos in DGBL appears scant. Therefore, the aim of this study was to implement the use of an instructional video and collaboration in DGBL to support students' science learning, for the purpose of examining how an instructional video and collaboration impact learners' intrinsic motivation, cognitive load, and learning behaviors. This study, therefore, sought to answer the following research questions:

(1) How does the presence of an instructional video in DGBL affect students' learning achievement, intrinsic motivation, cognitive load, and learning behaviors?
(2) How does the context of learning arrangement (i.e., collaborative versus solitary) in DGBL affect students' learning achievement, intrinsic motivation, cognitive load, and learning behaviors?
(3) How does an instructional video interact with the context of learning arrangement in DGBL to impact students' learning achievement, intrinsic motivation, cognitive load, and learning behaviors?

2. Review of the relevant literature

2.1. Digital game-based learning (DGBL)

DGBL, which is a digital game-based approach to learning (Prensky, 2001), incorporates game features into teaching content, thereby providing students with immediate learning aids. The characteristics of DGBL are a pictorial interface and the presentation of adaptive challenges that encourage learners to actively engage in learning, thereby enhancing their learning motivation and learning outcomes and stimulating joy in an entertaining environment (Bawa, Watson, & Watson, 2018). DGBL is also characterized by its ability to combine games with educational content and achieve learning outcomes that are as good as those of traditional learning (Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013). As a result, DGBL can provide an effective learning environment in which learners are able to develop basic skills and knowledge in specialized fields in the digital technology era (Hwang, Chiu, & Chen, 2015).

The effectiveness of DGBL often depends upon students to set meaningful goals while completing the challenges, to take ownership for achieving the goals, and to monitor progress to determine if strategies are valid for achieving the goals. However, students are found to experience difficulty in completing such inquiry-oriented activity in DGBL. Therefore, for the instructor or facilitator, the continual monitoring of student progress during DGBL and the provision of the guidance and support to help students managing the DGBL context is critical. In fact, in recent studies, the attention has shifted toward addressing the instructional practices that are effective when incorporated with DGBL (Chen & Law, 2016; Sung, Hwang, Lin, & Hong, 2017). In this study, we examine two common instructional practices—that is, instructional videos and collaborative learning—that are used in the DGBL environment. The aim of this exploration is to provide empirical evidence of the effective and efficient use of DGBL.

2.2. Instructional video use in DGBL

The use of instructional videos enables the simultaneous display of multiple representations that correspond to learners' observations at the macroscopic level. Accordingly, instructional videos are a widely used tool in educational settings, and this popularity is a result of the recent trend of flipped learning (Bergmann & Sams, 2012). It has been argued that among the variety of media, instructional videos are particularly useful and suitable for learners because they can convey settings, characters, and action in an interesting way and portray complex and interconnected problems (Overbaugh, 1995). In addition, compared to other expository materials, the use of instructional videos can help learners to more easily understand and remember content (Jonassen et al., 1999). Researchers have found that the information that is acquired visually is more memorable because the simultaneous processing auditory and visual information can enhance comprehension and retention (Kozma, 1991). Consequently, the use of instructional videos can have numerous benefits for enhancing learning and knowledge transfer. However, the drawbacks of teaching and learning using instructional videos cannot be overlooked. An instructional video generally combines text, animation, and voice (Mayer, 2001). From a cognitive-load perspective, the combination of different sources of information can easily overload operational memory, ultimately resulting in the creation of obstacles, including hindrances to cognitive development and processes (Sweller, 1994).

Despite the fact that the use of an instructional video can induce different learning outcomes, its structure, content, and context for learning warrant further discussion. Several studies on multimedia learning have investigated multiple-channel presentations of instructional videos and the resulting split-attention phenomenon (Mayer & Moreno, 1998; Schmidt-Weigand, Kohnert, & Glowalla, 2010). When learners process multiple-channel presentations—either auditorily or visually—from an instructional video, they initiate a different working-memory capacity. For instance, the use of dual-mode (audio-visual) instructional programs reduces cognitive load and processing information, and the use of visual and auditory channels increases the limited capacity of working memory (Mousavi, Low, & Sweller, 1995).

In addition, the presentation styles of the content delivered in instructional videos have received attention from researchers as these can influence cognitive processes. Instructional video content that is divided into two areas may cause split-attention problem; even if processing only one locus of attention, learners must focus on two areas on the screen. The split-attention effect occurs when learners are required to mentally integrate disparate information physically or temporally, where each source of information must be combined before they can be understood (Chen & Wu, 2015). This effect also increases the learner's cognitive load, as multiple information sources must be integrated with each other (Ayres & van Gog, 2009).

Although numerous educational researchers have examined the benefits and drawbacks of instructional videos in regard to structure and presentational style, no conventional guidelines are available (Homer, Plass, & Blake, 2008). Importantly, the merits and limitations of implementing instructional video use in the DGBL context have not yet been thoroughly investigated. In particular, the effectiveness of instructional videos for game-based learning and usability is poorly understood. The results of the present study contribute significantly to researchers' understanding whether instructional videos can maximize DGBL performance. This study is, therefore, expected to raise educational researchers' awareness of the affordances of instructional video use for DGBL.

2.3. Collaborative learning in DGBL

According to Vygotsky (1978)'s sociocultural theory, human learning is a process of collaboration that stimulates the transition from externalization to internalization and ultimately influences cognitive development. Collaborative learning has become a common instructional practice in educational settings. Such learning environments were developed using the sociocultural approach, whereby learning is based on interaction, knowledge co-construction, and reflection (Feltovich, Spiro, Coulson, & Feltovich, 1996). Collaborative learning is regarded as a necessary contributor to active learning and is used to foster learning through information sharing and knowledge exchange among peers; this not only enhances student competitiveness but also promotes learning performance (Chen, Law, & Chen, 2017).

The adoption of collaborative DGBL has gained attention among researchers and practitioners. For example, massive, multiplayer, online role-playing games foster collaboration among players, and the typical learning environment includes chat features that allow for communication and idea construction (Parasleva, Mysirlaki, & Papagianni, 2010). While, according to the existing research, collaborative DGBL promotes knowledge enhancement and learning motivation more effectively than individual game-based learning (Chen, Wang, & Lin, 2015; Melero, Hernández-Leo, & Manatunga, 2015), a recent study called for research attention to be paid to specifically to the integration of different types of scaffolding that may support effective collaborative DGBL (Chen & Law, 2016). Because collaboration makes GBL more effective, more research is needed to investigate the multifaceted structure of collaboration in GBL and the requisite conditions or situations in which effective collaborative GBL occurs (Chen, 2018).

2.4. Intrinsic motivation in DGBL

Due to the motivational attributes that are built into digital games, they have the power to attract players (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012). In the context of digital game use in education, the concept of *intrinsic motivation* is crucial. Deci and Ryan (2000) view the origin of intrinsic motivation as the individual's own desire, as opposed to extrinsic motivation, which they argue originates from factors outside the self. Numerous researchers assert that intrinsic motivation leads to satisfaction and pleasure in the learning process as learners gain competencies and knowledge (Elliot & Harackiewicz, 1996). Moreover, it has been demonstrated in the literature that compared to extrinsically motivated students, those who are intrinsically motivated are more likely to persist when facing learning challenges (Huang, 2011; Song & Grabowski, 2006).

A key concept in this study context relates to the motivational pull of the DGBL context. In instructional design, DGBL may prove to be a useful motivational tool for both students and teachers, who may be attracted to peripheral DGBL elements, such as peer collaboration and instructional support. Therefore, this study extends the existing research on the periphery of DGBL, which includes the use of instructional videos and collaborative learning, as well as their influences on intrinsic motivation.

2.5. Cognitive load in DGBL

The term *cognitive load*, which was originally derived from *mental workload* and is considered primarily from the psychological, physiological, and cognitive perspectives, relates to the exploration of the impact of an individual's total load on his or her accomplishment of a specific task and the benefits of his or her information processing (Paas, Van Gog, & Sweller, 2010). Sweller (1990) claimed that if instructional design and teaching content exceed the range of cognitive abilities that learners can afford to load, these learners' cognitive abilities will become overwhelmed, thereby negatively affecting their interest in learning and learning outcomes.

Sweller, van Merrienboer, and Paas (1998) divided cognitive load into three areas: *intrinsic*, *extraneous*, and *germane*. Intrinsic cognitive load refers to the complexity and difficulty of the learning content itself. Extraneous cognitive load refers to the presentation and organization of teaching materials or content design and curriculum that are irrelevant to the learning. Germane cognitive load refers to the cognitive capacity used in schema construction. In other words, to achieve the reduction of extraneous cognitive load, the instruction should allocate the learner's cognitive capacity toward the process of schema construction (germane cognitive load) (Sweller et al., 1998). As Chandler and Sweller (1991) conceptualized, well-planned teaching materials and instructional design can reduce the learner's extraneous cognitive load and increase his or her working memory resources for construction, which, in turn, induces his or her germane cognitive load.

Mayer (2001) proposed a cognitive theory of multimedia learning that also supports the limited capacity hypothesis—that an individual's operational memory system can handle only a limited amount of information at once. If the amount exceeds the learner's operational memory load, learning will be hindered. The interrelationships between multimedia learning, motivation, and learning outcomes have been pointed out in a number of studies based on theories of cognitive load and multimedia learning (Huang & Huang, 2015; Mayer, 2014). Homer et al. (2008) found that students who watched only video-based lectures containing slideshow presentation experienced more extraneous cognitive load than those who listened to an audio recording of the lecture combined with slideshow presentation. Therefore, content presentation affects the cognitive load on students' working memory.

Studies have shown that DGBL can improve learning outcomes if it can reduce the cognitive load during learning (Hawlitschek &

Joeckel, 2017; Schrader & Bastiaens, 2012). However, several other studies have indicated that different degrees of immersion are apt to increase cognitive load and decrease the effectiveness of learning (Korakakis, Pavlatou, Palyvos, & Spyrellis, 2009). Comparing learning in immersive DGBL environments with learning in a low-immersion hypertext environment, Schrader and Bastiaens (2012)) found that learning through DGBL leads to a higher cognitive load, and thus lower learning, retention, and migration of physical knowledge, than does learning in low-immersion hypertext environments. Therefore, high degrees of immersion have a negative impact on cognitive load. While this finding has important implications, there remains a lack of discussion and exploration of the relationship between DGBL and cognitive load.

3. Methodology

3.1. Design and participants

This study employed a pretest–posttest, 2 × 2 factorial research design. The first factor was the presence or absence of an instructional video, and the second was the mode of game play: collaborative or solitary. The participants in this study were seventh-grade students enrolled in middle school in a school district located in rural central Taiwan. A total of 109 students (59 males and 50 females) agreed to participate. At the conclusion of the study, the video, game, and collaboration (VGC) condition had 25 participants, the video and game (VG) condition had 28, the game and collaboration (GC) condition had 30, and the game-only condition had 26. The median age of the participants was 12 years old, with participants ranging from 10 to 12 years old.

3.2. Materials

3.2.1. Game implementation and description

The DGBL environment adopted in this study is called *SumMagic*. The architecture of *SumMagic* is shown in Fig. 1. As learners log in to the game, their identities are verified before they proceed to game-level selection. All the information about the students' gaming behaviors, including score, game-play duration, and progression, are automatically recorded and saved in the game database. The game interface and procedure are displayed in Fig. 2. Fig. 2 shows the opening interface, which requires the user's login name and password, after which it shows the game level 1-1. Upon the completion of game level 1-1, a final scoreboard appears, showing the ranking of the game players, their completion times, and their individual scores, as well as the time completed, number of attempts, and number of stars. The players can attempt to play game level 1-1 again or can proceed to the next game level (1–2). In this study, learners had access to game levels 1-1 and 1–2, which feature Newton's first law of motion. Each game level includes basic and advanced modes. Figs. 3–5 represent the game flowchart for login/selection and the basic and advanced game levels, respectively.

3.2.2. Instructional video

An instructional video was created to accompany the *SumMagic* content that was covered in this study—velocity and speed. The video, which included explanations of the concepts, along with graphics, animation, sound, and narratives, was designed to scaffold the development of explicit understandings of the relationships between speed, distance, and velocity. Thus, the instructional video is a scaffold whose goal is to support learners' sense-making by helping them bridge their intuitive understandings of the game with their disciplinary knowledge. The instructional video may also be considered an advance organizer because it presents the general concepts of speed, distance, and velocity and provides concrete examples of their use in real contexts. Fig. 6 exemplifies the information presented in the instructional video concerning the concepts of displacement and length of path. It starts with the definitions of displacement and length of path. For example, displacement is the distance from the starting point to the end point. It is also defined as the change in the position of an object and is specified with either a positive or a negative sign to indicate direction. Following the basic definition, a detailed example with illustrated animations is provided. As evident in the example, the arc path of a

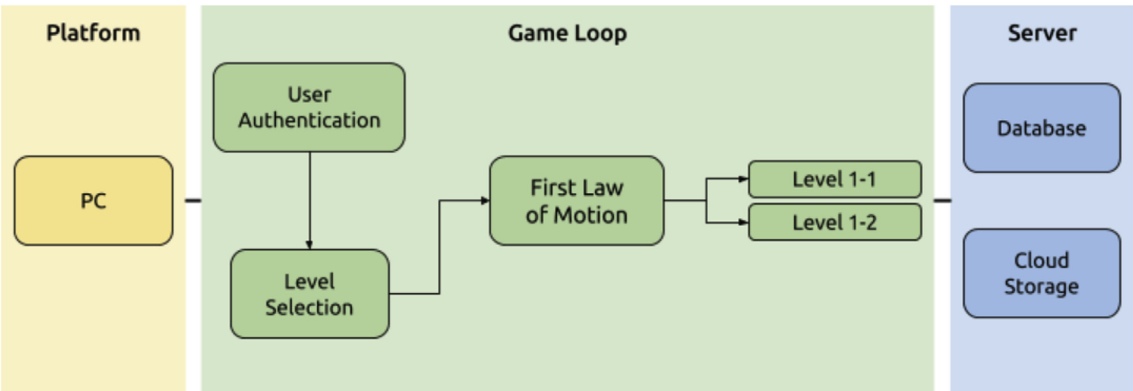

Fig. 1. Architecture of *SumMagic* game.

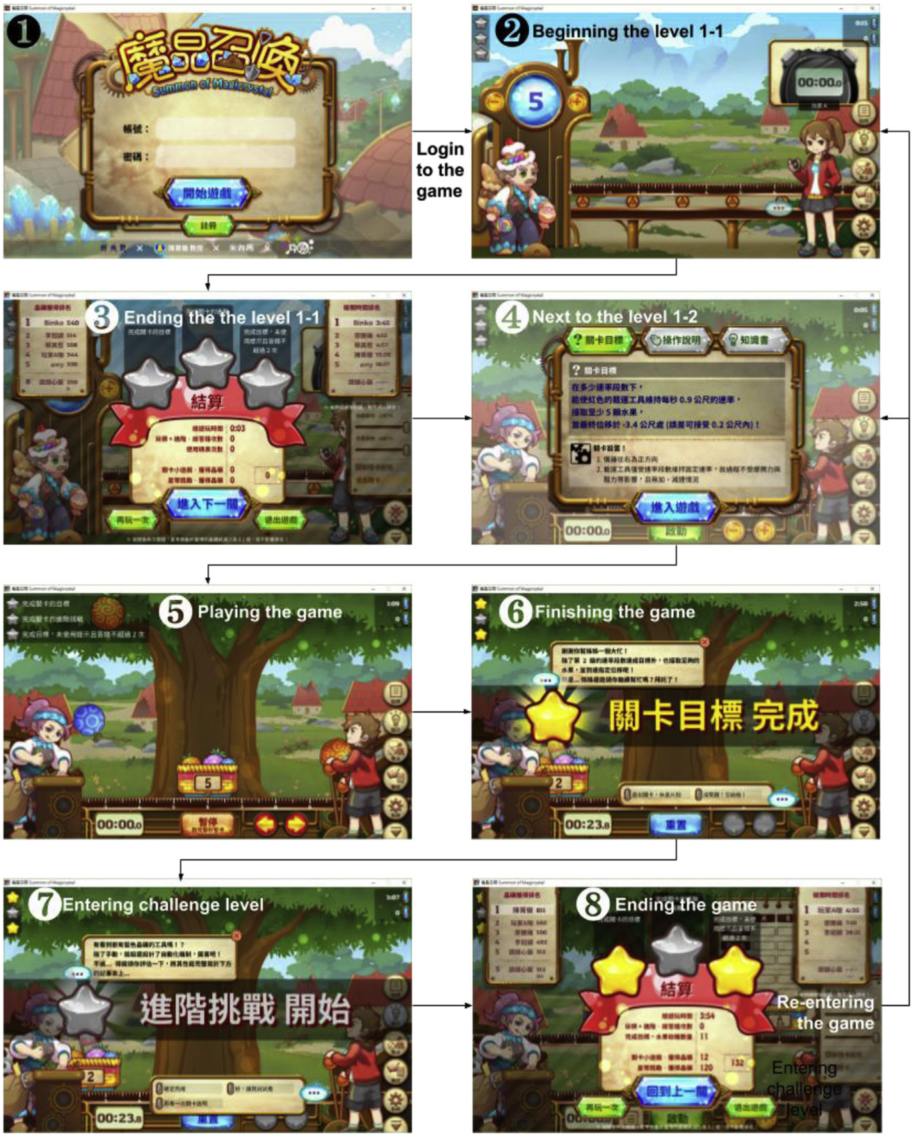

Fig. 2. *SumMagic* interface and procedure.

basketball into a net is called the length of path. The straight line from the starting point of the ball to the end point of the basketball net is called displacement. If the basketball moves 5 m in the opposite direction, the displacement is indicated as -5 m. The participants could review the instructional video at their own pace at any time during game play.

3.3. Measures

3.3.1. Learning achievement test

A total of twenty questions, comprising sixteen multiple-choice and four fill-in-blank questions, were created by two experienced science teachers and later validated by a university professor to ensure their validity in relation to the content covered in the game. The achievement test encompassed topics related to Newton's first law of motion (e.g., time, distance, velocity, speed, displacement, and length of path). The reliability of the learning achievement test is indicated by its Cronbach's alpha of .875.

An example of a multiple-choice question is “When running for one-half circle along a circle with a radius of 50 m, what is the displacement?” The associated answers were (A) 50 m, (B) 100 m, (C) 50πm, and (D) 0. An example of a fill-in-the-blank question is “If the typhoon advanced by 10 km per hour, then after 6 h, it would have advanced ___ km.”

3.3.2. Intrinsic motivation

The intrinsic motivation survey, which was adapted from Deci and Ryan (2000), comprised fourteen statements, including “This

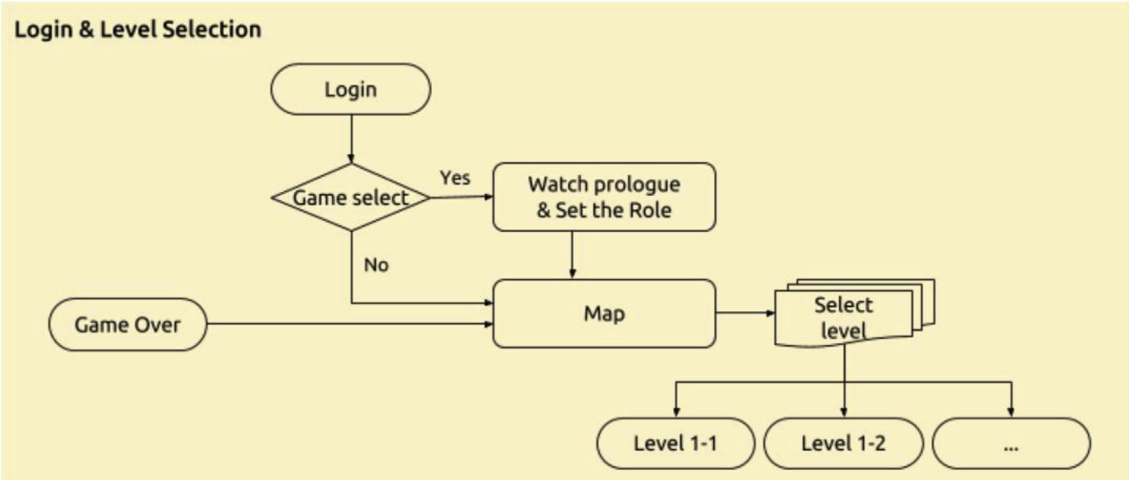

Fig. 3. *SumMagic* flowchart I.

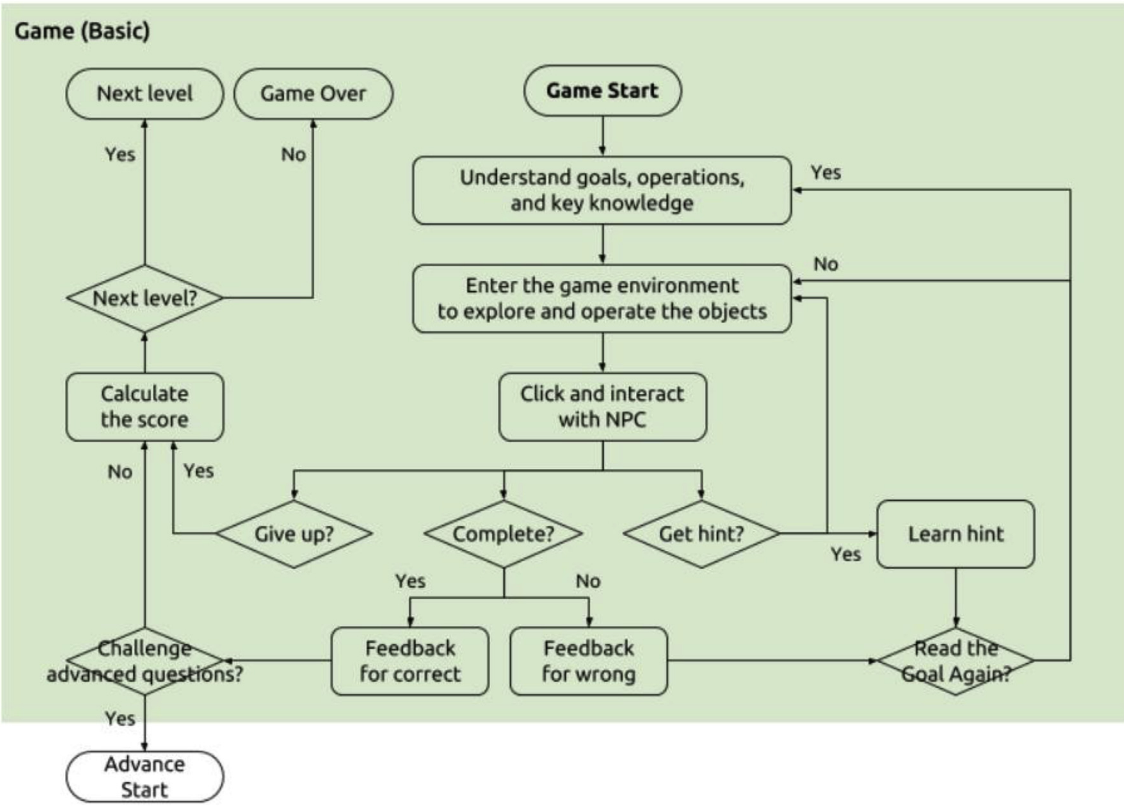

Fig. 4. *SumMagic* flowchart II.

activity was fun to do" and "I see the value of the work I learn in the game." The reliability of the intrinsic motivation scale is indicated by its Cronbach's alpha of .82.

3.3.3. Cognitive load surveys

The cognitive load surveys were adapted from Leppink, Paas, Van der Vleuten, Van Gog, and Van Merriënboer (2013). The survey totaled ten questions that based on three constructs—intrinsic load (three questions), extrinsic load (three questions), and germane load (four questions)—each of which was given a rating of 0–10 (0 = *not at all the case*; 10 = *completely the case*). A sample item for intrinsic load is "The topics covered in the activity were very complex." For extrinsic load, a sample question is "The instructions during the activity were very unclear." For germane load, a sample question is "The activity really enhanced my understanding of the

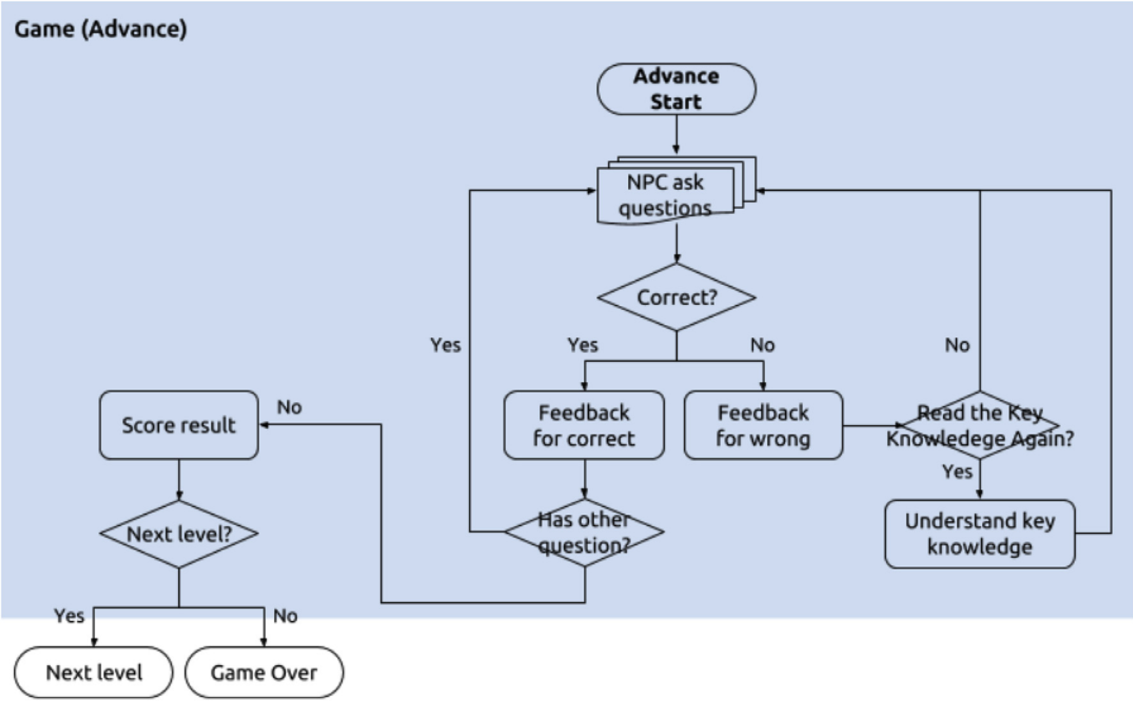

Fig. 5. *SumMagic* flowchart III.

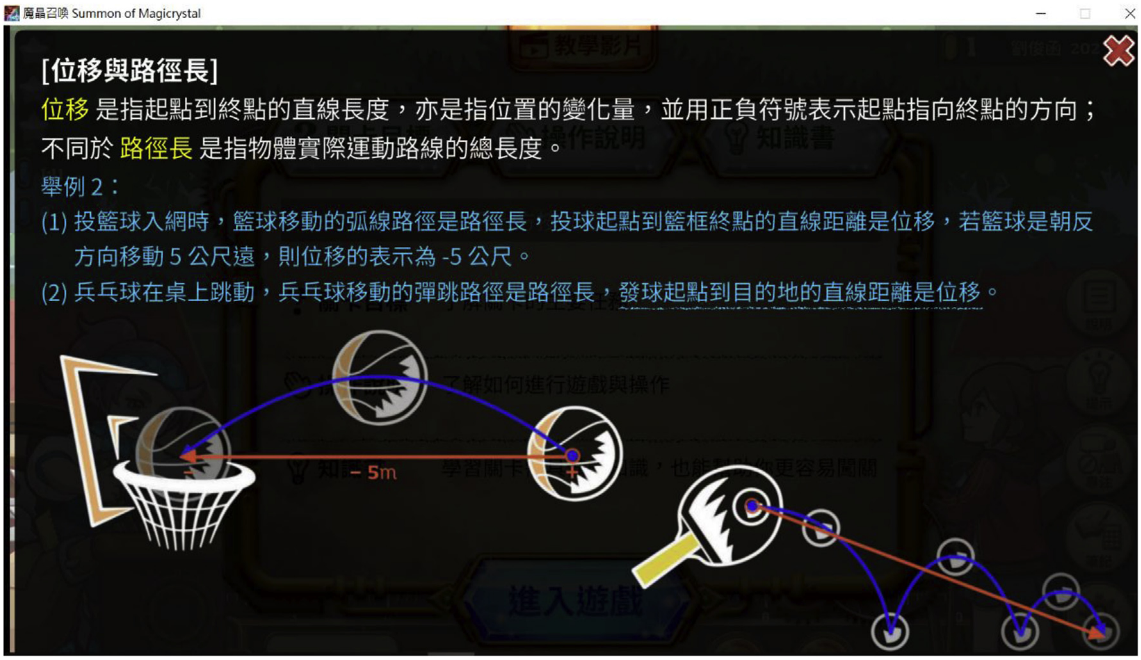

Fig. 6. Screenshot of instructional video.

topic(s) covered.” The Cronbach's alpha scores for the three aspects of the cognitive load surveys were 0.87, 0.91, and 0.78, respectively.

3.4. Procedure

After each student was assigned to one of the four treatment groups, each group participated in two 45-min sessions over two

Table 1
Examples of categories, codes, and descriptions SumMagic game level 1-2.

Categories	Codes	Descriptions
Speed change	SC	Students can click on or change the speed to observe it as time passes.
Game process	GP	When the game goal is achieved, students proceed to the advanced level.
Game start	GS	This shows that the basic level of game play is starting.
Board reading	BR	Students can read the game instructions and knowledge book to acquire more information.
Role click	RC	Students can click on the NPC to see whether they have successfully achieved the goal.
Hint use	HU	Students can seek help by clicking on the hint button.
Timer control	TC	Students can observe the timer to see how time has passed.
Note use	NU	Students can use the notebook to record the answers for game problems.
Calculator use	CU	Students can use the provided calculator to carry out calculations.

weeks period. The study took place in computer labs, with one teacher and two trained researchers present throughout the process. Before the game play, the students had approximately 20 min to complete the learning achievement pretest individually. In the first session of the study, the participants were introduced to the research team, informed of the general purpose of the study, and then given a description of the procedure. Thereafter, each student was given a unique username and password to access the digital game environment and proceed with the learning modules. Depending on their treatment conditions, the students had to play the game with or without watching the instructional video and do so alone or in a team of two or three members. After completing the game play, the students took the learning achievement posttest and completed the intrinsic motivation and cognitive load surveys.

3.5. Data analyses

Two major analyses were carried out in this study: (1) a 2 × 2 analysis of co-variance (ANCOVA) and (2) a lag sequential analysis (LSA). A 2 × 2 ANCOVA was conducted to evaluate whether the presence of an instructional video and collaboration affects learning achievement, intrinsic motivation, and cognitive load. A 2 × 2 ANCOVA method was chosen for this analysis because, first, it eliminates unwanted variance on the dependent variable, and second, it increases test sensitivity (Tabachnick & Fidell, 2013).

To thoroughly gauge the information concerning the students' behavior patterns, the students' gaming behaviors for game level 1–2's basic and advanced modes (totaling 28 students in the VGC group, 29 in the GC group, 8 in the VG group, and 6 in the game-only group) were retrieved and analyzed using LSA. When categorizing the gaming behaviors, we derived a categorization scheme or coding frame. The categories we adopted are the main functions that were used by the players in the gaming environment (see Table 1). Each category was given a specific code (such as SC, BR, or TC). LSA enables us to determine the transitions from one code to the next. The LSA steps involved the computation of a z-score for each transition, and if the z-score was above the 1.96 level, then a transition from one code to another was considered significant (Bakeman & Gottman, 1997). An adjusted residual table was also generated to explain significant associations between codes. The transitions were then depicted graphically by the researchers.

4. Results

4.1. Effects on learning achievement

Table 2 shows the descriptive statistics and results of ANCOVA on learning achievement, as well as the intrinsic motivation and cognitive load measures for the four treatment conditions. The results indicated a significant main effect of the instructional video, $F(1, 104) = 6.86$, $p = .01$, partial $\eta 2 = 0.06$, and observed power = .74; and a significant effect of the instructional video by

Table 2
Descriptive statistics and results of ANOVA on learning achievement, intrinsic motivation, and cognitive load.

	Instructional Video Present				Instructional Video Absent				F	η^2	Observed Power
	Video, game & collaboration (VGC) (N = 25)		Video & game (VG) (N = 28)		Game & collaboration (GC) (N = 30)		Game only (G) (N = 26)				
	Mean	SD	Mean	SD	Mean	SD	Mean	SD			
Posttest	66.60	13.67	45.18	18.23	44.83	12.83	48.65	15.07	10.71**	.09	.90
Intrinsic motivation	4.86	1.12	4.16	1.77	3.83	1.29	3.33	1.70	5.46*	.05	.64
Intrinsic cognitive load	5.47	2.25	6.67	2.21	6.87	2.22	6.89	2.22	1.89	.02	.28
Extraneous cognitive load	2.36	1.56	4.64	2.64	4.25	2.04	3.75	2.25	10.86**	.10	.91
Germane cognitive load	6.59	1.83	4.75	2.12	5.67	2.15	5.54	2.34	4.17*	.04	.53

*p < .05; **p < .01

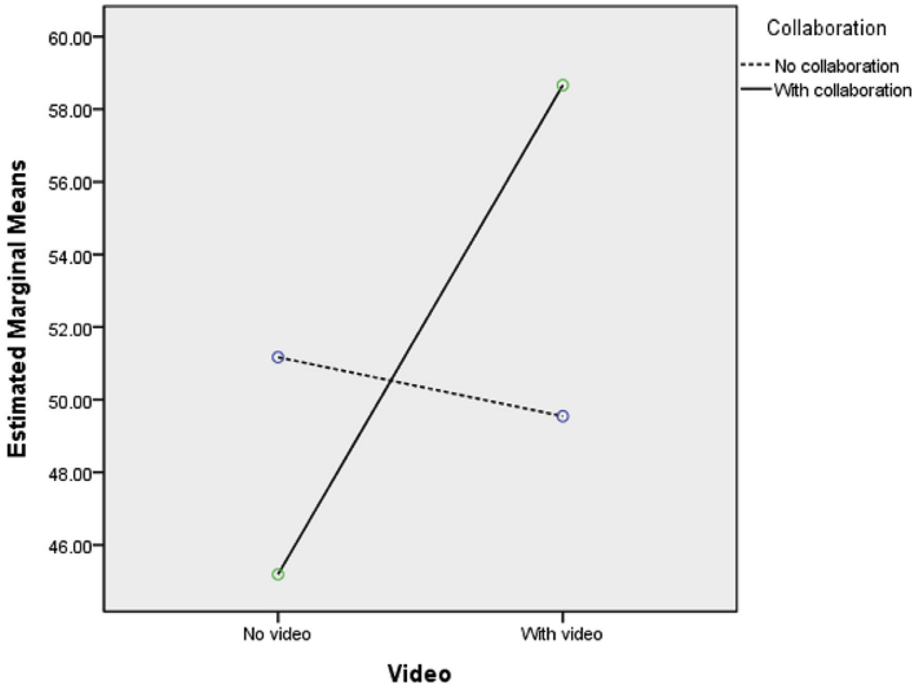

Fig. 7. Estimated marginal means of learning achievement by group.

collaboration, F (1, 104) = 10.71, p = .001, partial η^2 = 0.09, and observed power = .90. However, the main effect of collaboration was not significant. Fig. 7 illustrates the four groups' learning achievements.

4.2. Effects on intrinsic motivation and cognitive load

The effects of the instructional video and collaboration on students' intrinsic motivation and cognitive load were examined. For intrinsic motivation, the results indicated a significant main effect of collaboration, F (1, 103) = 8.53, p = .004, partial η^2 = 0.08, and observed power = .83. The results also indicated a significant effect of instructional video by collaboration, F (1, 103) = 5.46, p = .02, partial η^2 = 0.05, and observed power = .64. The main effect of the instructional video was not significant.

With regard to intrinsic cognitive load, no significant main effects of video, collaboration, or interaction were found. However, we found that for extraneous cognitive load, the main effect of collaboration was found to be significant, F (1, 104) = 4.46, p = .04, partial η^2 = 0.04, and observed power = .55. The interaction between video and collaboration was also significant, F (1, 103) = 10.86, p = .001, partial η^2 = 0.10, and observed power = .91. Similarly, for germane cognitive load, the main effect of collaboration was significant, F (1, 103) = 5.62, p = .02, partial η^2 = 0.05, and observed power = .65, and the interaction between video and collaboration was significant, F (1, 103) = 4.17, p = .04, partial η^2 = 0.04, and observed power = .53.

4.3. Effects on behavior patterns

Next, we succinctly explain the results from the LSA for each group and describe the indications for the significant behavior patterns.

4.3.1. Instructional video, game, and collaboration (VGC) group

As shown in Fig. 8, the significant behavior paths were SC ↔SC (z = 8.172), CU → NU (z = 7.541), NU → CU (z = 7.52), GS → BR (z = 7.134), GS ↔GS (z = 6.906), TC ↔TC (z = 6.426), RC → HU (z = 3.526), RC → GP (z = 3.145), RC → GP (z = 3.145), HU → BR (z = 2.223), and BR → HU (z = 1.8). These paths revealed the following important patterns: (a) the players had the tendency to do the same things again and again; (b) during game play, the players consistently read the instructions provided by the game to enable them to gain a better understanding of its goal and rules; (c) during the course of game play, the players tended to utilize the hints provided by the game to help them understand the problems; (d) the players consistently followed the guidance of the non-player character (NPC) to help themes proceed through the game; and (e) the players tended to use the calculator provided in the game to help them compute the equations and record the answers in the notebook.

4.3.2. Instructional video and game (VG) group

As shown in Fig. 8, the significant behavior paths were SC ↔SC (z = 8.44), GS → BR (z = 7.45), GS ↔GS (z = 6.81), RC → HU

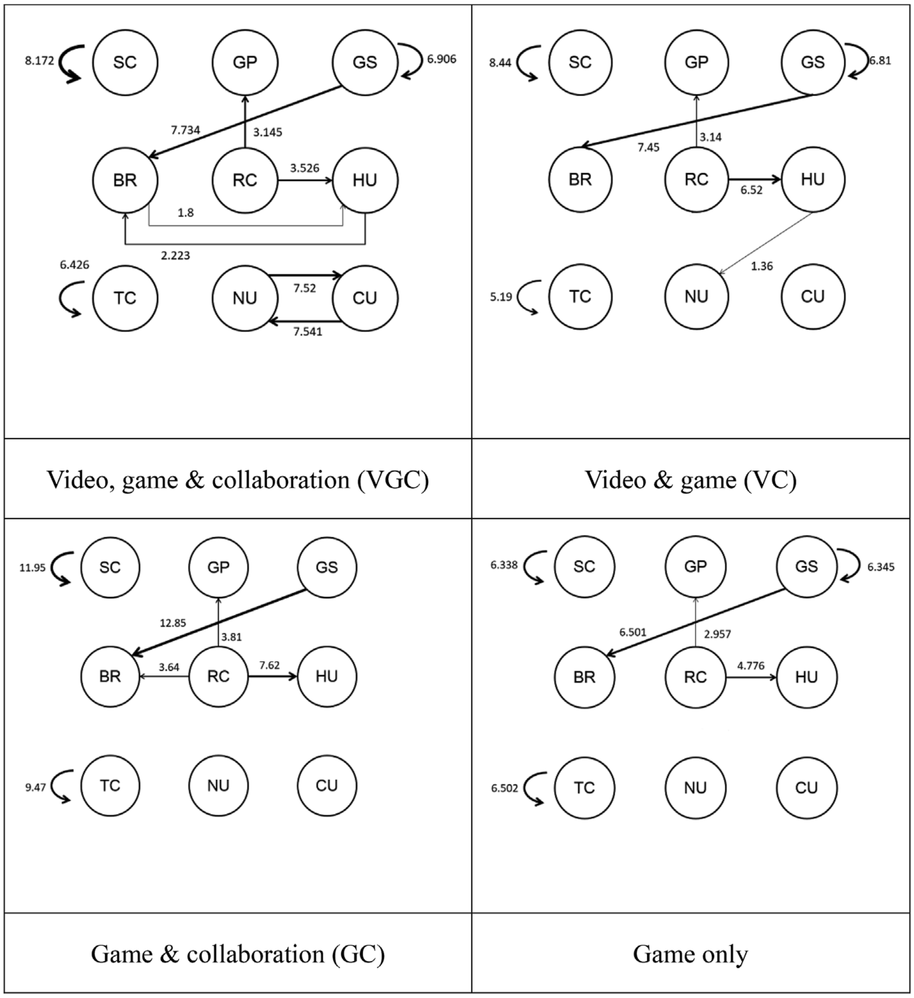

Fig. 8. Learning behavioral patterns of the four groups.

(z = 6.52), TC ↔TC (z = 5.19), PU → NU (z = 4.8), RC → GP (z = 3.14), and HU → NU (z = 1.36). These paths yielded some important patterns: (a) the players tended to do the same things repeatedly; (b) during game play, the players consistently read the instructions provided by the game to enable them to gain a better understanding of the goal and rules; (c) the players were aware of the hints that could help them respond to the questions asked by the NPC; and (d) the players recorded the answers for the hints in the notebook.

4.3.3. Game and collaboration (GC) group

As shown in Fig. 8, the significant behavior paths were GS → BR (z = 12.85), SC ↔SC (z = 11.95), TC ↔TC (z = 9.47), RC → HU (z = 7.62), RC → GP (z = 3.81), and RC → BR (z = 3.64). These paths revealed the following important patterns: (a) the players tended to do the same things repeatedly; (b) during game play, the players consistently read the instructions provided by the game to enable them to acquire a better understanding of its goal and rules; and (c) the players tended to follow the guidance of the NPC to help them understand the game problem and hints.

4.3.4. Game-only group

As shown in Fig. 8, the significant behavior paths were SC ↔SC (z = 6.338), GS → BR (z = 6.501), RC → HU (z = 4.776), GS ↔GS (z = 6.345), TC ↔TC (z = 6.502), and RC → GP (z = 2.957). These paths yielded some important patterns: (a) the players tended to do the same things repeatedly; (b) during game play, the players consistently read the instructions provided by the game to enable them to better understand its goal and rules; and (c) the players were aware of the hints that could help them respond to the questions asked by the NPC.

Based on the abovementioned behavior patterns, we found similarities and differences among the groups. We found that all the players had the tendency to do the same things again and again. This implies that guess-and-check strategies were typically adopted by the players. Another common strategy used by all the players was to view the hints for problem decomposition; we speculate that a large proportion of the players did this without attempting to answer, as evidenced by their constant reliance on assistance from the NPC to verify the correctness of the answers corresponding to the hints. However, in the VGC and GC groups, we observed alternate problem-solving strategies in regard to the use of hints. In the VGC group, the players may have already given correct answers but wished to compare the process used by the NPC by subsequently reflecting upon the problem-related goals and rules. In other words, the players in the VGC group were more likely to perform goal-oriented action planning during game play. In the VG group, we observed that the players took notes and wanted to answer the hints, but the players who engaged in this behavior may have been relying on scaffolding even when this technique was not needed.

5. Discussion

This study investigated the effects of collaboration and the use of an instructional video on students' learning achievement, intrinsic motivation, and cognitive load as they engaged in DGBL concerning Newton's first law. One specific purpose of the study was to meld two areas of research: collaboration theories and multimedia learning. While these research areas have been examined separately in both the traditional classroom and online learning contexts, few studies have empirically examined their effects or interrelationships in a DGBL setting.

5.1. Instructional videos, collaboration, and learning achievement

Expanding on the existing literature, which discusses the positive effects of instructional video use on learning (Homer et al., 2008; Overbaugh, 1995), this study found that instructional video use led to improved DGBL achievement. With regard to collaborative DGBL, our findings differ from those of past studies (Chen et al., 2015; Sánchez & Olivares, 2011). In the existing literature, collaboration is a common practice in DGBL. However, some studies suggest that certain scaffolds for collaborative learning in DGBL are necessary for the optimization of learning outcomes (Chen & Law, 2016; Wong, Boticki, Sun, & Looi, 2011). This study took a different approach by integrating an instructional video into collaborative DGBL. In this context, the effect of the instructional video was more pronounced when it was combined with collaborative learning. While past studies have examined the use of instructional videos and collaboration separately, this study found that, together, they seemed to lead to better learning achievement in the DGBL environment. The strengths of instructional videos can be further enhanced when they are combined with collaboration in the DGBL context.

5.2. Instructional videos, collaboration, intrinsic motivation, and cognitive load

Echoing the previous literature (Plass et al., 2013; Wouters et al., 2013), this study found that collaborative learning can increase students' intrinsic motivation in DGBL. While no effects of instructional video use on students' intrinsic motivation were found, there was a significant interaction effect of collaboration and instructional video use on students' intrinsic motivation. With regard to cognitive load, the scores for the intrinsic cognitive load instrument were all above the midpoint of the scale, suggesting that students exhibited greater mental workload and an increased level of effort when playing the game. The results indicate that this DGBL activity increased cognitive demand. According to our results, when intrinsic cognitive load is withheld, the students reported having a significantly lower extraneous cognitive load and higher germane cognitive load when engaging in instructional video and collaborative learning. In other words, the students perceived the DGBL as demanding increased mental workload and effort, and the instructional video and collaborative learning helped to increase their cognitive resources for the construction of a conceptual model, which, in turn, generated more cognitive capacity to progress in the DGBL. In addition, it can be inferred from the results that when students take the time to go over necessary mental processes for game play by watching an instructional video and discussing it with their teammates, they may be able to manage their cognitive resources more effectively, thereby contributing to improved learning motivation.

This study contributes to the collaborative learning and multimedia learning literature by providing empirical evidence against the intuitive assumption that collaborative learning reduces cognitive load in DGBL environments. It is possible that scaffolding, such as the use of instructional videos, does help to reduce extraneous cognitive load in collaborative DGBL. In examining the relationship between multimedia learning and collaborative DGBL, it is productive to look beyond a one-dimensional, universal-effect model to investigate how multimedia learning influences cognitive load in the DGBL context.

5.3. Instructional videos, collaboration, and learning behavior patterns

Students' gaming behaviors in the DGBL context were analyzed to provide further insights into the learning behavior patterns of different groups. The results of each group's learning behavior patterns are discussed here. Although all the students who played the game employed a guess-and-check strategy, the students in a collaborative DGBL setting were more likely to use the hints provided within the game than those who played the game alone. Further, those who played collaboratively and had access to the instructional video tended to perform goal-oriented behaviors, which means that their actions seemed strategically planned. It is speculated that instructional videos provide the necessary background knowledge to enable students to free up time for strategic game play. Additionally, in regard to teamwork, students can make use of the possible tools provided within the game environment, make judgments, and then react, all of which represent a hallmark of the problem-solving process.

6. Conclusion and implications

Overall, the findings suggest that, when combined with collaborative learning, instructional video use is an effective means of supporting learning achievement in the DGBL context. Moreover, such a combination can lead to reduced extraneous cognitive load, which may further contribute to improved learning. The behavior patterns further revealed that the instructional video provides the necessary knowledge background to enable students to free up time for strategic game play, and students performed goal-oriented action planning during game play in the collaborative DGBL context.

The study has two practical implications. First, for students to learn to apply principles and rules to solve science problems in the DGBL context, collaborative learning alone is insufficient. Scaffolding, such as the use of an instructional video, contains the necessary information for conceptual understanding and can lead to successful DGBL outcomes. Second, in the DGBL context, the combination of instructional video and collaborative learning provides optimal support for students' intrinsic motivation and maximizes their use of cognitive resources for tasks that are directly related to learning.

This study also has a few limitations, which should be considered when duplicating it in the future. First, we have little knowledge of whether students' prior gaming experience influenced their perceptions or the outcomes of the study; such prior experience may also have influenced their gaming strategies and decisions. Moreover, the students' characteristics, such as gender, can affect the quality of their participation in collaborative learning (Prinsen, Volman, & Terwel, 2007). While this study did not examine the effect of group composition on participation in the DGBL context, future research is needed to investigate the extent to which students' characteristics in regard to their participation in DGBL are related to their learning outcomes. Further, greater insight is required into how gender differences can contribute to learning with video-supported DGBL in a collaborative modality. It would also be worthwhile to conduct in-depth studies on the structure and presentational styles of multimedia-based learning-support materials and how they interact with other instructional contexts, as this would enable the meticulous exploration of their impacts on DGBL. For example, the question of which types of presentational styles in the instructional video affect learning outcomes warrants more evidence-based research so that assertions of their effectiveness can be ensured. A third limitation of this study is the selection of measurement tools for different aspects of cognitive load. Comparative indicators of the accuracy and reliability of the tools that were used should be established to enable the interpretation and value of the findings to be further ensured.

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