Learning through gaming: Examining the learning outcomes of EEK! game

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Video games have become interwoven into many aspects of modern daily life, with over three billion players spread across many devices (Wijman, 2021). This user growth has also been accompanied by rapid innovation of technology. In recent years, video games have reached education with game-based learning and has helped students develop useful skills and competencies (Barr, 2018). Incorporating games into educational environments can also increase student engagement and interest in topics, particularly those related to science and technology (Annetta et al., 2009; Honey & Hilton, 2011).

One such game developed with this intent is the Engineering Engagement Kit (EEK!), designed by Boston University's Engineering Center in Cellular Metamaterials (CELL-MET). The game aims to provide information about engineering and increase student engagement and interest towards the subject. Game content is based on the lab process of reconstructing functional heart tissue and attempts to broadly introduce players to the steps involved. With a single and multiplayer round, game developers also hope to mimic the teamwork required to work in a real laboratory for players to experience.

This research will explore the learning outcomes of an online prototype of EEK! to determine whether students will retain informational content, have increased curiosity and gain a greater appreciation of teamwork after game play. Specifically, this research will examine the most effective order of content and activity presentation, and discover if presenting an informational video before, during, or after gameplay will maximize learning outcomes.

Video Games for Learning Purposes

Video games can be designed to provide users with a multimedia learning experience by including instructional messaging in printed or spoken text and through using graphics with educational intent (Mayer, 2019). Research on game-based pedagogy has received a lot of attention in recent years, and scholarship shows that students prefer simulation games to traditional learning methods (Ding et al., 2017).

Research at this intersection has examined how educational games have influenced student's engagement with learning content introduced in the games. Whitton's (2011) study defines engagement as a subjective state that is observable only by the individual participating in the activity through their interaction with the activity at a given time. Whitton (2011) proposes a five-factor model of learning engagement that takes into account how the factors: challenge, control, immersion, interest and purpose, contribute to overall sense of engagement.

Engagement has been shown to correlate with success of educational games (Sharek & Wiebe, 2014). The work of Sabourin and Lester (2014) reported students in a game-based learning environment were less likely to report negative emotions that were reported during traditional learning activities. Their research also suggests that a balance between independent and guided problem-solving influences the level of game engagement. Therefore, the organization of media content can impact engagement, which can impact the learning outcomes from game-based learning (Sabourin & Lester, 2014).

Presentation Order of Media Exposure

Excitation-transfer theory has been extensively applied to understand interactions between individuals and media. Particularly, excitation-transfer theory explains that emotional arousal induced by media content can linger after content exposure has ended. This lingering arousal can remain into subsequent information processing (Zillmann, 1996). For example, consuming suspenseful programming like sports games can influence favorability towards the advertisements that followed it (Bee & Madrigal, 2012). Further, research reveals listening to music can influence later moods and emotional responses towards subsequent settings

(Timmerman et al., 2008). In an educational context, researchers found that posing questions and personalizing communication during class time can have a positive impact on children's information acquisition after the class (Tamborini & Zillmann, 1985).

As arousal arises from a preceding activity in excitation-transfer theory, order is a key element that must be considered (Zillmann, 1996). Empirical studies on order-of-play in video games have shown that effects are more evident in games with less complexity (Muller & Sadanad, 2003). Past research found that initial content introduced can impact the benefits of learning sequences (Katona, 1942).

Relatedly, studies on game transfer show that thoughts, sensations, and actions that occur while playing video games can be transferred into players' real lives when elements are similar (Ortiz de Gortari et al., 2011). For example, hearing a song from a game's soundtrack can trigger the same emotions felt during gameplay. The structural characteristics, content, and activities found in the game can all impact later experiences (Ortiz de Gortari, 2015).

Enjoyment, a key concept within the context of game transfer, is defined as a pleasant experiential state, including physiological, cognitive, and affective components (Vorderer et al., 2004). Video games can evoke joy, with empirical studies on behavior showing that people's intrinsic motivation to play video games is to achieve innate satisfaction or enjoyment (Przybylski et al., 2010). This pleasant arousal can also be transferred where attitudes towards brands advertised in video games are more favorable when the attitude towards the game itself is favorable (Vanwesenbeeck et al., 2017). Educational research shows that an exciting lecture with activities arouses students' enjoyment and in turn results in better performance compared to a standard lecture (Hernik & Jaworska, 2018). Revealing an existing effect of presentation order on student enjoyment, Wang et al. (2019) argued that students who can self-regulate the sequence of educational gameplay experience a higher enjoyment from learning. Another study found that task resolution and switching strategically between different sources of fun positively correlates to an experience being enjoyable, and could help students maintain a positive experience even when performance-based enjoyment is low (Klimmt et al., 2009).

Research also suggests interest can be transferred, with one study concluding interest towards a sports program can influence favorability on subsequent advertisements (Bee and Madrigal, 2012). Interest is defined as containing three dimensions: perceptions of meaningfulness, involvement, and prior knowledge (Weber & Patterson, 2000). This concept is separated into two distinct categories of personal interest and situational interest (Schraw et al., 1995). Personal interest comes from prior knowledge and involvement in the subject by the individual. It is unique, personalized, and lasts over a long period of time. In contrast, situational interest arises based on the specific context, is short term, and experienced by groups of individuals (Schraw et al., 1995). Past studies show that personal interest has a strong connection with comprehension and knowledge acquisition while situational interest has mixed effects on both increasing information recall and interfering with learning (Schraw et al., 1995). Therefore, interest can be influenced by presentation order, and it might even relate to an increase in knowledge acquisition.

Transfer of Knowledge

Widely used in educational research, transfer theory refers to when skills or knowledge received in a preceding context are applied to a different yet similar context after (Lieberman et al., 2014). Near-transfer occurs when knowledge is transferred between two contexts that are closely related (Lieberman et al., 2014), such as learning languages with the same linguistic roots. In contrast, far-transfer describes the situation where knowledge is transferred between contexts that are distantly related and with less clear overlap (Lieberman et al., 2014). For example, the skills to play a wind instrument are different from those required to play percussion, but the general knowledge of music and instruments can transfer and make learning the drums easier. Research has shown that video games can be a source of transfer of knowledge from online to offline, non-digital contexts (Lieberman et al., 2014).

Knowledge acquisition, or the process of "locating, collecting, and refining knowledge," (Harmon & King, 1986) has been shown to be an example of transfer that occurs while gaming (Lieberman et al., 2014). Studies in the past have investigated the effects of gaming approach on knowledge acquisition (Ricci et al., 1996). For instance, Ricci et al. (1996) found that the use of games led to higher retention of knowledge than traditional methods of learning among military trainees (Ricci et al., 1996). Past research has also shown that gaming can be useful for learning-related memory processes in college students (Goodman et al., 2006). Empirical work related to information recall suggests that presenting messaging within a game can influence the participants' memory of that messaging (Lee et al., 2007).

Skills, like teamwork, can also be transferred from one context to another (Lieberman et al., 2014). Conceptually, collaboration refers to a combined effort between two or more people to accomplish a task (Ulrich et al., 2019). It involves using soft skills such as interpersonal communication, problem solving, and adaptability. Collaborative games have been shown to teach these skills, with students in one study citing improv games as helpful for, "interacting with new people," "accommodating," and "sharing ideas" (Rice-Bailey, 2021). Majority of participants also viewed collaboration as a transferable skill gained through gameplay.

Research Questions

As past empirical research has shown, the presentation order of content and gameplay can be impactful on the transfer of knowledge and collaboration skills. Excitation transfer theory also explains that order can influence how the audience processes the material, resulting in increases in interest and engagement. Participants' enjoyment of exciting educational content can also result in better academic performance (Hernik & Jaworska, 2018).

This study explores how different order placements of the scientific content affects learning outcomes of EEK! and content transfer for game players. The video game includes three main components; an informational content video on the engineering of heart tissue reconstruction, accompanying instructional videos for the game, and the gaming activity.
One goal CELL-MET prioritized in game development was to educate players on basic engineering ideas mainly presented in accompanying content videos.

To understand the role order of presentation in the EEK! game has on knowledge acquisition, the following research question is proposed:

RQ 1: How does the presentation order of content and activity in EEK! gameplay impact players' knowledge acquisition?

Excitation-transfer theory states that arousal generated by one activity can be carried over to subsequent stimuli. The present study will determine whether players' situational interest in engineering will increase after video gameplay. Past research supports this kind of excitation transfer by finding that interest for an initial stimulus can influence favorability towards following content (Bee & Madrigal, 2012). To examine the effect of order of presentation in the EEK! game has on perceived situational interest in engineering, the following research question is raised:

RQ 2: How does the presentation order of content and activity in EEK! gameplay impact players' interest in engineering?

The EEK! game includes a single player mode and a multiplayer round that requires teamwork between players. Collaboration, or a combined effort between people to accomplish a task, includes communication, problem solving, and adaptability (Ulrich et al., 2019). Both the accompanying content video and instructional video emphasize the importance of teamwork to run a successful laboratory. As skills gained in one context can be transferred to subsequent contexts (Lieberman et al., 2014), the following research question is raised:

RQ 3: How does the presentation order of content and activity in EEK! gameplay impact players' perception of collaboration?

The work of Sabourin and Lester (2014) suggests that a balancing between varying activity challenges influences the level of game engagement. Other studies have also stated engagement as relevant to the success of educational games (Sharek & Wiebe, 2014). Given the significance of game engagement, the following research question is raised:

RQ 4: How does the presentation order of content and activity in EEK! gameplay impact players' perception of their level of engagement with the game?

Alongside engagement, another important variable of consideration is enjoyment from the game. This pleasant experiential state can generate arousal (Vorderer et al., 2004), which might be passed on to sequential stimuli. Review of literature also suggests student enjoyment can lead to a more sustained, long-term process of knowledge acquisition (Mohsen, 2016; Hernik & Jaworska, 2018). Enjoyment as a possible confound aligns with both excitation-transfer theory and transfer theory. Therefore, the following research question is raised:

RQ 5: How does the presentation order of content and activity in EEK! gameplay impact players' knowledge acquisition, when controlling for players' level of enjoyment?

Past scholarship also suggests a relationship between enjoyment and participants' engagement with the game. The five-factor model of learning engagement includes the factors of challenge, control, immersion, interest, and purpose (Whitton, 2011). Interest and motivation has been shown to increase in students when enjoyment is high (Mohsen, 2016). Control over task-switching and the process of educational gameplay has also been found to correlate with higher enjoyment levels (Wang et al., 2019; Klimmt et al., 2009).

As enjoyment has been established to be an important possible confound, the following research question is raised:

RQ 6: How does the presentation order of content and activity in EEK! gameplay impact players' perception of their level of engagement with the game, when controlling for players' level of enjoyment?

Method

Pilot Study

A preliminary pilot study was run prior to data collection to improve experimental design and inform methodology. There were eight participants in the pilot study, including both undergraduate and graduate students. All participants played the single player mode against the computer and watched the accompanying information content videos. Additionally, four participants played the multiplayer mode in pairs. Participants were encouraged to ask questions, which researchers documented.

The questions raised by pilot study participants were related to three topics: game operation, game content, and the collaboration aspect of the game. Notably, the most frequently asked question concerned clarification of instructions. Specifically, people asked for more information on the dice swap rules in the multiplayer collaborative round of the game. These findings contributed to the development of a detailed script used by researchers while conducting the formal experiment. In this script, pre-written answers were included for frequently asked questions regarding game play and instructions. However, to avoid confounding variables, it was decided questions around game content and strategy would not be answered by researchers during the formal experiment.

Qualitative observations from the pilot study also provided insights about the game and different types of participants. For example, previous gaming experience seemed to be a factor affecting the player's ability. Participants who were frequent gamers understood the game quicker compared to participants with little video game experience. This finding led to the addition of a question on video game experience in the pre-test questionnaire used in the formal study.

Experiment

Participant Recruitment

A total of 42 participants were recruited through on-campus and online forum fliers. Participants were self-identified as at least 18 years old with normal or corrected-to-normal vision. Anyone currently studying engineering, biology or medicine, or who has seriously pursued those fields in the past, were asked not to participate. Participants included undergraduate students, graduate students, and young working professionals. All participants were compensated with a $10 Amazon gift card delivered digitally.

Participants signed up through an online scheduling platform linked on the recruitment flier. Each available time slot required two players because of the multiplayer rounds of the

EEK! game. Hence, some participants registered in pairs with chosen partners, while others were paired with whomever else was available. In the cases when a second participant could not be found, the registered individual participant was asked to reschedule.

Procedure

Participants were greeted by two researchers at the beginning of the study session who followed the same pre-written script to maintain consistency across sessions. Participants were led into a computer lab and provided with informed consent forms. Once informed consent was obtained, they completed a questionnaire measuring their initial interest in engineering, then subsequently showed the instructional video to the game. Then, they engaged in the engineering activities, conditionally manipulated. After gameplay was completed, participants were instructed to answer a second questionnaire measuring their knowledge acquisition, interest in engineering, level of engagement with the game, and perception of collaboration. To wrap up their participation, they were instructed on how they would receive their gift card via email and were thanked for participating in the research study.

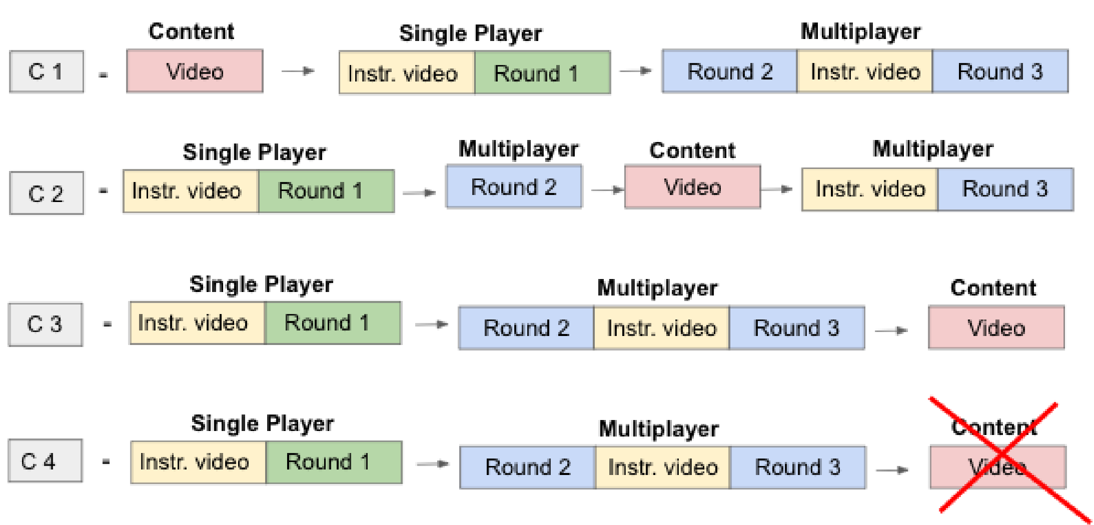
Conditions

In this between-subjects experiment, presentation order was manipulated through four experimental conditions. Particularly, the order in which participants were presented with an informational video providing the scientific context of the game, two instructional videos explaining the rules of the game, and three rounds of gameplay, differed by condition. The conditions are represented in Figure 1. In Condition 1 (C1), participants started by watching the informational content video. Then, they watched an instructional video explaining how to play the game. Participants proceeded to individually play the first round in single player mode on two separate laptops. After completing the round, participants were asked to play on the same laptop and asked to play individually again, but on a split screen with different halves of the keyboard. Participants were told this was a practice round to adjust to the new set-up, and researchers noted which side each participant played on. After this round was completed, a second instructional video was shown introducing new collaborative game tasks. Finally, participants played the third multiplayer round. Researchers noted if the pair won or lost the final round.

Condition 2 (C2) followed a similar structure, but the informational content video was shown to participants after the practice round before the second instructional video. In Condition 3 (C3), the informational content video was shown to participants at the end after the last round of gameplay was completed. Finally, the informational content video was not shown at all in Condition 4 (C4).

Figure 1

Experimental Conditions



Measurement

Knowledge Acquisition. Knowledge acquisition was measured in two parts: (1) a series of seven true/false questions with exclusive ground truth, based on information found in the content presented in the experiment; (2) questions to identify all keywords relevant to the presented content from a list. In total, 7 items were used with a categorical scale (yes/no). The items included statements like, "The heart cannot heal itself," and "CELL-MET Lab builds heart tissue." Researchers used statistical software, SPSS, to recompute the categorical scale to a numerical scale. Based on the ground truth of each question, the correct answers from participants were re-coded as 1 and incorrect answers were recoded into 0. The knowledge acquisition score of each participant was calculated by aggregating the number of correct answers (M= 5.05, SD = 1.431) and used for further statistical analysis.

Interest in Engineering. Situational interest in engineering was measured both before and after the experiment. The Perceived Interest Questionnaire from Schraw et al. (1995) was adapted to measure interest in engineering both before and after gameplay. The statements presented in the post-gameplay questionnaire and those in the pre-gameplay questionnaire remained consistent in meaning but were differently worded. In total, the perceived interest in Engineering consists of 10 items using a 5 point Likert scale ((1 = strongly disagree, 5 = strongly agree, α = .92, M=3.15, SD = 0.81). The scale consisted of items like, "I think engineering is very interesting", "I would like to discuss developments in engineering with others at some point" and "I would read a news story on engineering." Mean score of interest in engineering of each conditions are: C1 (M=3.29, SD=1.08), C2 (M=3.10, SD=0.66), C3 (M=3.33, SD=0.75), and C4 (M=2.86, SD=0.67).

Perception of Collaboration. Participants' perception of collaboration was measured using a three-item with 5 point Likert scale (1=strongly disagree, 5=strongly agree) adapted from Gandolfi's (2018) instrument (α = .60, *M*=3.78, *SD* =0.71). Specific items included statements like, "You shared game strategies and tips with your game mates" and "You were receptive to your game mates."

Engagement. Participants' perceived level of engagement with the game was measured using a 17-item, 5-point Likert scale (1=strongly disagree, 5=strongly agree), adapted from Whitton's (2007) Game Engagement Questionnaire (α = .88, *M* = 3.54, *SD* = 0.59). This included items like "I felt absorbed in the game," "I felt that time passed quickly," and "I found the game frustrating."

Enjoyment. Participants' perceived level of game enjoyment was measured on an 11-item, 5-point Likert scale (1=strongly disagree, 5=strongly agree), using the computer gameplay enjoyment instrument by Feng et al. (2008) (α = .71, *M*= 3.36, *SD* = 0.50). Some of the items in the scale were "I felt happy when playing this game" and "I felt miserable when playing this game." Mean score of perceived enjoyment of each conditions are: C1 (*M*=3.32, *SD*=0.45), C2 (*M*=3.08, *SD*=0.43), C3 (*M*=3.50, *SD*=0.56), and C4 (*M*=3.53, *SD*=0.51).

Qualitative Assessment. To qualitatively understand players' experiences, a set of open-ended questions on game operation, challenges faced while playing, and the overall experience of playing the game were included in the questionnaire administered at the end of the experiment. These included questions like, "What features of the game kept you focused?" "What features of the game distracted you?," "Which part of the game did you enjoy the most?" and, "Which part of the game did you find most challenging?. The questionnaire from Fu et al. (2009) for players of learning games was adapted to gain qualitative insights on knowledge advancement, inter-player collaboration, interest in engineering, and engagement with the game perceived by the participants after gameplay. This included statements, with Yes or No response options, like "I felt the game increased my knowledge," "I felt the game encouraged me to collaborate with my partner," "The game made me curious about developments in engineering," and, "I could remain concentrated in the game."

Manual content analysis was used to analyze the data from the open-ended questions. This involved the deductive coding of the self-reported experience of playing the EEK! Game to understand participant perception of knowledge acquisition, collaboration, interest in engineering, and engagement and enjoyment from playing the game. Inductive coding was also used to identify themes that were recurring in the respondents' perceptions of the game.

Results

In total, 42 people participated in the experiment. Two participants were removed after data collection because their college programs of study violated the recruitment criteria. The final sample was 40 participants (11 participants involved in condition 1 (C1); 9 participants involved in condition 2 (C2); 10 participants involved in condition 3 (C3); and 10 participants involved in condition 4 (C4)), comprising 18 males and 22 females. The age of the participants ranged from 19 to 38 years old, with 24 participants (60%) from the sample being between 19-24 years old. Most of the participants were students, spanning 17 academic majors. Of the 40 participants, 20 participants reported a master's degree level of education, representing 47% of the total. Over 67.5% of the total sample, or 27 participants, identified as East Asian. Also, 20 participants reported Mandarin to be their primary language.

When asked about video game habits, 10 participants said they played video games every day, 13 participants said they played video games every week, 7 participants said they played video games every month, and 10 participants said they rarely played video games. There were no significant differences in gameplay habits across conditions. Examined by a cross-table analysis, each gameplay habit frequency was represented in each condition by between 1-5 participants. This indicates that participants with different gameplay experiences are relatively equally distributed across conditions.

Effect of presentation order on knowledge acquisition

In order to understand the effect of presentation order of content and activity in EEK! Gameplay on players' knowledge acquisition, a one-way between-subjects analysis of variance (ANOVA) test was conducted to test the effect of EEK! gameplay's content and activity presentation order on players' knowledge acquisition. There is no statistically significant difference in mean score of knowledge acquisition in the different presentation order conditions ($F(3, 36) = [.736]$, $p = .537$, $\eta^2 = .058$). Thus, the presentation order of content and activity in EEK! gameplay did not affect players' knowledge acquisition.

Effect of presentation order on interest in engineering

A one-way between-subjects ANOVA test was also performed to test the effect of presentation order of content and activity in EEK! Gameplay on players' interest in engineering. There is no statistically significant difference in mean interest score in the different presentation order conditions ($F(3, 36) = [.693]$, $p = .562$, $\eta^2 = .055$). Therefore, the presentation order of content and activity in EEK! gameplay also did not impact players' interest in engineering.

The results of a one-tailed paired samples t-test on participants' interest in engineering reported in pre-gameplay and post-gameplay questionnaires suggested that the level of interest in engineering is higher post gameplay. The participants showed significantly higher interest in engineering (*M* = 3.15, *SD* = .81, *t*(40) = -9.38, *p* < .001, d_{Cohen} = -1.48) after gameplay compared to their self-reported interest in engineering before the gameplay (*M* = 2.19, *SD* =0.76, 95%).

Effect of presentation order on perception of collaboration

A one-way between-subjects ANOVA was also conducted to test the effect of presentation order of content and activity in EEK! Gameplay on players' perception of collaboration. There is a statistically significant difference in mean collaboration perception score between the conditions ($F(3, 36)$ = [3.63], p = .022, η^2 = .232). Hence, the presentation order of content and activity in EEK! gameplay has a main effect on players' collaboration perception. A Tukey HSD test for multiple comparisons reveals that mean collaboration perception score is significantly different between C1 and C2 (*p* = .029, 95% C.I. = [0.07, 1.62]), and C2 and C4 (*p* = .033, 95% C.I. = [-1.65, -0.05]) (see Table 1). Mean collaboration perception scores in 4 different conditions are: C1 (*M* = 4.03; *SD* = 0.526); C2 (*M* = 3.19; *SD* = 0.58); C3 (*M* = 3.8; *SD* = 0.757); C4 (*M* = 4.03; *SD* = 0.693).

Table 1

Post - Hoc Tests: Tukey HSD for Multiple Comparisons; Dependent Variable: Perception of Collaboration

Presentation Order (i)	Presentation Order (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C1	C2	.85*	0.29	0.029	0.07	1.62
	C3	0.23	0.281	0.845	-0.53	0.99
	C4	0	0.281	1	-0.76	0.75
C2	C1	-.85*	0.29	0.029	-1.62	-0.07
	C3	-0.61	0.296	0.18	-1.41	0.18
	C4	-.85*	0.296	0.033	-1.65	-0.05
C3	C1	-0.23	0.281	0.845	-0.99	0.53

	C2	0.61	0.296	0.18	-0.18	1.41
	C4	-0.23	0.288	0.849	-1.01	0.54
C4	C1	0	0.281	1	-0.75	0.76
	C2	.85*	0.296	0.033	0.05	1.65
	C3	0.23	0.288	0.849	-0.54	1.01

Note, C1 refers to the condition with the content video before any rounds, C2 refers to the condition with content video between rounds, C3 refers to the condition with content video after all rounds, C4 refers to the condition without content video.

Effect of presentation order on game engagement

A fourth one-way between subjects ANOVA was also performed to examine how the presentation order of content and activity in EEK! gameplay impacts players' perception of their level of engagement with the game. This compared players' engagement level in the four different presentation order conditions, as well as overall engagement level across all four presentation order conditions. As Table 2 indicates, players' overall engagement level across all four presentation order conditions is quite high (M = 3.542, SD =0 .586).

Table 2

Descriptive Analysis for Game Engagement

Presentation Order	Mean	Std. Deviation	N
C1	3.7594	0.48824	11
C2	3.0458	0.5671	9
C3	3.6765	0.60388	10
C4	3.6176	0.49078	10
Total	3.5426	0.58574	40

There is a statistically significant difference in mean engagement level score in the different conditions (F(3, 36) = [3.43], p = .027, η^2 = .222). Hence, the presentation order of content and activity in EEK! gameplay has a main effect on the players' level of engagement. A

Tukey HSD test for multiple comparisons reveals that the mean engagement level score is significantly different between C1 and C2 ($p = .027$, 95% C.I. = [.06, 1.36]) (see Table 3). Mean engagement level scores in 4 different conditions are: C1 ($M = 3.759$; $SD = 0.488$); C2 ($M = 3.046$; $SD = 0.567$); C3 ($M = 3.677$; $SD = 0.604$); C4 ($M = 3.618$; $SD = 0.491$).

Table 3

Post - Hoc Tests: Tukey HSD for Multiple Comparisons; Dependent Variable: Level of Engagement

Presentation Order (i)	Presentation Order (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C1	C2	.7136*	0.24166	0.027	0.0628	1.3644
	C3	0.0829	0.23492	0.985	-0.5498	0.7156
	C4	0.1417	0.23492	0.93	-0.491	0.7744
C2	C1	-.7136*	0.24166	0.027	-1.3644	-0.0628
	C3	-0.6307	0.24703	0.068	-1.296	0.0346
	C4	-0.5719	0.24703	0.113	-1.2372	0.0934
C3	C1	-0.0829	0.23492	0.985	-0.7156	0.5498
	C2	0.6307	0.24703	0.068	-0.0346	1.296
	C4	0.0588	0.24044	0.995	-0.5887	0.7064
C4	C1	-0.1417	0.23492	0.93	-0.7744	0.491
	C2	0.5719	0.24703	0.113	-0.0934	1.2372
	C3	-0.0588	0.24044	0.995	-0.7064	0.5887

Note, C1 refers to the condition with the content video before any rounds, C2 refers to the condition with content video between rounds, C3 refers to the condition with content video after all rounds, C4 refers to the condition without content video

Effect of presentation order on knowledge acquisition when controlling for enjoyment

An analysis of covariance (ANCOVA) including game enjoyment as a covariate of knowledge acquisition was used to examine the how presentation order of content and activity in the EEK! Gameplay impacts knowledge acquisition, when controlling for players' level of enjoyment. Results indicated a statistically non-significant effect of presentation order on knowledge acquisition when game enjoyment was controlled for, F (3, 35) =[3.758], $p = .525$, $\eta^2 = .078$. Therefore, the presentation order of content and activity did not have an effect on players' knowledge acquisition, when controlling for players' level of enjoyment.

Effect of presentation order on game engagement when controlling for enjoyment

An ANCOVA including game enjoyment as a covariate of perceived game engagement was used to examine how presentation order of content and activity in EEK! gameplay impacts players' perception of their level of engagement with the game, when controlling for players' level of enjoyment. Results indicate a significant effect of presentation order on perceived game engagement when game enjoyment was controlled for, F (3, 35) =[3.443], $p = .027$, $\eta^2 = .662$. Results also reveal that the level of enjoyment, as a covariant, significantly adjusts the association between the presentation order and the level of engagement, F (1, 35) =[45.46], $p < .001$, $\eta^2 = .439$. Therefore, the presentation order of content and activity in the gameplay have an impact on players' perception of engagement with the game, when controlling for their level of enjoyment.

Qualitative Results

Perception of Collaboration in EEK! Gameplay

Overall, 38 out of 40 participants (95%) reported that the EEK! Game encouraged them to collaborate with their game partner by agreeing with the statement, "I felt the game encouraged me to collaborate with my partner." In addition, 30 participants (75%) expressed that collaboration improved their understanding of the game by showing their agreement with the statement, "Collaboration with my game partner helped me understand the game better."

Furthermore, 38 participants (95%) perceived that collaborative gameplay contributed to their enjoyment of the game. This was evident in their agreement with the statement "Collaboration with my game partner helped me enjoy the game better."

Recurring responses of participants to the open-ended question, "What in your opinion were the learning tasks?" showed that respondents found EEK! Game to be conveying the importance of collaboration for a successful outcome. Participants identified "working in a team," "being attentive of the other player," and taking action "to help each other" as learning tasks associated with the game. One participant recalled that the game helped them learn "how teammates could collaborate successfully in a limited time" (Participant A). Participants recalled exchange of colored dice, a game feature that required collaboration, when asked to identify game features that aided learning. Some participants particularly reflected on the importance of communication between team members to achieve a common goal in a limited time as seen in the following examples:

> Exchanging certain colors with each other by double-clicking a letter…made us aware of each other's needs to complete the game and we needed clear communication to achieve it. (Participant B)
>
> When two people play together, they could save time and have less attempts to complete their goal. (Participant C)

Participants' descriptive responses to the question, "Which part of the game did you enjoy the most?" also assert that the opportunity provided by multiplayer mode "to share time" and "work with another person to attain the goal" added to the understanding and enjoyment of the game.

Knowledge Acquisition from EEK! Gameplay

Present study found that 28 participants (70%) agreed with the statement, “Most of the gaming activities are related to this learning task,” suggesting that most participants felt that the game was a learning experience. Several participants reported gaining an understanding of the collaborative process involved in interdisciplinary engineering research, particularly in the reconstruction of the heart tissue. Participants’ descriptive responses to the question, “What features of the game were examples of learning tasks,” suggests that players identified knowledge about heart reconstruction as a key learning from the game. This is exemplified in the response from Participant D who said that, “matching the color squares to the appropriate box was supposed to simulate building heart tissue.” The perception that the game imparted knowledge about heart tissue engineering echoed in participants’ descriptive responses to the question, “What in your opinion were the learning tasks?” Most respondents mentioned “bioengineering,” “coordination in formation of heart cells,” “understanding the process of building a heart tissue,” and transforming the “heart tissue problem into a process” that “required collaboration.”

Engagement and Enjoyment from EEK! Gameplay

Thirty six respondents (90%) found the game to be engaging when asked if they could remain concentrated in the game and 34 participants (85%) expressed enjoyment in playing the EEK! Game when asked to show their agreement, or lack thereof, with the statement “I enjoyed the game.” The overarching sentiment of the participants was that they found the game to be engaging. For instance, a participant said in response to the question, “What is your overall experience of playing this game?”:

“Very entertaining. This would be helpful to educate even kids, very nicely developed and not overly complicated to understand" (Participant E).

Participants identified specific game features such as task completion and color coordination as factors that contributed to the sustained feeling of engagement during gameplay when asked the question, “What features of the game kept you focused?.” Descriptive player responses indicated that making themselves accountable to the “sense of tasks” and the time taken “to achieve the task” aided their concentration while playing. Participants also expressed that “paying attention to the colors” helped them better engage with the game. This is evident in the response of Participant F, who explained, “the color-coding made it easier to complete the task.” Another participant reported that “trying to match the colored boxes to the corresponding square within a time frame” was the most enjoyable aspect of the game when asked, “Which part of the game did you enjoy the most?.”

Other features of the EEK! game that were specified by the participants as boosting their level of engagement with the game were the competition and dice rolling present in the game. Some of them said in their descriptive answers to the question, “What features of the game kept you focused?”, that “the interactive component of rolling the dice and selecting the squares of the same color” and the “competitive nature of trying to uncover all of the pieces" helped them remain concentrated on the game.

In addition, previous experience with video gaming was also reported to aid concentration during gameplay. However, a few participants identified the overall game layout, and inadequate length and clarity of instructional videos for the game as responsible for their lack of engagement with the game when they were asked, “What features of the game distracted you?” Participants also reported challenges that were faced during the gameplay. The timed nature of the game while keeping the players engaged also made the game more challenging for some of the participants. The presence of "countdown" and the need "to solve the game in a specific time frame" were cited in descriptive answers by these participants when asked, "Which part of the game did you find most challenging?" Several participants also found the game to be challenging in single player mode, where there was no option to collaborate with a game partner. While most participants felt that the ability to collaborate with a partner made the game engaging, it did not come without difficulties. Participants found game features in the multiplayer mode such as locking and trading of dice between players to be particularly demanding.

Discussion

Present research studied the learning outcomes of the EEK! computer game, created by Boston University's CELL-MET Center. Particularly, the study tested the effect of placement of an accompanying informational content video within the gameplay sequence. The variables measured were knowledge acquisition, interest in engineering, perception of collaboration, engagement with the game, and enjoyment of the game. Our study revealed mixed results about the significance of the order in which content for learning is introduced in pedagogical approaches using games.

The presentation order was not found to have a significant impact on players' knowledge acquisition. Although transfer theory suggests a relationship between these variables, this was not found in the present study. While participants seemed to remember information from gameplay, the knowledge acquisition scores did not differ significantly between conditions with varying orders of presentation. It is possible that gameplay did increase participants' attention to the educational content, but it is concluded that the sequential order of content and activity did not have an impact on acquiring knowledge.

The qualitative results showed participants felt the majority of the gameplay was educational in nature. Answers to the question, “What in your opinion were the learning tasks?” included “bioengineering,” “coordination in formation of heart cells,” and “understanding the process of building a heart tissue.” Largely, participants perceived the game to include educational information.

Similarly, interest in engineering was reported to be significantly higher after gameplay than prior to playing the EEK! game. This is aligned with past literature on excitation transfer theory which discusses the media effect of transfer of motivation and interest. However, there was no statistically significant difference in mean interest levels between conditions. This reflects the presentation order’s lack of impact on the variable. The content video’s sequential placement did not seem to influence the higher levels of interest in engineering seen in the participants.

However, the present research found that a significant relationship exists between presentation order and players’ perception of collaboration. Collaboration between players specifically refers to the last round of gameplay, when participants worked together, and the game developers had hoped for a high level of perceived collaboration. The data shows participants in C1, when the informational content video was presented at the beginning, and C4, when the informational content video was never presented, reported the highest levels of perceived collaboration post-gameplay. It is possible that seeing the content video prior to gameplay helped the players better understand the context of the game which in turn facilitated better collaboration. C4 was a control condition in which content video was not shown. It is likely here that the absence of the content video, and thereby the context of the game, led participants to working together as a team to figure out the goals of the game. It is also plausible that the collaborative multiplayer round aroused positive emotions, which lingered into the post-gameplay questionnaire. Future research should examine arousal of participants during collaborative gameplay in the different conditions.

The qualitative results showed the large majority of participants felt the game encouraged collaboration with their partner. Anecdotal evidence suggests a possible relationship between perception of collaboration and game enjoyment, as well. Several participants also reported the single player mode to be more challenging than the multiplayer mode. This study did not explicitly analyze the difference between the outcomes of single-player and multiplayer gameplay, but this can be considered by future research.

Game engagement levels were high across all four conditions. However, the present study showed that the order of presentation significantly impact players' self-reported engagement with the game. Participants reported the highest level of engagement in C1 when content preceded activity. Specifically, participants reported feeling more focused and engaged when the informational content video was presented prior to gameplay. This might be explained by the video's narrative, which described the purpose and conceptual goals of the game, helping players engage better with the game. On the other hand, C2 received the lowest engagement score. This condition's sequential order presented the informational content video in the middle of two rounds of gameplay. It is possible that this interruption fragmented the gaming experience and disengaged players, even if only temporarily.

Overall, participants said EEK! was engaging and held their attention. Qualitatively, participants said gameplay elements like task completion, color coordination, interactivity, and against-the-clock competition kept them engaged. However, some cited length of instructional videos as a distraction. The participants in C2, which received the lowest quantitative engagement score, were presented with the content video immediately before the multiplayer instructional video. This further suggests a possible disruption in gaming experience by the later presentation of content video that delineates the context of the game.

Finally, the majority of participants expressed enjoyment of the game, but its impact as a confound is difficult to conclude. Excitation-transfer theory suggests that higher positive arousal, triggered by enjoyment, could lead to more focused attention and higher information retention. However, knowledge acquisition was not significantly impacted by presentation order when enjoyment was both controlled and not controlled for. Opposingly, the association between presentation order and perceived engagement was significantly adjusted when controlled for enjoyment. However, the relationship was still significant with and without the control. This suggests that presentation order has a main effect on participants' reported engagement levels.

Limitations and Future Directions

Due to resource constraints, our study's sample size was limited. The majority of participants had some college education, and they all lived around the Boston area. As a result, the sample lacked diversity. A larger, more diverse sample could have further increased the study's validity.

Because EEK! was developed to be played by both adults and children, a complete analysis of its learning outcomes cannot be delivered. The impact of presentation order on learning outcomes might differ for children and can be examined by future research.

Measurement of dependent variables relied on self-report instruments administered before and after the experiment. Since excitation-transfer theory deals with transfer of arousal, biometric measures would reveal better insight about the relationship between the variables studied in this research. Such work would cast a more comprehensive look on the media effects on learning outcomes.

Qualitative results also revealed possible confounding variables in the EEK! Gameplay experience. Some participants reported certain tasks in the game to be challenging. Clarity of instructions was also a concern, with some participants asking researchers nearly ten technical questions throughout the experiment. Further research should utilize different video games to see if results vary significantly.

Conclusion

The study utilized excitation-transfer theory and transfer theory to suggest an impact on learning outcomes caused by presentation order. The sequential placement of the informational content video and gameplay were shown to impact player engagement levels and perceptions of collaboration. Highest level of engagement and perceived collaboration were reported by participants who viewed the content video providing the scientific context of the game before any gameplay began. Therefore, it is concluded that content-before-activity is the most effective presentation approach. Our research suggests that introducing content before gameplay is most conducive for engagement and collaboration while playing EEK! game.

The present research contributes to existing scholarship by revealing some important implications of using video games as educational tools. Educators looking to utilize digital learning activities should include supplemental content providing narrative and meaningful context prior to beginning the learning activity. When the latter is introduced before the activity, higher engagement and collaboration within the activity is possible.

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