Current Issues in Education
Mary Lou Fulton Teachers College • Arizona State University
PO Box 37100, Phoenix, AZ 85069, USA

Volume 15, Number 3 September 7, 2012 ISSN 1099-839X

Human-Computer Interaction Factors in Designing Educational Video Games

Andrew Tawfik
Concordia University Chicago

Joi L. Moore, Zhenyu He, and Ngoc Vo
University of Missouri

Educational video games present an opportunity to engage learners within immersive problem-solving experiences. Despite the potential benefits, educational video games may result in cognitive overload and thus preclude the informal learning benefits for those who lack experience. This study compared five males and five females when playing an educational video game. The goal of the study was to elucidate aspects that factor into the human-computer interaction and the subsequent learning engendered from these pedagogical tools. Descriptive data revealed that males improved in posttest scores to a greater degree when compared with females. Qualitative data was also gathered to ascertain educational video game aspects that were important to the human-computer interaction. Results suggest that concept interaction, sustained challenge, directions, and navigation might serve as instructional design principles for future educational video games construction.

Keywords: educational video games, cognitive load, grounded theory methodology, gender differences

The vast expansion of multimedia technologies provides the field of education with innovative opportunities that instruct the learner through engagement. Video games in particular provide an ideal multimedia tool that present concepts in a manner that is engaging, fun, and informal (Rieber & Noah, 2008; Squire, 2008). Furthermore, educational video games promote constructivist principles by allowing the individual to engage in immersive worlds and take ownership of knowledge (Barab, Gresalfi, & Ingram-Goble, 2010; Barab et al., 2009; Salen & Zimmerman, 2004).

A central challenge of educational game instructional design is how to provide engagement in a way that supports learning (Barab et al., 2007; Squire, Giovanetto, Devane, & Durga, 2005) while accommodating cognitive load for a diverse set of users (Heeter & Winn, 2008). While emergent forms of multimedia provide novel ways to transfer information, educational technologies are not created equal in their ability to engender learning (Paas, van Gog, & Sweller, 2010; Sweller, 2010). Elements of the human-computer interaction such as navigation and interface design are often overlooked during the instructional design phases because the impetus of the developmental process has often focused on content conveyance or technical features (Wang & Wu, 2009). As such, cognitive load may be taxed beyond working memory limitations and thus render the game ineffective for learning.

Because the research of video game instructional design is very limited (Squire & Jan, 2007; Wu et al., In Press), this study implemented a mixed methods design to investigate the human-computer interaction elements that are necessary for instructional designers to successfully create video games that instruct as well as engage users. Knowledge of the human-computer interaction elements are essential to inform instructional design theory as it relates to educational video game construction for diverse learning demographics such as gender and video game experience. Due to the lack of empirical research, the qualitative portion of this study employed grounded theory to investigate the transcripts of 10 post-secondary science students' human-computer interactions as they interacted with an immunology educational video game.

Literature Review

Video Games and Education

Despite research that demonstrates how knowledge emerges within a community of practice, previous theories of pedagogy have emphasized the linear and well-structured approach promoted by the didactic model of learning. Researchers have argued that knowledge cannot be stripped of context because learning is the interdependence between context, culture, and concepts (Henning, 2004; Jonassen, 2011; Kolodner, Cox, & Gonzalez-Calero, 2005). Brown, Collins, and Duguid (1989) further cautioned that traditional, didactic forms of education merely emphasize skills such as concept recall and thus preclude key components of problem-solving skills. This topic based approach merely provides learners with a general overview about the topics and therefore fails to support contextualized problem-solving (Henry, Tawfik, Jonassen, Winholtz, & Khanna, 2012; Jonassen, 2011).

Because individuals learn as new knowledge is assimilated with previous experiences, instructional strategies should present concepts in a way that engenders application and problem-solving. However, it remains difficult for educators to administer knowledge that represents the full complexity of an authentic situation. Pedagogical multimedia offers opportunities for contextualized learning because of the immersive visualization and potentially interactive elements afforded by the technology (Barab et al., 2007). Proponents suggest that educational video games in particular promote constructivist principles by anchoring instruction as students solve meaningful problems (Corbit, 2005; Dickey, 2005).

Gee (2005) proposed that video games offer a great degree of contextually embodied pedagogical benefits by: empowering learners, providing problem-solving opportunities, and promoting understanding. Gee notes that empowering learners through games allows individuals to become active producers of knowledge and engender identity as the individual takes ownership of the learning throughout the game. Problem-solving opportunities embedded within games afford the learner a safe place to fail and experiment with the material as learners encounter new knowledge. Lastly, understanding describes how knowledge and concepts fits within a broader system of meaning (Gee, 2003). The systematic nature of games provides a unique environment for learners to investigate the intersection between objects, attributes, and internal relationships (Salen & Zimmerman, 2004).

O'Neil et al. (2005) further suggested that educational video games reveal "complex and diverse approaches to learning processes and outcomes; interactivity, ability to address cognitive as well as affective learning issues, motivation for learning" (p. 455). That is, games consist of rich and immersive contexts that allow meaning to emerge (Salen & Zimmerman, 2004). Educational video games within the science, technology, engineering, and mathematics (STEM) disciples are particularly advantageous (Mayo, 2007, 2009) because of the emphasis upon critical thinking skills (Dickey, 2005), self-regulated learning (O'Neil et al., 2005; Squire et al., 2005), causal reasoning (Squire & Jan, 2007), problem-solving (Sun, Wang, & Chan, 2011), and scientific inquiry (Barab et al., 2010, 2009; Ketelhut, Schifter, & Nelson, 2010). An oft-cited potential benefit of educational video games is the ability to generate engagement and intrinsic motivation (Annetta, Minogue, Holmes, & Cheng, 2009; Bourgonjon, Valcke, Soetaert, & Schellens, 2010; Ryan, Rigby, & Przybylski, 2006). Engagement and attraction to video games stem from the goal oriented nature and discovery opportunities situated in an environment of limited negative consequence for risks.

To date, emergent empirical research has shown video games to be constructive for various higher order learning outcomes. Wang and Wu (2011) found that an educational video game of computer science caused the content to be more enjoyable, motivating, and interesting compared with other students who were not exposed to the multimedia. Similarly, Sindre et al. (2009) found that implementation of a computer science educational video game caused postsecondary students to become more engaged in the learning process when compared with paper exercises. Although the authors caution no quantitative results were found to verify the increase in posttest scores, the research suggested educational video games encouraged the learner to voluntarily spend additional time engaged with the content.

Despite the studies noted above, empirical research to date regarding educational video games is still limited (Wu et al., In Press). The most persistent criticism is that these tools are often flawed in terms of instructional design (Gunter, Kenny, & Vick, 2007; O'Neil et al., 2005; Squire & Jan, 2007; Wu et al., In Press). Critics have argued that, although motivation to play may increase, educational video games are not advantageous to learning if game progression is not predicated upon mastery of core concepts (Gunter et al., 2007; Muratet, Torguet, Jessel, & Viallet, 2009). More research is therefore required for instructional designers to understand the core elements of the human-computer interaction that promote engagement without compromising pedagogy (Barab et al., 2007, Squire & Jan, 2007; Tobias & Fletcher, 2012).

Video Games and Cognitive Load

Multimedia learning tools such as educational video games enables individuals to foster knowledge as they construct mental representations of concepts (Moreno & Valdez, 2005). However, cognitive load theory states that that the working memory necessary for meaningful learning includes inherent limitations (Sweller, 2010). That is, individuals possess a limited capacity to process and make sense of the information that is received from pictorial and verbal channels (Mayer & Moreno, 2003; Moreno & Valdez, 2005). Moreover, the limitations of working memory are exacerbated during interactions with unfamiliar information (Jonassen, 2011). Working memory limitations are therefore key considerations for instructional designers during the educational technology design process.

In the context of commercial video games, learners demonstrate various skillsets such as game mastery, navigation, and motor skills as s/he progresses through game objectives that may tax cognitive load (Ang, Zaphiris, & Mahmood, 2007). However, educational video games also necessitate knowledge acquisition and therefore exacerbate the strain upon working memory requirements (Ketelhut et al., 2010; Nelson & Erlandson, 2007; Nelson & Ketelhut, 2007). Although the research of cognitive load has often occurred within 2-dimensional learning environments (Nelson & Erlandson, 2007), further research is needed for educational video games (Squire & Jan, 2007). Human-computer interaction that disregards the limitations of working memory renders the educational video game ineffective because schema formation necessary for meaningful long-term learning is not completed (Paas et al., 2010; Sweller, 2010).

The research community has proffered some instructional design guidelines for educational video games. Aldrich (2009) proposed that games can be designed to facilitate learning by supporting comprehension of accomplishment requirements, identification of causal relationships, application of various tactics to overcome failure, presentation of 'breadcrumbs', and application of content to the real world (p. 286). Aldrich thus suggested including game features such as failure feedback, resources for users to consume throughout the game, first-person shooter options, and after-action reviews that serve to engage the learner and improve game satisfaction. He further noted that pedagogy is supported in educational tools through intuitive interface features that highlight content and inputs throughout the interaction. Similarly, Salen and Zimmerman (2004) described various failure state scenarios of game design and how users might recover from errors. However, extant research has yet to empirically validate the human-computer interaction elements and instructional design requirements necessary for educational video games (Squire & Jan, 2007).

Purpose of the Study

Previous research has shown that individuals with prior commercial video game experience resulted in better performance when playing novel commercial video games (Enochsson et al., 2004; Frey, Hartig, Ketzel, Zinkernagel, & Moosbrugger, 2007). Experience not only impacts in-game practices such as strategies, but also knowledge of maneuvering and navigation (Hayes, 2005). Educational video games in particular may alienate users who may not be accustomed to the human-computer interaction elements necessary for successful interaction.

Although the preliminary impact of educational video games is encouraging, no empirical research has investigated the human-computer-interaction elements of educational video games that play a role in cognitive load (Squire et al., 2005). As to not exclude learner demographics, educational video game research needs to further investigate the human-computer elements that play a role in the cognitive load and subsequent learning for various user groups. Therefore, the research questions were as follows:

1. What are the human-computer interaction characteristics that factor into cognitive load for educational video games?
2. Based on the knowledge of human-computer interaction, what instructional design guidelines are needed to increase the efficacy of educational video games for diverse learner demographics?

Methodology

Immune Attack is an educational video game created by the Federation of American Scientists to instruct high school and early college students about the basics of human immunology. The game provides a hypothetical situation about a female child who suffers from Skids disease. The user is charged with navigating a nanobot that fights the elements that contribute to her disease (see Figure 1). Ideally, as the user plays the game, informal learning occurs as pertinent elements of immunology are encountered.

Participants

Five females and five males were recruited to participate for the study. All the participants were first year health science students. Introductory health and science students were chosen because the research team reasoned that the 30 minute game session would be most effective with students who had some prior knowledge of the subject matter as opposed to individuals who were interacting with both the video game and immunology concepts for the first time.

Procedures

The data collection took place at a usability lab within a large Midwestern University. Before the students began the video game, the research team asked the student

Figure 1. Immune Attack Interface.

to complete a survey of demographic information survey (Appendix A) as well as an immunology pretest (Appendix B). The participant demographic information survey captured information such as age, self-reported video game experience, and perceived video game expertise.

The research team recorded video game interactions with Morae Recorder for each session. Upon playing the game for 30 minutes, all participants took part in an eight-question semi-structured exit interview regarding topics related to the interaction.

Materials

Pretest/Posttest. The pretest/posttest methodology design served to establish a baseline of prior knowledge for which posttest learning gains could be assessed upon completion of the video game interaction. This assessment tool (Appendix B) was constructed with the help of the Federation of American Scientists primary instructional designer of Immune Attack. The instructional designer was chosen as the subject matter expert because the she had extensive knowledge of the science objectives embedded within the video game. Moreover, the instructional designer was also deemed qualified because of her advanced degrees in both biochemistry and microbiology.

Semi-structured Interview. A semi-structured interview (Appendix C) was a data collection method employed to investigate various themes. In alignment with grounded theory (Corbin & Strauss, 2008, Fassinger, 2005) interview questions were intentionally designed to elicit open discussion for a myriad of aspects that may have factored into the human-computer interaction. As such, questions ranged from game favorability, opportunities for improvement, and specific features that played a role in the usability of the learning environment. Questions were also included to stimulate a discussion about the learning gains and engagement with the game storyline.

Data Analysis

Because the research team was not aware of any previous research that investigated the human-computer interaction elements of educational video games, a grounded theory approach was chosen (Corbin & Strauss, 2008: Fassinger 2005). Upon verbatim transcription, three researchers analyzed the semi-structured interviews for themes related to the video game interaction. An open-coding theme was selected to identify emergent themes not previously discussed within the literature. After organizing the data according to the initial set of codes, the three researchers met to compare results of open coding and to finalize the categories. Once completed, the researchers reviewed and re-categorized the transcripts in accordance with the final codes.

Results

Descriptive Statistics

The initial survey data was imported into a spreadsheet for the purposes of generating descriptive statistics of the participants (see Table 1). The performance results showed, on average, participants scored a 41% on the pretest (baseline) and improved to

Table 1
Mean Posttest Improvement Scores by Gender

Gender	**Mean Pretest**	**Mean Posttest**	**Mean Improvement**
Female	46%	54%	8%
Male	36%	72%	36%
Total	41%	63%	22%

Table 2
Mean Posttest Improvement Scores by Video Game Experience

Game Experience	**Frequency**	**Female Frequency**	**Male Frequency**	**Average Improvement**
Never	1	1	0	0.00
Several Times a Year	3	3	0	3.3%
Several Times a Month	3	1	2	26.7%
Several Times a Week	3	0	3	43.3%

63% on the posttest that immediately followed the game interaction. The data was further broken down to understand differences based on gender. While the results showed that both male and female groups improved, males increased from 36% to 72% whereas the female group only improved from 46% to 54%, a difference of 8%.

Despite the improvement in posttest scores, the research team sought to investigate the considerable disparity between male (36%) and female (8%) posttest improvement scores. Therefore, the posttest scores were compared with the demographic data regarding self-reported commercial video game experience. Quantitative data revealed a synchronous relationship between self-reported video games experience and posttest improvement scores. That is, individuals who described themselves as playing video games several times a month or several times a week performed markedly better than those who described themselves as playing never or only several times a year.

The data from Table 2 also revealed that participants who categorized themselves as having less video game experience were generally female. Moreover, all but one of the female participants described themselves as playing never or only several times a year. The study findings of increased male video game experience are consistent with the literature that has underscored the dominance of male gaming experience when compared to those of females (Barab et al., 2007; Heeter & Winn, 2008).

Qualitative Data

Upon game completion, all 10 participants discussed their game reactions in a semi-structured-exit interview. The interview data revealed the human-computer interaction characteristics that factored into the experience. Four themes emerged during the grounded theory analysis: concept interaction, sustained challenge, directions, and navigation. Analysis of qualitative data suggested that most participants, regardless of video game experience, expressed an appreciation for the concept interactions and sustained challenge aspects of the human-computer interaction. Alternatively, individuals provided disparate perceptions of the directions and navigational elements based on video game experience.

Concept Interaction

In line with the multimedia principle (Mayer & Moreno, 2003), nearly all of the participants noted that one of the most favorable aspects about the video game was the ability to visualize and interact with the abstract immunology concepts. For instance, when asked the best characteristic of the game, a female participant with limited game experience noted: "Kind of fun way of seeing [the concepts]. In anatomy, they tell you all that, but you have to build that in your mind. This helps to visualize." Although this particular participant did not significantly progress in the game when compared with others, she still described how the video game assisted her with being able to visualize concepts previously discussed during her lectures. Similarly, when asked about the benefits of the game, another participant who played commercial video games several times a week expressed enjoyment in being an interactive participant: "I really enjoy it. I like getting to see it firsthand instead of just watching."

Another male participant that played several times a week noted how the visualization helped to elucidate and supplement abstract concepts encountered in course lecture:

> "I saw something like this in class, but I mean just getting to see it. Actually, getting to see it in the video game and being able to see it in real life. That was really interesting to see. Just the way the immune system actually works. I mean, just like she [the instructor] was saying, how naturally things may not work and how you have to get things to work. And just how to see different connecting pieces."

It is noteworthy that the above quotes suggest participants enjoyed the ability to visualize immunology using this technology across varying levels of experience. As such, the video game provided participants with an inventive presentation of the concepts that aided in mental model construction. The quotes above lend further credence with the multimedia principle that suggest that words in conjunction with graphics are more effective for learning when compared with text alone (Mayer & Moreno, 2003).

Sustained Challenge

During the exit interview, a question was posed to elucidate aspects that made the video game interaction favorable to the participants. This question was asked to ascertain elements that may be incorporated for future design of educational video games. Most learners, regardless of video game experience, noted that the challenge and pace of the game was an essential component of the interaction. When asked about the most important facet in video games a female that described herself as playing video games several times a month commented:

> "A good challenge. If they are just going to hand it to you, it's not worth playing. I love Tetris and you can play it over and over again. It's just speed. Speeding up the figures makes it a lot harder and fun because it's challenging."

In describing the most important part of an educational video game, a less experienced video game female participant echoed this sentiment when she responded: "Storyline a lot. It has to keep you interested. A lot of people have problems with the same thing over and over again, so just keeping it fresh." However, when a question was posed to an experienced participant (multiple times a month) about whether he would play this game to study, the participant described how the sustained challenge factored into his perception of the game as a study tool:

> "I guess it seems like it was pretty slow getting that one point across so I would probably cover more ground studying through the textbook. If it's too easy, you don't want to play it again. If it's challenging, you want to keep playing until you break it or beat it."

It is noteworthy that multiple participants, regardless of video game experience, concluded that a sustained challenge was a critical component to adoption and future interactions with the technology. The above comment in particular suggested the learner perceived time as better spent using other instructional materials if a sustained challenge is not present throughout the human-computer interaction.

Directions

Although participants seemed to generally agree about the favorability of concept interaction and sustained challenge, the feedback was markedly different for directions. The directions posed either a significant problem or minor nuisance during the interaction depending on the level of video game experience. A female who described herself as only playing several times a year questioned the overall goal of the game when she commented: "I didn't get any objective. I understand they [the nanobots] needed to go a direction, I understand they need to get to the infection site, but what were the little circular things?" This comment underscored how the perceived the lack of direction played a role in her ability to fully understand the concepts and learning objectives throughout the interaction. Alternatively, those with game experience described the directions as overly redundant and an obstacle to playing the game. One participant who described himself as an adept user that played several times a week complained: "But it also felt it went through the instructions a little slowly. And I thought some of the things I thought could've been picked up a lot quicker naturally."

As highlighted by the above comment, experienced users suggested the directions were redundant and impeded the perceived initial challenge and subsequent interaction. For those without familiarity with video game experience, the interaction was diminished because there remained some ambiguity about the goals and elements that the participants could interact with. As such, inexperienced users may have felt cognitive overload and were thus unclear how to progress or process the immunology concepts encountered.

Navigation

As the case with directions, navigation provided either a severe impediment or a minor setback for users depending on previous video game experience. Participants with limited game experience commented that they were generally not able to progress as far in the video game. One female user with only limited experience (several times a year) described controls as being a limitation. She underscored her frustration with the navigation when she criticized: "It took me about 20 minutes to get it where I wasn't staying in the wall the entire time." Alternatively, a male participant who played several times a week described a much different experience when asked about the controls:

> "I was a little more focused on trying to figure out what I was doing rather than what they were telling me. So if I was to play it again and know what I was doing, I could focus on what the things were called and what exactly they were doing."

The participant with more experience suggested that he could eventually learn to balance the cognitive load between the concept interactions and the direction. Other participants with additional video game experience also suggested they eventually overcame the initial barrier of navigation. For instance, a male who played several times a month underscored the initial navigational frustration when he commented:

> Participant: I did like the control setup, but just going up and down was really different. It took a little bit to get used to it.
>
> Facilitator: Do you feel like you were able to get used to it?
>
> Participant: Eventually, yeah, but it was tough to get a feel for it.

Similarly, a female participant (played several times a month) described how her cognitive effort focused on the game controls reduced her initial ability to focus on the learning aspects of the game:

> "Whenever I was told what to do, I was like 'Uh, Okay'. I was just going around. I was so confused what I was supposed to be doing. I was finally able to figure it out."

The differing views of navigation were a common theme throughout the interviews. All participants noted some degree of navigational frustration, but those who rated themselves as more experienced players expressed confidence in their ability to eventually overcome the initial cognitive strain and progress through the learning concepts found within the game. Those without game experience suggested the cognitive effort toward navigation was a major deterrent to their overall learning. As such, they were less likely to express a desire to embrace the technology for future instruction.

Discussion

The study revealed that educational video games interactions differed based on a variety of factors. According to the descriptive statistics, participants with increased commercial video game experience improved posttest scores to a greater degree when compared with those participants who did not play commercial video games as frequently. In addition, descriptive statistics revealed that those who rated themselves as less experienced video game players were largely from the female demographic. These results have implications both for instructional designers and school administrators. If educators hastily implement video games in classrooms because they perceive these unique tools as rife with potential for informal learning and motivation, the pedagogical benefits will presumably only extend to users who are already skilled at playing video games. Less experienced users may struggle with human-computer interaction factors such as navigation and directions. Because males generally have additional game experience (Barab et al., 2005; Heeter & Winn, 2008), the female subset of learners may be inadvertently overlooked.

The qualitative research suggested that four instructional design principles may be most pertinent to the human computer interaction with educational video games: concept interaction, sustained challenge, navigation, and directions. The concept interaction and sustained interaction factors in particular indicated educational video games may be a viable pedagogical alternative for concepts perceived by learners as too abstract or unfamiliar. These may be especially true for science and mathematical concepts (Annetta et al., 2009). Participants suggested that the video games aided in learning by being able to "visualize", "see it firsthand", and "see different connecting pieces". Because the concept interaction serves to elucidate concepts and fortify mental models, it is important that this aspect of instructional design include elements necessary for schema formation with respect to working memory limitations. Furthermore, the sustained challenge aspect of the interaction not only distinguishes this learning tool from others, but maintains engagement and provides the learner a reason to continually utilize the game. If challenge is absent, learners will most likely perceive the time as better served engaging with other instructional tools.

Research has shown that cognitive load may be taxed due to demands of essential processing, incidental processing, and representational holding during multimedia interactions (Mayer & Moreno, 2003). The current research presented suggests that that cognitive load may be exacerbated in educational video games where the learner is not only interacting with the concepts (germane load), but also the interaction elements of the technology (extraneous cognitive load). Qualitative data suggests that instructional designers should give particular consideration to the directions and navigation elements throughout the design phases. If users have trouble with the navigation and directions, the subsequent pedagogical benefits will be impeded due to unnecessary demands brought upon by incidental processing and extraneous cognitive load. Proficient video game users noted that directions and navigation were minor distractions that “took a bit to get used to” and an aspect they were “finally able to figure it out”. Others with less game experience suggested they were “confused what I was supposed to be doing” and attention was diverted to “figure out what I was doing rather than what they were telling me.” That is, the extraneous cognitive load upon working memory by navigation and directions impeded the participant’s ability to understand the overall learning objective of the game. To accommodate the need for sustained challenge for diverse user sets, instructional designers could include the option for learners to select challenge levels in educational video games (e.g. novice, intermediate, expert). This would allow the novice users to gain experience with the human-computer interaction while also allowing experienced users to select challenge level deemed appropriate for their expertise.

The findings lend further support to Mayer and Moreno's (2003) caution that a significant pitfall of multimedia learning is a scenario whereby essential processing is overloaded. The segmentation effect in particular suggests that better transfer ensues when processing is controlled by the user. To accommodate learner’s needs, designers could strategically allow the user to select and replay ‘debriefing’ segments (Aldrich, 2009) that advance the storyline and display concepts the learner had encountered in the previous level. This would allow for additional processing time for less-experienced users to visualize the concepts while reducing the cognitive demands brought on by the interaction with the video game.

The pretraining effect suggests that transfer is increased when the learner knows behaviors of system components (Mayer & Moreno, 2003). As such, allowing individuals to view the learning concepts prior to the video game interaction or when the user clicks pause could further reduce the demands upon working memory. In doing so, the user is afforded control and provided time to process concepts without the additional cognitive load imposed by game navigation. A design solution that supports the pretraining effect could also be accomplished in the form of a challenging, yet attainable, introductory level for less experienced users (Aldrich, 2009).

Educational games generally tend to incorporate additional subject matter as the individual progresses to more challenging game stages. However, if users are unable to progress to higher levels due to problems with navigation or direction, they may be severely limited in the concepts encountered. By allowing more uniformity of concepts across game stages, with respect to working memory limitations for novel information (Merriënboer & Sluijsmans, 2008; Sweller, 2010), inexperienced users would still able to visualize and interact with the abstractions. This design feature will also enable the game to be challenging enough for experienced users.

Conclusions

The participants of this study noted that a requirement of educational video games is an engaging experience incited by game challenges. However, this condition adds complexity to instructional designers as they attempt to accommodate differences in technology expertise across a myriad of user demographics. As educational video games become further integrated into the classroom, working memory limitations (Sweller, 2005) should not only be considered for the subject matter, but also the entire human-computer interaction. Specifically, the results from the study note that concept interaction, sustained challenge, directions, and navigation are potential instructional design guidelines that must be balanced with knowledge acquisition and schema formation. If the additional working memory strains are not considered, the potential learning effects of educational video games may be precluded.

The present research suggests that individuals who are adept at playing video games may benefit the most from video games because their familiarity with the technology places less of a strain on working memory. As such, individuals who are unfamiliar with recreational video games may find themselves at a disadvantage to benefit from pedagogical video games. The results of this study provide further empirical validation that suggests females may not employ video games as frequently when compared with males (Barab et al., 2007; Barab et al., 2010; Heeter & Winn, 2008). Learning benefits may therefore be impeded for an important demographic group because of oversights during the instructional design process. Designers should not only consider the chief extant group of users, but consider instructional design elements such as concept interaction, sustained challenge, directions, and navigation for diverse learner demographics to increase the efficacy of learning through educational video games.

Future Research

The researchers suggest additional studies to build upon the present findings. One such study could include an expansion of the video game experience and gender treatments groups such that the quantitative results are statistically significant. In addition, a longitudinal study could uncover important usage patterns during various parts of the semester as learners become more adept at playing the educational video game (Tobias & Fletcher, 2012).

The study also suggests that participants with educational video experience may be at an advantage to learn from these pedagogical technologies. An additional study could therefore investigate whether training materials such as a tutorial prior to the interaction could reduce some of the interaction gap for novice video game players. This would inform the research community with implementation strategies to engage a diverse set of learners using educational video games.

Studies could also investigate the efficacy of educational video games as a learning tool in comparison with other instructional methods. For instance, researchers could compare learning gains of educational video games in comparison with a textbook reading or concept mapping task. This research would provide additional validation as to the efficacy of video game pedagogy as it compares with other forms of instruction.

References

Aldrich, C. (2009). *The Complete Guide to Simulations and Serious Games: How the Most Valuable Content Will be Created in the Age Beyond Gutenberg to Google* (1st ed.). Pfeiffer.

Ang, C. S., Zaphiris, P., & Mahmood, S. (2007). A model of cognitive loads in massively multiplayer online role playing games. *Interacting with computers*, *19*(2), 167–179.

Annetta, L. A., Minogue, J., Holmes, S. Y., & Cheng, M. T. (2009). Investigating the impact of video games on high school students' engagement and learning about genetics. *Computers & Education*, *53*(1), 74-85.

Baek, E. O., Cagiltay, K., Boling, E., & Frick, T. (2008). User-centered design and development. In J. M. Spector, M. D. Merrill, J. van Merrienboer, & M. Driscoll (Eds.), *Handbook of Research on Educational Communications and Technology* (3rd ed., pp. 659-670). New York, NY: Routledge.

Barab, S., & Dodge, T. (2008). Strategies for designing embodied curriculum. In J. M. Spector, M. D. Merrill, J. van Merrienboer, & M. Driscoll (Eds.), *Handbook of Research on Educational Communications and Technology* (3rd ed., pp. 97-110). New York, NY: Routledge.

Barab, S., Dodge, T., Tuzun, H., Job-Sluder, K., Jackson, C., Arici, A., Job-Sluder, L., et al. (2007). The Quest Atlantis Project: A socially-responsive play space for learning. In B. Shelton & D. Wiley (Eds.), *The Educational Design and Use of Simulation Computer Games* (pp. 153-180).

Barab, S., Gresalfi, M., & Ingram-Goble, A. (2010). Transformational Play. *Educational Researcher*, *39*(7), 525.

Barab, S., Scott, B., Siyahhan, S., Goldstone, R., Ingram-Goble, A., Zuiker, S. J., & Warren, S. (2009). Transformational play as a curricular scaffold: Using videogames to support science education. *Journal of Science Education and Technology*, *18*(4), 305–320.

Barab, S., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development*, *53*(1), 86-107.

Barab, S., Zuiker, S., Warren, S., Hickey, D., Ingram-Goble, A., Kwon, E. J., Kouper, I., et al. (2007). Situationally embodied curriculum: Relating formalisms and contexts. *Science Education*, *91*(5), 750–782.

Bourgonjon, J., Valcke, M., Soetaert, R., & Schellens, T. (2010). Students' perceptions about the use of video games in the classroom. *Computers & Education*, *54*(4), 1145-1156. doi:10.1016/j.compedu.2009.10.022

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32-42.

Carr, D. (2005). Contexts, gaming pleasures, and gendered preferences. *Simulation & Gaming*, *36*(4), 464 -482. doi:10.1177/1046878105282160

Corbin, J. M., & Strauss, A. L. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Sage Publications, Inc.

Corbit, M. (2005). Moving into cyberspace: Game worlds for learning. *Knowledge Quest: Journal of the American Association of School Librarians*, *34*(1), 18–22.

Dickey, M. D. (2005a). Three-dimensional virtual worlds and distance learning: two case studies of Active Worlds as a medium for distance education. *British Journal of Educational Technology*, *36*(3), 439–451.

Dickey, M. D. (2005b). Engaging by design: How engagement strategies in popular computer and video games can inform instructional design.

Educational Technology Research and Development, *53*(2), 67-83.

Enochsson, L., Isaksson, B., Tour, R., Kjellin, A., Hedman, L., Wredmark, T., & Tsai-Felländer, L. (2004). Visuospatial skills and computer game experience influence the performance of virtual endoscopy. *Journal of gastrointestinal surgery*, *8*(7), 874–880.

Fassinger, R. E. (2005). Paradigms, Praxis, Problems, and Promise: Grounded Theory in Counseling Psychology Research. *Journal of Counseling Psychology*, *52*(2), 156-166. doi:10.1037/0022-0167.52.2.156

Frey, A., Hartig, J., Ketzel, A., Zinkernagel, A., & Moosbrugger, H. (2007). The use of virtual environments based on a modification of the computer game Quake III Arena in psychological experimenting. *Computers in Human Behavior*, *23*(4), 2026-2039.

Gunter, G. A., Kenny, R. F., & Vick, E. H. (2007). Taking educational games seriously: using the RETAIN model to design endogenous fantasy into standalone educational games. *Educational Technology Research and Development*, *56*(5-6), 511-537. doi:10.1007/s11423-007-9073-2

Hayes, E. (2005). Women, video gaming and learning: Beyond stereotypes. *TechTrends: Linking Research & Practice to Improve Learning*, *49*(5), 23-28.

Heeter, C., & Winn, B. (2008). Implications of gender, player type and learning strategies for the design of games for learning. *Beyond Barbie to Mortal Combat: New perspectives on games, gender, and computing.* Cambridge, MA: MIT Press.

Henning, P. (2004). Everyday cognition and situated learning. In D. Jonassen (Ed.), *Handbook of Research on Educational Communications and Technology: A Project of the Association for Educational Communications and Technology* (2nd ed., pp. 829-861). LEA.

Henry, H., Tawfik, A., Jonassen, D., Winholtz, R., & Khanna, S. (2012). “I Know This is Supposed to be More Like the Real World, But . . .”: Student Perceptions of a PBL Implementation in an Undergraduate Materials Science Course. *Interdisciplinary Journal of Problem-based Learning*, *6*(1), 43-81.

Jonassen, D. (2011). *Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments* (1st ed.). Routledge.

Ketelhut, D. J., Schifter, C., & Nelson, B. C. (2010). Exploring Cognitive Load in Immersive Educational Games: The SAVE Science Project. *International Journal of Gaming and Computer Mediated Simulations*, *2*(1). doi:10.4018/jgcms.2010010103

Kolodner, J. L., Cox, M., & Gonzalez-Calero, P. (2005). Case-Based Reasoning-Inspired Approaches to Education. *The Knowledge Engineering Review*, *20*(03), 299-303.

Leemkuil, H., de Jong, T., de Hoog, R., & Christoph, N. (2003). KM Quest: A Collaborative Internet-Based Simulation Game. *Simulation & Gaming*, *34*(1), 89-111.

Lusk, D. L., Evans, A. D., Jeffrey, T. R., Palmer, K. R., Wikstrom, C. S., & Doolittle, P. E. (2009). Multimedia learning and individual differences: Mediating the effects of working memory capacity with segmentation. *British Journal of Educational Technology*, *40*(4), 636-651.

Mayer, R. E., & Moreno, R. (2003). Nine Ways to Reduce Cognitive Load in Multimedia Learning. *Educational Psychologist*, *38*(1), 43–52.

Mayo, M. J. (2007). Games for science and engineering education. *Communications of the ACM*, *50*(7), 30–35.

Mayo, M. J. (2009). Video games: A route to large-scale STEM education? *Science*, *323*(5910), 79.

Merriënboer, J. J. G., & Sluijsmans, D. M. A. (2008). Toward a Synthesis of Cognitive Load Theory, Four-Component Instructional Design, and Self-Directed Learning. *Educational Psychology Review*, *21*(1), 55-66.

Moreno, R., & Valdez, A. (2005). Cognitive load and learning effects of having students organize pictures and words in multimedia environments: The role of student interactivity and feedback. *Educational Technology Research and Development*, *53*(3), 35-45.

Muratet, M., Torguet, P., Jessel, J. P., & Viallet, F. (2009). Towards a Serious Game to Help Students Learn Computer Programming. *International Journal of Computer Games Technology*, *2009*, 1-12.

Nelson, B. C., & Erlandson, B. E. (2007). Managing cognitive load in educational multi-user virtual environments: reflection on design practice. *Educational Technology Research and Development*, *56*(5-6), 619-641.

Nelson, B. C., & Ketelhut, D. J. (2007). Scientific inquiry in educational multi-user virtual environments. *Educational Psychology Review*, *19*(3), 265–283.

O’Neil, H. F., Wainess, R., & Baker, E. L. (2005). Classification of learning outcomes: Evidence from the computer games literature. *Curriculum Journal*, *16*(4), 455-474.

Paas, F., van Gog, T., & Sweller, J. (2010). Cognitive Load Theory: New Conceptualizations, Specifications, and Integrated Research Perspectives. *Educational Psychology Review*, *22*(2), 115–121.

Pelletier, C. (2005). The uses of literacy in studying computer games: Comparing students' oral and visual representations of games. *English Teaching: Practice and Critique*, *4*(1), 40-59.

Rieber, L. P., & Noah, D. (2008). Games, Simulations, and Visual Metaphors in Education: Antagonism between Enjoyment and Learning. *Educational Media International*, *45*(2), 77-92.

Riedel, J., Fitzgerald, G., Leven, F., & Toenshoff, B. (2003). The Design of Computerized Practice Fields for Problem Solving and Contextualized Transfer. *Journal of Educational Multimedia and Hypermedia*, *12*(4), 377–399.

Ryan, R. M., Rigby, C. S., & Przybylski, A. (2006). The motivational pull of video games: A self-determination theory approach. *Motivation and Emotion*, *30*(4), 344–360.

Salen, K., & Zimmerman, E. (2004). *Rules of Play: Game Design Fundamentals*. MIT Press.

Sindre, G., Natvig, L., & Jahre, M. (2009). Experimental Validation of the Learning Effect for a Pedagogical Game on Computer Fundamentals. *IEEE Transactions on Education*, *52*(1), 10-18.

Squire, K. (2008a). Video game–based learning: An emerging paradigm for instruction. *Performance Improvement Quarterly*, *21*(2), 7–36.

Squire, K. (2008b). Video Games and Education: Designing Learning Systems for an Interactive Age. *Educational Technology*, *48*(2), 17-26.

Squire, K., & Jan, M. (2007). Mad City Mystery: Developing Scientific Argumentation Skills with a Place-based Augmented Reality Game on Handheld Computers. *Journal of Science Education and Technology*, *16*(1), 5-29.

Squire, K., Giovanetto, L., Devane, B., & Durga, S. (2005). From users to designers: Building a self-organizing game-based learning environment. *TechTrends*, *49*(5), 34–42.

Sun, C. T., Wang, D. Y., & Chan, H. L. (2011). How digital scaffolds in games direct problem-solving behaviors. *Computers & Education*, *57*(3), 2118-2125.

Sweller, J. (2005). Implications of Cognitive Load Theory for Multimedia Learning. In R. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (pp. 19-30). New York: Cambridge University Press.

Sweller, J. (2010). Element Interactivity and Intrinsic, Extraneous, and Germane Cognitive Load. *Educational Psychology Review*, *22*(2), 123-138.

Tobias, S., & Fletcher, J. D. (2012). Reflections on "A Review of Trends in Serious Gaming." *Review of Educational Research*, *82*(2), 233–237.

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, *114*(1), 104.

Wang, A. I., & Wu, B. (2009). An Application of a Game Development Framework in Higher Education. *International Journal of Computer Games Technology*, *2009*, 1-12.

Wang, A. I., & Wu, B. (2011). Using Game Development to Teach Software Architecture. *International Journal of Computer Games Technology*, *2011*, 1-12.

Wu, W. H., Chiou, W. B., Kao, H. Y., Hu, C. H. A., & Huang, S. H. (In Press). Re-exploring Game-assisted learning research: The perspective of learning theoretical bases. *Computers & Education*.

Appendix A

Demographic Survey

1. Age ________
2. Gender ________Male ________Female
3. Health Sciences Major ________Yes ________No
4. How often do you play video games? (select one):
    a. Never
    b. Several Times a Year
    c. Several Times a Month
    d. Several Times a Week
    e. Everyday

Appendix B

Pretest/Posttest

1. What is one of the first responses of the body to an infection?

    a. Upset stomach

    b. Inflammation

    c. Headache

    d. None of the above

    e. I don't know

2. What does the word “macrophage” mean?

    a. Big eater

    b. Natural killer

    c. Antibody

    d. None of the above

    e. I don't know

3. How do cells of the immune system get to the site of an infection?

    a. They travel from lymph nodes

    b. They reproduce at the site of the invading bacteria

    c. They exit the blood vessel through spaces between cells

    d. None of the above

    e. I don't know

4. How do macrophages summon other cells to help fight an infection?

    a. They send special macrophage recruits to the lungs

    b. They send a special chemical signal

    c. They divide into specialized cells that recruit other cells

    d. None of the above

    e. I don't know

5. How do macrophages recognize infectious bacteria?

a. They identify specific colors that only invading bacteria display

b. They recognize molecular patterns displayed on the surface of the invading bacteria

c. They recognize cells doing specific behaviors, such as destroying healthy cells

d. None of the above

e. I don't know

6. What type of cell is a macrophage?

a. Red blood cell

b. White blood cell

c. T cell

d. None of the above

e. I don't know

7. How do cells sense things in their environment?

a. Cells see everything around them.

b. Cells feel everything around them.

c. Cells have specific proteins on their outsides that only bind to certain things around them.

d. Cells only interact with proteins.

e. I don't know.

8. If a cell moves, how does it know which way to go?

a. Cells do not move.

b. Cells only move toward food.

c. Cells move in response to some kinds of chemical signals.

d. Cells only move in a random manner.

e. I don't know.

9. How do macrophages kill bacteria?

a. Macrophages eat bacteria.

b. Macrophages keep the bacteria from growing.

c. Macrophages produce antibiotics that kill bacteria.

d. I don't know.

10. How big is a human cell?

a. About 50 meters (m) wide.

b. About 50 micrometers (μm) wide (μm is 1x10-6 meters)

c. About 50 nanometers (nm) wide (nm is 1x10-9 meters)

d. I don't know

Appendix C

Exit Interview

1. What are your overall impressions of the game?

2. What do you like about the game?

3. What do you not like about the game?

4. What would you like to change in the game?

5. What do you think of the FPS (first person shooter) mode?

6. Do you feel like you learned anything? If so, what concepts?

7. Do you feel like you understood the storyline?

8. What do you are some aspects in other video games that you find favorable?

Article Citation

Tawfik, A., Moore, J. L., He, Z., & Vo, N. (2012). Human-computer interaction factors in designing educational video games. *Current Issues in Education*, *15*(3). Retrieved from http://cie.asu.edu/ojs/index.php/cieatasu/article/view/987

Author Notes

Andrew Tawfik, Ph.D.
Concordia University Chicago - College of Graduate and Innovative Programs
7400 Augusta Street, River Forest, IL. 60305
Andrew.tawfik@cuchicago.edu

Dr. Andrew A. Tawfik is an Assistant Professor of Instructional Design and Technology within the College of Graduate and Innovative Programs (GIP) at Concordia University Chicago where he teaches courses in collaborative learning and emerging technologies. Dr. Tawfik's research interests include problem- based learning, case-based reasoning, case library instructional design, human-computer interaction, and computer-supported collaborative learning. He earned his Master's in Information Science from Indiana University and his PhD in Learning Technologies from the University of Missouri.

Joi L. Moore, Ph.D.
University of Missouri
303 Townsend Hall, Columbia, MO 65211
moorejoi@missouri.edu

Dr. Joi L. Moore is an Associate Professor in the School of Information Science & Learning Technologies at the University of Missouri where she manages and teaches courses in the Digital Media Curriculum. Dr. Moore's current research interests include: Online Learning Environments, Performance Support Systems, Usability Engineering, and Human Computer Interaction. Dr. Moore received her B.S. degree in Computer Science and M.S. degree in Management from North Carolina State University. She earned her Ph.D. in Instructional Technology from the University of Georgia.

Zhenyu He
University of Missouri
111 London Hall, Columbia, MO 65211
zhfff@mail.mizzou.edu

Zhenyu He is a doctoral candidate in School of Information Science & Learning Technologies at MU. Her research interest is usability testing and information behavior of people with learning differences. She is also interested the application of pedagogy and technology tools to enhance learning in online learning environments.

Ngoc Vo
University of Missouri
111 London Hall, Columbia, MO 65211
ngocvohn@gmail.com

Ngoc Vo is a doctoral student in the Department of Architectural Studies at the University of Missouri. She holds a Master's degree in Technology and Education from the University of Missouri and a Bachelor's degree in Linguistics. Her research interest include the collaborative learning and discovery learning in virtual environments.

Current Issues in Education
Mary Lou Fulton Teachers College • Arizona State University
PO Box 37100, Phoenix, AZ 85069, USA

Manuscript received: 4/23/2012
Revisions received: 6/22/2012
Accepted: 8/13/2012

Current Issues in Education

Mary Lou Fulton Teachers College • Arizona State University
PO Box 37100, Phoenix, AZ 85069, USA

Volume 15, Number 3 | September 7, 2012 | ISSN 1099-839X