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Investigating the impact of video games on high school students' engagement and learning about genetics

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A B S T R A C T

The popularity of video games has transcended entertainment crossing into the world of education. While the literature base on educational gaming is growing, there is still a lack of systematic study of this emerging technology's efficacy. This quasi-experimental study evaluated a teacher created video game on genetics in terms of its affective and cognitive impact on student users. While statistical results indicated no differences ($p > .05$) in student learning as measured by our instrument, there were significant differences ($p < .05$) found in the participants' level of engagement while interfacing with the video game. Implications on this emerging line of inquiry are discussed.

1. Introduction

Play systematically confronts a child with a learning situation that could only be located within the area of close development; that is, it often involves a task located slightly above the acquired skills. This notion has led to the arguments for the use of games in preschool establishments and beyond (Vygotsky, 1967). Games play as a vehicle for learning is not a new concept. Regardless of a game's complexity and whether or not technology integration is the impetus for the game, games can aid in the learning process.

From the simplest of games like *Peek-A-Boo* to the complexity of *Dungeons and Dragons*, games have engaged and inspired people for decades. From an educational standpoint, games are engaging and adaptable to almost any subject. They can be particularly useful for teaching cause-and-effect relationships, and the lessons learned from games often tend to stay with students because of the interactive nature of the learning experience (The New Media Consortium [NMC], 2005). Today games and technology are being combined in increasingly more interesting ways. Until recently most computer-based games were linear by design and lacked sustainability as a teaching and learning tool.

Many top scholars have reported on the potential of harnessing the popularity of video games (often called serious games or educational games) for engaging children and helping them learn difficult concepts (e.g. Gee, 2005; Prensky, 2001; Squire, 2002). What is lacking, however, is concrete empirical data to support or refute these theoretical claims. Britain and Liber (2000) suggested that teachers (and we add researchers) need to evaluate video games from an educational perspective to determine whether they can be embedded into their teaching practices. These aims of adding to the empirical research base and examining the educational impact of video games lie at the center of the work presented here.

2. Study purpose

This study integrated a teacher created *Multiplayer Educational Gaming Application* (MEGA) (Author, 2006) covering key genetics concepts into a high school biology course. MEGAs, a new construct, differ from other video games in that a teacher

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creates them solely for instructional purposes. While they share many of the features of educational *Multi-User Virtual Environments* (MUVEs), discussed a bit further below, MEGAs are set apart by the fact that the classroom teacher is the primary game author.

We postulate that because the teacher designs and builds the MEGA, they will take ownership of their MEGA and will be more likely to use it in their class. Additionally, MEGAs should align with curricular content standards and will thus help drive inquiry instruction due in part because the teacher has the ability to use the common experiences of the students in the virtual environment as a foundation for probing deeper student understanding of the embedded content.

Because evaluating the effectiveness of MEGAs as a teaching and learning tool has no precedence, this study focused on two areas in which the MEGAs use might impact students: understanding of genetics concepts and engagement in science class activities. The specific research questions were:

1. Do students who play a computer-based MEGA develop deeper understandings of embedded genetics concepts when compared to peers engaged in more traditional instruction?
2. Are students more engaged in science instruction while interfacing with a MEGA when compared to peers that are engaged in traditional science class activities?

3. Background to the study

3.1. Learning through video games

Oblinger and Oblinger (2005) depicted today's middle, high and college aged students as the *Net Generation* and characterized them as those who like to be connected, need immediate responses, desire experiential learning, and require social interaction. The *Net Generation* thinks fundamentally different than those who have not spent thousands of hours playing digital games. Some advocates of digital game-based learning imply that developing educational games is a moral imperative, as kids of the net generation do not respond to traditional instruction (Prensky, 2001). During the *Summit on Educational Games*, held by the Federation of American Scientists, Trotter (2005) reported that it is becoming more critical that America finds a way to combine the time children spend playing video games and the time they don't spend on academic work.

It has been fairly well documented that video games have the potential to encourage students to explore beyond the boundaries of a given material thus allowing for a proactive and exploratory nature that allows the student to become a self-reliant learner (Taradi, Taradi, Radic, & Pokrajac, 2005). Rickard and Oblinger (2004) discussed how gaming provides learners the opportunity to learn by doing, experience situations first-hand, and though role-play. Bransford and colleagues (as cited in Squire, 2002) have found that students perform best when given access to lectures in the context of completing open-ended complex problem solving tasks. Gaming environments allow both the simulation of experiences that students might have in the real world and also the creation of compelling experiences that cannot normally be experienced directly (Winn, 2002).

The military has been successfully using game-based simulation for years. Military games became mainstream through the free game (Department of Defense funded) *America's Army*™. While studying the learning aspects of *America's Army*™, Belanich, Sibley, and Orvis (2004) found that participants recalled procedures better than facts, recalled information relevant to game progression, graphic images and spoken text were recalled more accurately than printed text, and the realism, challenge, exploration, and control were factors influencing motivation. The hands-on/minds-on virtual experiences of *America's Army*™ should be the Rosetta Stone of MEGA design.

The multiplayer component of MEGAs allows students to interrelate while interacting with the virtual environment making games more dynamic and interesting. This notion of cooperative play lends another dimension to learning through games (Consortium, 2005). Munger (2005) reported that video games improved student performance in reading comprehension, spelling, and math. With multiple avatars (digital representation of oneself) in a virtual environment, MEGAs lend themselves to anonymous exploration in teams or individually.

As suggested earlier, the technology being investigated in this work shares many of the features of educational *Multi-User Virtual Environments* (MUVEs). Briefly stated, MUVEs are 3-D virtual worlds in which learners control avatars and explore their environment, communicate with other users, and often engage in collaborative learning activities. These educational games commonly require the use of logic, memory, problem solving and critical thinking skills, visualization and discovery. Moreover, the use of these gaming technologies requires that users manipulate virtual objects using electronic tools and develop an understanding of the complex systems being modeled.

Some examples of MUVEs include but are not limited to *River City* (Dede, Ketelhut, & Ruess, 2002; Ketelhut, 2006), *Quest Atlantis* (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005), and *WolfDen* (Author, 2006)- all of which have been used to advance inquiry-based teaching and learning. A comprehensive review of this game-based movement was recently completed by Nelson and Ketelhut (2007).

Generally speaking, these educational games seem to be effective in enhancing motivation and increasing student interest in subject matter (Yee, 2006), yet the extent to which this translates into more effective learning is less clear. The lack of empirical data, due primarily to the scarcity of systematic investigations into the cognitive impact of serious games, underscores the timeliness of this study.

3.2. Student engagement

A **complete** and just review of the voluminous research base regarding student engagement is well beyond the aim and scope of this article. Instead we focus only on the intersection of educational games and student engagement. The multidisciplinary nature of games lends itself to whole-curriculum programs, where knowledge is applied across many subjects (NMC, 2005). This cross-disciplinary characteristic is what helps motivate science students who do not customarily succeed in science class but do succeed in other content areas. Because playing doesnot feel like ''working'', students may spend more time with a game than they would reading related material or doing problems at the end of the chapter.

The amount of student learning and personal development associated with any educational program is directly proportional to the quality and quantity of student involvement (e.g. Heath et al., 2005). Jones (1998) and Shernoff, Csikszentmihalyi, Schneider, and Shernoff (2003) used *Flow Theory* to examine student engagement. Shernoff concluded that high school students experienced increased engagement when the challenge of the task and their own skills were high and in balance. Games engage students in abstract thinking of complex and physical phenomena and immerse the learner in worlds that not only represent scientific phenomena, but can also behave according to the laws of physics (Dede, Salzman, & Loftin, 1999).

Ahlfeldt, Mehta, and Sellnow (2005) suggested student engagement is higher with more problem-based activities. Although some might argue against competition, competition motivates students to participate in uninteresting or routine educational activities and has been seen to stimulate involvement and interest (Yu, 2001). Jayakanthan (2002) concluded that putting two or more children in the same game, there is improved participation, achievement, and motivation due in part to the competitive nature of games. These may be reasons why educational games are often couched in a problem-based environment. Author (in press), stated that playing is developmentally appropriate for children and when children are actively engaged in play, they are learning.

Additionally, games have the potential to reach students who do not do well academically with traditional teaching and learning strategies. Rapid advances in information technology are reshaping the learning styles of many students (Dede, 2005). Because the *Net Generation* has had almost everything at the touch of a button, their attention span has become shorter. This change in attention is impacting teachers and classrooms in every subject (deCastell & Jenson, 2004). Computer software with a game format led to increases in active engaged time and decreases in off-task behaviors relative to independent seatwork in a study on math understanding for children with attention-deficit hyperactive disorder (Ota & DuPaul, 2002). A similar result has been reported on students with emotional and behavioral disorders (Wilder & Black, 2001). Multiple external representations contributed to student developments in reasoning of genetics by engendering their motivation and interest (Tsui & Treagust, 2003). Regardless of the disability, games seem to have potential to reach the seemingly unreachable.

3.3. Cognition and multiple-representations

In educational settings visualizations are an important consequence of an increased emphasis on inquiry learning that often exploit the human ability to identify patterns in images and video (Edelson, Gordin, & Pea, 1997). To assist in the construction of science knowledge, scientific models and visualizations can help individuals make sense of abstract concepts (Treagust, Chittleborough, & Mamialo, 2002). Science education, in particular, is one area in which multimedia instruction has been increasingly employed to communicate complex ideas and concepts in instructional settings, providing additional entry points for students to leverage understanding through alternate modalities (Gardner, 1993). However, as Srinivasan and Crooks (2005) note, multimedia instruction in the sciences has typically fallen short of its instructional promise.

For this reason (and others) there has been considerable interest in the learning sciences research community as to the cognitive basis of multi-representational learning (e.g. Mayer & Moreno, 2003; Paas, Renkl, & Sweller, 2003a; Ploetzner & Lowe, 2004). One broad line of research that attempts to address these issues is based on cognitive load theory (e.g. Paas, Tuovinen, Tabbers, & Van Gerven, 2003b; Sweller, Merrienboer, & Paas, 1998) and a related theory of multimedia learning (e.g. Mayer & Moreno, 2003; Moreno, 2002). Both of these theories are based on a model of cognitive architecture that includes a discrete, limited-capacity working memory component (Baddeley, 1999; Newell & Simon, 1972). While this model is based on core, historical models of cognitive architecture, more current related work based on connectionist models and using neuropsychological techniques continue to support this basic model of a limited-capacity working memory component (e.g. Bunge, Klingberg, Jacobsen, & Gabrieli, 2000; Just & Varma, 2002). Theoretical work on the structure and function of working memory has posited unique processing mechanisms for both visual and auditory information (Baddeley, 1999; Paivio, 1986).

These theories become important to the current study because video games juxtapose graphics and audio that stimulate the player. Video gamesmanship represents conscious, deliberate mental and physical activity and promotes active learning by shifting players into the participant role. Each strategic movement generates a visible response. Moreover, the immediacy of reciprocal responses reduces the sense of distance between the player's efforts and successes. External stimuli are controlled to focus and define exploration and problem solving. Challenges are matched to players' developmental levels to create a psychological sense of flow (Bowman, 1982).

Researchers have reported powerful combinations of animated graphics and audio as useful an instructional design strategy (e.g. Mayer & Moreno, 2003; Rieber, Tzeng, & Tribble, 2004). The educational advantage of this sensory combination is often linked to a reduction of the working memory demands being imposed on the user (Paas et al., 2003b; Sweller et al., 1998). But while much of the research on the use of animations has reported favorable responses by learners, results of studies that have looked specifically at the advantages of using animations in the promotion conceptual understandings are mixed (e.g. 'Hegarty, 2004; Hutcheson, Dillon, Herdman, & Wood, 1997). While a static image is likely to be re-inspected numerous times (Carpenter & Shah, 1998; Hegarty, 1992), the image elements of interest in a video game are likely to change shape, location, etc. or disappear altogether as the user plays. There may be issue as to whether cognitive processing can keep up with the rate of presentation (Bodemer, Ploetzner, Bruchmuller, & Hacker, 2005; Lowe, 1999). This is a central concern in MEGA design and use.

3.4. Students' understanding of genetics

For this particular study the MEGA created targeted genetics concepts, as such attention must be paid to some of the prior work that has looked at students' understandings of genetics. Despite its worldwide presence in secondary school science curricula and its critical importance in modern biomedical sciences, agriculture, forensics, and the pharmaceutical industry, genetics remains conceptually and linguistically difficult to teach and learn (Tsui & Treagust, 2007). Generally speaking, the prior research focusing on students' understandings of core genetics concepts (e.g. DNA, RNA, gene, chromosome, protein, DNA replication, transcription, translation, and Mendelian inheritance) suggest that the simultaneous exposure to objects and processes at the macro and molecular levels of organization and the scarcity of direct concrete experiences with these ideas has made their learning difficult, at best (Bahar, Johnstone, & Sutcliffe, 1999; Hackling & Treagust, 1984; Lewis & Wood-Robinson, 2000; Marbach-Ad, 2001; Stewart & Hafner, 1994).

While several researchers (e.g. Kindfield, 1994; Malacinski & Zell, 1996; Peebles & Leonard, 1987; Rotbain, Marbach-Ad, & Stavy, 2006; Tsui & Treagust, 2007) point to improved understandings due to the use of models (both physical and computer-based), the development of robust concepts of and efficient problem solving in genetics continues to be a struggle for most children. These conceptual difficulties also help build a case for the importance of this current study.

4. Research methods

4.1. Study design and sample

This quasi-experimental study employed a posttest only control group design in which the treatment (or experimental) group played a MEGA that focused on core genetics principles (this MEGA is described in further detail in the next section). The study was set in four general biology classes from a single high school in the South Eastern United States. All four classes were taught by the same teacher. While no formal matching techniques were used, judgmental sampling (an extension of convenience sampling) was employed. This approach allowed us to leverage the expert discretion of the classroom teacher who was familiar with the characteristics of this population of students in the assignment of treatment groups (Fraenkel & Wallen, 1996). Together the researchers and classroom teacher reviewed students' archival data (e.g. report card grades and state test results) and discussed their in-class performance and engagement prior to group assignments. This sampling strategy helped ensure equivalency among the four intact classes chosen to participate prior to the start of the study. The participants ranged from 14 to 18 years of age.

In the experimental group, a MEGA was introduced to students as a review of a genetics unit. Sixty-six students (35 males and 31 females) were exposed to the MEGA. Students played the MEGA in pairs for one block of 90 min using a PC-based desktop in their school's computer lab. Interestingly although much has been reported on the popularity of video and computer-based games, the majority of this sample reported not playing games of any type outside of school. The three control or comparison classes consisted of 63 students (28 males and 35 females) bringing the total number of participants to 129.

It is important to note that the MEGA was only used as a review of a genetics unit and that all 129 students experienced the "business as usual" genetics instruction. At this particular school this included a fairly well balanced combination of whole group lecture, hand-on inquiry-based activities, small and large group discussion, and independent practice. Thus the key difference between the groups of students was the type of *unit review* they engaged in, the experimental group played the MEGA while the comparison group reviewed the material via independent paper and pencil practice and whole group discussion.

4.2. The Intervention

The MEGA used in this study was designed and built to probe student understandings of pedigrees, Mendelian inheritance, blood types, and DNA fingerprinting through a problem-based crime scene investigative mystery. See Fig. 1 for a representative screen-shot of the game.

The setting of the game is a large mansion although students will teleport to a crime lab setting. The back-story, a critical component of game design, of the MEGA introduces users to *Mr. I.M. Megabucks* and *Mrs. I.M. Megabucks*. Both characters have recently deceased leaving a large inheritance to a number of relatives. They passed away tragically when they were struck by lightning while climbing up a playground's metal slide during a storm. When family members show up for the reading of the will, the inheritance is stolen out of the safe. Only family members have access to the combination. There is a small amount of blood left at the crime scene. The only other clue is that the butler witnessed the crime. He observed a dark figure wearing a ski mask running out of the room carrying a large bag (presumably full of the inheritance). As the masked burglar rushed past the butler the person gave the "thumb's up" sign. The butler noticed that this person had a bent thumb.

During game play, *Mr. I.M. Megabucks* tells the story of how he and his wife passed away. *Mrs. I.M. Megabucks* explains the relationship between the family members so the players can construct a pedigree. Other key characters include: the *butler* who gives out

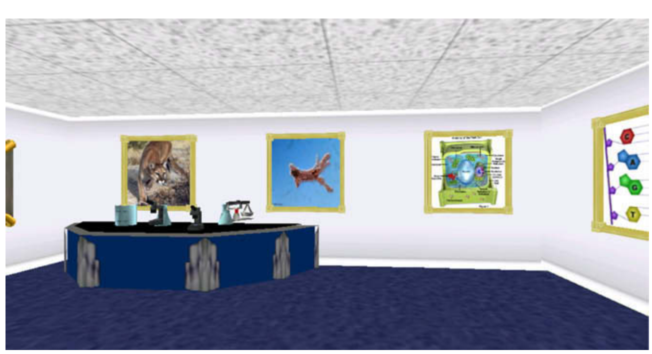

Fig. 1. A representative screen-shot of the MEGA used in this study.

Table 1
Levels of engagement in the *Protocol for Classroom Observations* (2004).

Student obeys, not engaged in new learning [1]
Student opens book as directed, organizes materials
Student listens as teacher gives familiar directives – how to line up, how to behave going to lunch
Student moves desk, gets in line Teacher rearranges furniture
Student On Task [2]
Student practices task or routine already modeled or highly familiar
Student does oral summary/review work
Student writes notes as teacher directs (copies from board, overhead, etc.)
Student reads text as teacher directs; listens to teacher reading
Student Engaged in Learning [3]
Student checks understanding of assignment or expectations
Student works actively on assigned task, follows directions as given
Student performs manipulation of appropriate materials consistent with the assignment
Student reads assigned text, answers questions from text/teacher; demonstrates basic level of understanding
Student-Directed Inquiry/Academic Rigor [4]
Student infers, problem solves
Student analyzes, synthesizes; student forges a connection to another lesson or content area
Student makes authentic connections independently
Student applies high levels of thinking and understanding
Student raises questions/discusses rigorous content with teacher/peer

the information that the thief has a bent thumb, the *investigator* who helps players by giving them information about thumbs and which thumb type each family member has, the *lab technician* who helps players take the blood sample to the crime lab so it can be typed and helps players through the DNA fingerprinting process once the list of suspects is narrowed down. Towards the end of the game, *family members* (15) line up in the mansion and when the player knows who committed the crime he/she goes upstairs and select the guilty person.

Readers should keep in mind that the classroom teacher is the primary author/creator of the game. In theory, this helps ensure that the game play, game goals, and genetics concepts covered during the unit of study are well aligned.

4.3. Data sources and instrumentation

In order to establish equivalency between the experimental and control group in this study, each participant's average grade on their last three report cards in the biology course was calculated and recorded. In order to assess if playing the MEGA impacted students' understanding of the embedded genetics concepts, participants' grade on a teacher constructed genetics unit test (see Appendix A.) administered post-intervention were compared across treatment groups.

Additionally, student engagement was assessed using the *Protocol for Classroom Observations* from the Annenberg Institute for School Reform (2004). Table 1 illustrates this framework. The bold categories are the levels of engagement with its corresponding score while the sub-categories show possible student actions. The observations of student engagement were made by two researchers using videotapes of the students' participating in MEGA play and live classroom observation of the control group. Eighteen observations (every two minutes) were made and subsequently coded. Rater reliability scores from the observations were accomplished through a double rating, near-point procedure (Allen & Yen, 1979; Crocker & Algina, 1986). Rater scores were found to be 89% reliable. The near-point method was incorporated to analyze rater agreement to one point within comparable scores.

Table 2
Comparison of Genetics Unit Test Scores Across Treatment Groups.

	Experimental Group ($n = 66$)		Control Group ($n = 64$)			
	Mean rank	Sum of ranks	Mean rank	Sum of ranks	*U*	*p*
Genetics unit test score	65.39	4315.50	65.62	4199.50	2104.50	.971

Note: Possible scores ranged from 0 to 4. The Mann-Whitney U test was used to compare treatment groups.

Table 3
Comparison of student engagement across treatment groups.

	Experimental group (36 observations)		Control group (36 observations)			
	Mean Rank	Sum of Ranks	Mean Rank	Sum of Ranks	U	p
Protocol for classroom observations	53.67	1932.00	19.33	696.00	30.00	.000**

Note: Possible scores ranged from 0 to 4. The Mann-Whitney U test was used to compare treatment groups.
** $p < .01$

4.4. Data analysis

As mentioned earlier, in order to establish equivalence between the treatment groups, each participant's average grade on their last three report cards in the biology course was calculated. Letter grades were reported for students in this school based on the following percentages: $A = 90–100$, $B = 80–89$, $C = 70–79$, $D = 60–69$, and $F =$ below 60. For our analysis these grades were coded as: $A = 4$, $B = 3$, $C = 2$, $D = 1$ and $F = 0$. The same coding scheme was adopted for use with the genetics unit test. Stratifying students devised groups with equivalent achievement to each of the respective groups. This stratification ensured that not all high achievers were in one group and not all low achievers were in another.

Since the data generated is ordinal in nature nonparametric inferential statistics were employed in all analyses. In order to help determine if engaging in the genetics MEGA impacted student understandings of genetics concepts, scores on the post-intervention unit test were compared across treatment groups using a Mann-Whitney U test. The data on student engagement generated from observations of video-taped and live interactions of the participants was also compared across treatment groups using a Mann-Whitney U test of significance.

5. Results and discussion

This section first presents the results of the statistical analyses and then goes on to provide both theoretical and practical explanations of the observed results. Mean report card grades for the treatment groups were not statistically different suggesting that the students entered the study with similar understandings of the science concepts. Direct comparison of student scores on the genetics unit test, administered post-intervention, indicated that the distribution of test scores were not significantly different across treatments (see Table 2).

The results of the student engagement data analysis (Table 3) indicated that students in the experimental group were more engaged then control group students.

5.1. The inherent complexity of educational games

Because using video games as a teaching and learning tool is breaking new ground in the educational research community, it is becoming increasingly important to more fully understand how they are being played. Due to the relatively short intervention period it may not be surprising that statistically significant differences in the cognitive assessment used in this study were not found. Most "gamers" must play a given game many times for many hours before they learn to navigate and negotiate in the synthetic world efficiently let alone learn content embedded in the game. Since the student participants were exposed to the MEGA just once, it can be argued that the bulk of their time was spent exploring the surroundings and "getting a feel" for the game play. This strategy is not uncommon for game players. However it is important to note the micro-games are now being developed, such as the MEGA described here, to ensure learning during short exposure to game play. From the results on engagement, we can be certain student participants were immersed in the learning environment. It is probable that because students were forced to apply genetics content knowledge to authentic scenarios, a level of cognitive conflict caused students to question what they have learned through other activities within the teaching unit and thus may have hindered achievement on the end of unit test.

Learning is situated not only within the game but also around it. The practice of learning a video game is an enculturation practice that involves not only learning the mechanics of game play, but learning how to negotiate the context of play, the terms and practices of a game's players, and the design choices of its developers. These levels of engagement are what Gee (2003) calls, respectively, internal and external design grammars for a given domain. These design grammars are present in any given *semiotic domain* (a term used to describe distinct and embodied contexts, matrices of environmental attributes and, crucially, social practices in which signs are given a distinct meaning, and in which a person can be literate) from a basketball game to an archaeological dig (Craft, 2004; Gee, 2003). Video games allow gamers to simulate, learn, and manage design grammars in a way that traditional teaching practices do not. This may in itself lead to powerful but "messy" (in terms of our ability to assess it) learning.

5.2. Assessing learning

These cognitive results raise critical questions about assessment of student learning in these new immersive learning environments. For example, is there a fundamental mismatch between the 3D sensorily rich instructional intervention and the 'test'? Does a 2D written paper and pencil cognitive assessment access learning/performance differences that actually existed between the treatment groups?

Perhaps a more sensitive assessment of student learning would be to have them create their own original educational game that is then assessed, in part, on its scientific accuracy. However, these researchers believed that by using the teacher created test, it provided a more authentic assessment to what students and teachers use in classes. If it is our goal as researchers to seamlessly assess interventions in an authentic setting then using validated instrumentation may not always be the best form of measurement. This teacher has used this test for three years and all of the items were derived from released end of grade, standardized tests in North Carolina.

A rival explanation of the observed results takes the "teacher effect" into account. A primary aim of this study was to measure the efficacy of this innovative intervention (as compared to "regular" teaching) and the findings can be reasonably attributed to the impact of an expert teacher. That is to say, the results of no significant difference between the treatment groups on the cognitive assessment items may be due to the fact that all of the study participants were well-taught in the first place, which may have diluted the pedagogical impact of the MEGA. Presumably, there is a connection between quality teaching and being an early adopter of instructional technology (Jacobsen, 2000). Clearly, future work in this area should attempt to carefully pull the impact of the technology on student learning apart from the cognitive impact of a skilled teacher.

5.3. Measuring student engagement

Engagement is a multidimensional and dynamic construct. Fredricks, Blumenfeld, and Paris (2004) propose three dimensions of learner engagement. They are *cognitive engagement*, which is defined as the learner's mental investment in learning, effortful strategy use, and deep thinking and commitment to academic work, *emotional engagement*, which refers to a learner's affective reactions to others, and connections with the school community, and *behavior engagement*, which is viewed as active participation in both the school and academic activities as demonstrated through attention, persistence and asking and answering questions. Although Fredricks et al. (2004) organized engagement to fall into three categories; they suggest that a "fusion" of these categories is essential to get a deeper and more satisfying handle on student engagement.

While we acknowledge that motivation and engagement alone does not ensure achievement, cognitive engagement does mediate the ways in which values and needs relate to learning and achievement. Blumenfeld, Kempler, and Krajcik (2006) point out the influences and challenges of four specific features of learning environments on motivation and cognitive engagement: *authenticity*, *inquiry, collaboration and technology*. They suggest that technology has motivational benefits as a "hook" that gets learners to participate.

5.4. Video games as a curricular tool

Other recent research suggests that playing computer games, as a curricular tool, has enormous potential for motivating and engaging children of all ages in deep learning (Barab et al., 2005), but that the distractions in the 3D multiuser virtual environment (3D MUVE), with its complexities and the difficulties learners face, could actually result in the lack of engagement (Lim, Nonis, & Hedberg, 2006). Blumenfeld et al. (2006) also noted that it may be the case that these features of learning environment work to promote motivation, but may only serve to "hook" but do not sustain student interest. Designers and teachers will need to explore what steps can be taken to combat the "novelty effect" in order to achieve sustained motivation without sacrificing high-quality cognitive engagement required for meaning making.

Further, from the results of this study MEGAs or video games in general might not be best used as a review of content but rather they may be more useful as an anticipatory set initiate student and attention. Used at this point of the instructional sequence they can then serve as a pre-assessment to gauge students' existing knowledge. Students can then re-play the MEGA or game as a review and the instructor can assess what learning gains might have occurred.

6. Conclusions

The statistical results of this study indicated that despite being more engaged in the instruction students who played computer-based MEGA games did not demonstrate a greater understanding of the genetics concepts presented. This finding, although disappointing to some degree, should not undermine the use of this emerging technology. Rather, it helps reinforce the critical need for further research aimed at isolating and documenting the cognitive impact of this technology.

We remind readers that cognitive processing is only one factor that contributes to effective learning; affective impacts and motivational factors should be considered as well (Schnotz, 2002). That is to say, if new and innovative technologies (such as educational games) are more engaging and appealing to students and if in turn these learners are motivated to interact with these learning environments longer than with traditional print materials then this in itself may justify the use of and deeper investigation of these new technologies.

7. Cautious optimism

Games are not a panacea. It is possible that games in education need to be more skilled-based then wrapped around a rich story line. This has proven successful in other Serious Games such as those created for the military and medical fields (Dugdale, Pallamin, & Pavard, 2006; Macedonia, 2000). Game design needs to take into account four meta-principles to support knowledge integration: making science accessible, making thinking visible, helping students to learn from each other, and promoting autonomous learning (Linn, 2004). More challenging is the fact that game design requires the ability to step outside of a traditional, linear approach to content creation – a process that is counter-intuitive to many teachers (Morrison & Aldrich, 2003).

The building and use of MEGAs may be a worthwhile endeavor because the classroom teacher designs and constructs them which we feel leads to curricular coherence and increased "buy-in". However, integrating any new concept or pedagogy into ones teaching requires in-depth and sustained professional development. Certainly more attention needs to be paid to how to best provide early adopters with the skills and support to incorporate MEGAs into their teaching repertoires.

While the potential power of video games in the classroom is becoming more apparent but the criteria for design and evaluation of the games needs to be established. This study begins to shed light on the criteria. Games need to be designed with close attention to the embedded instructional content and less emphasis on animation, text and audio that does not aid in the learning process. Moreover, if games engage students in the learning process then it is not unreasonable to assume that students can learn from playing games. Student time on task is the most influential factor in student achievement (Farragher & Yore, 1997; Tobin, 1986). What is crucial in the learning process is our ability to parlay student attention and engagement to aid them in the development of more robust understandings of complex science concepts. If this occurs, then game on.

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Appendix

2006-2007 Third Quarter Assessment for Biology I

Directions: Please mark your choice on the scantron provided. Do **NOT** write on this test.

1. In the cross Rr x Rr, the offspring are
   A. all Rr B. all RR C. ½ Rr, ½ rr D. ¼ RR, ½ Rr, ¼ rr

Use the following Punnett Square to answer questions 21 and 22.

AABB	AABb	AaBB	AaBb
AABb	AAbb	AaBb	Aabb
AaBB	AaBb	aaBB	aaBb
AaBb	Aabb	aaBb	aabb

2. What would be the genotypes of the parents who produce these offspring?
   A. AABB and aabb C. aaBB and AAbb
   B. AaBb and aabb D AaBb and AaBb

3. What is the probability that an offspring would display the dominant phenotype for both traits?
   A. 9/16 B. 4/16 C. 3/16 D. 1/16

4. A parent has the genotype AaBB. What gametes would this parent produce?
   A. Aa and BB B. AB and AB C. AB and aB D. AB only

5. The genotype of an individual who displays a dominant phenotype can be determined by crossing it with
   A. a homozygous dominant individual C. a heterozygous individual
   B. a recessive individual D. a different species

Use the following Punnett Square to answer questions 6 and 7.

	T	t
t	Box 1	Box 2
t	Box 3	Box 4

6. For the above Punnett Square, T represents the allele for being tall and t represents the allele for being short. What genotype would be in box 3?
   A. TT B. tt C. Tt D. tall

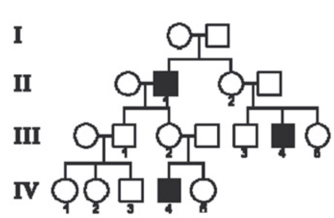
7. For the above Punnett Square, assume that these parents have 10 offspring who are all tall. What is the probability that their next offspring would be tall?
   A. 100% B. 75% C. 50% D. 25%

8. Somebody with blood type AB shows which of the following patterns of inheritance?
   A. dominant B. recessive C. codominant D. sex-linked

9. In rabbits, black fur (B) is dominant to brown fur (b). What is the phenotype of a heterozygous rabbit?
   A. Bb B. BB C. brown D. black

10. If you want to quickly know the phenotype of a bird's feathers, you should
    A. analyze its DNA
    B. look at its feathers
    C. observe what it eats
    D. examine its droppings

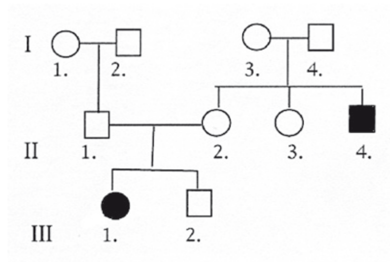
Use the following pedigree to answer questions 11 – 12.



11. Examine the above pedigree. What is the most likely inheritance pattern of this disorder?
    A. autosomal dominant C. autosomal recessive
    B. sex-linked dominant D. sex-linked recessive

12. In generation III, what is the genotype of individual #2?
    A. X^DX^d B. X^DX^D C. Dd D. dd

Use the following pedigree to answer questions 13-14.



13. What is the likely inheritance pattern of the trait shown in the above pedigree?
   A. autosomal dominant C. autosomal recessive
   B. sex-linked dominant D. sex-linked recessive

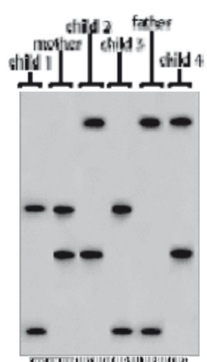
14. What is the genotype of individual #3 in the first generation?
   A. X^aX^a B. X^AX^a C. Aa D. aa

15. Mr. Sandival has Type B blood. Mrs. Sandival has Type AB blood. They have three biological children and one adopted child. Owen has type O blood. Mary has type AB. Susie has type A. Carl has type B. Which child was adopted?
   A. Owen B. Mary C. Susie D. Carl

16. Humans have
   A. 22 pairs of autosomes and 1 pair of sex chromosomes
   B. 23 pairs of autosomes and 1 pair of sex chromosomes
   C. 44 pairs of autosomes and 2 pairs of sex chromosomes
   D. 21 pairs of autosomes and 2 pairs of sex chromosomes

17. Which of the following is the best description of disorders such as heart disease and high cholesterol?
   A. They are completely genetic.
   B. They are completely environmental.
   C. They are a combination of genetics and environmental factors.
   D. No one knows why people get these diseases.

18. Results from a DNA fingerprint analysis for a man and woman and their four children are shown in the illustration. Which child, if any, could **NOT** be the biological offspring of the father?



   A. Child 1
   B. Child 2
   C. Child 3
   D. Child 4
   E. all children could be the biological offspring of the father

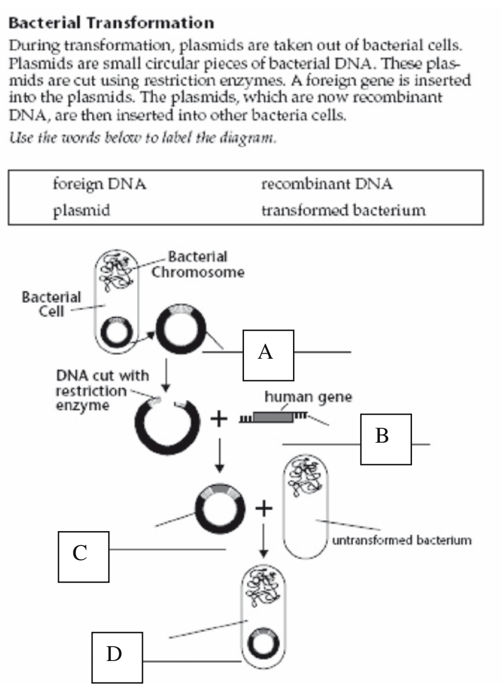
19. Look at the gel above: If the top of the gel is where the DNA was loaded, where are the largest fragments located?
   A. at the top C. evenly distributed throughout the gel
   B. at the bottom D. in the middle

20. Organisms that contain genes from another species are called:
   A. transgenic B. mutagenic C. donor organisms D. retro organisms

21. The process of attempting to cure genetic disorders by placing copies of healthy genes into cells that lack them is known as
    A. Gene therapy C. Rapid sequencing
    B. DNA fingerprinting D. Human genome project

22. To perform DNA fingerprinting, you need a source of the suspect DNA. You can obtain this DNA from:
    A. sperm B. hair C. skin cells D. white blood cells E. all of the above

Use the following diagram of bacterial transformation to answer questions 23-25.



23. Which letter above represents the recombinant plasmid?

24. Which letter above represents the cell that will produce the desired protein?

25. Which of the following would **NOT** be a product produced by the process shown in the diagram?
    A. insulin B. human growth hormone C. pest resistant corn D. cloned sheep

References

Ahlfeldt, S., Mehta, S., & Sellnow, T. (2005). Measurement and analysis of student engagement in university classes where varying levels of PBL methods of instruction are in use. *Higher Education Research and Development, 24*(1), 5–20.
Allen, M. J., & Yen, W. M. (1979). *Introduction to measurement theory*. Brookes Cole.
Annenberg Institute for School Reform (2004). Protocol for classroom observation. Retrieved 02/24/06 from http://www.annenberginstitute.org/images/class_obs.pdf.
Author (2006). Serious games: Incorporating video games in the classroom. Educause Quarterly.
Author (in press). Bridging reality to virtual reality: Investigating gender effects abd student engagement on learning through video game play in an elementary school classroom. *International Journal of Science Education*.
Baddeley, A. (1999). *Human memory*. Boston, MA: Allyn & Bacon. doi:10.1080/09500690801968656.
Bahar, M., Johnstone, A. H., & Sutcliffe, R. G. (1999). Investigation of students' cognitive structure in elementary genetics through word association tests. *Journal of Biological Education, 33*, 134–141.
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.
Belanich, J., Sibley, D. H., & Orvis, K. L. (2004). *Instructional characteristics and motivational features of a PC-based game*. Alexandria, Virginia: U.S. Army Research Institute for the Behavioral and Social Sciences.
Blumenfeld, P. C., Kempler, T. M., & Krajcik, J. S. (2006). Motivation and cognitive engagement in learning environments. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 475–488). Cambridge, NY: Cambridge University Press.
Bodemer, D., Ploetzner, R., Bruchmuller, K., & Hacker, S. (2005). Supporting learning with interactive multimedia through active integration of representations. *Instructional Science, 33*, 73–95.
Bowman, R. F. (1982). A Pac-Man theory of motivation: Tactical implications for classroom instruction. *Educational Technology, 22*(9), 14–17.
Britain, S., & Liber, O. (2000). *A framework for pedagogical evaluation of virtual learning environments* (No. 41): JISC Technologies Application (JTAP) Programme.
Bunge, S. A., Klingberg, T., Jacobsen, R. B., & Gabrieli, J. D. E. (2000). A resource model of the neural basis of executive working memory. *Proceedings Of The National Academy Of Sciences Of The United States Of America, 97*(7), 3573–3578.

Carpenter, P. A., & Shah, P. (1998). A model of perceptual and conceptual processes in graph comprehension. *Journal of Experimental Psychology: Applied, 4*, 75–100.
The New Media Consortium. (2005). The Horizon Report (No. ISBN 0-9765087-0-2). Stanford, CA.
Craft, J. (2004). A review of what video games have to teach us about learning and literacy. *Currents in Electronic Literacy, 8*.
Crocker, L. M., & Algina, J. (1986). *Introduction to classical and modern test theory*. Harcourt Brace Jovanovich College Publishers.
deCastell, S., & Jenson, J. (2004). Paying attention to attention: New economies for learning. *Educational Theory, 54*(4), 381–397.
Dede, C. (2005). Planning for neomillennial learning styles [Electronic Version]. *Educause*, 28, 11. Retrieved 3/17/05 from www.educause.edu/apps/eq/eqm05/eqmo511.
Dede, C., Ketelhut, D. J., & Ruess, K. (2002). Motivation, usability, and learning outcomes in a prototype museum-based multi-user virtual environment. In P. Bell, R. Stevens, & T. Satwicz (Eds.), *Keepinglearning complex: The proceedings of the fifth international conference of the learning sciences*. Mahwah, NJ: Erlbaum.
Dede, C., Salzman, M., & Loftin, B. (1999). Multisensory immersion as a modeling environment for learning complex scientific concepts. In W. Feurzeig & N. Roberts (Eds.), *Modeling and simulation in science and mathematics education*. New York: Springer-Verlag.
Dugdale, J., Pallamin, N., & Pavard, B. (2006). An assessment of a mixed reality environment: Toward an ethnomethodological approach. *Simulation and Learning, 37*(2), 226–244.
Edelson, D. C., Gordin, D., & Pea, R. (1997, March 20–24). Creating science learning tolls from experts' investigation tools: a design framework. Paper presented at the *Annual Meeting of the National Association for Research in Science Teaching*, Oak Brook, IL.
Farragher, P., & Yore, L. D. (1997). The effects of embedded monitoring and regulating devices on the achievement of high school students learning science from text. *School Science and Mathematics, 97*(2), 87–95.
Fraenkel, J. R., & Wallen, N. E. (1996). *How to design and evaluate research in education*. New York, NY: McGraw-Hill.
Fredricks, J., Blumenfeld, P., & Paris, A. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research, 74*, 59–109.
Gardner, H. (1993). *Frames of mind: The theory of multiple intelligences*. New York, NY: Basic Books.
Gee, J. P. (2003). *What video games have to teach us about learning*. New York: Palgrave.
Gee, J. P. (2005). Learning by design: Good video games as learning machines. *E-Learning, 2*(1), 5–16.
Hackling, M. W., & Treagust, D. F. (1984). Research data necessary for meaningful review of grade ten high school genetics curricula. *Journal of Research in Science Teaching, 21*, 197–209.
Heath, B., Herman, R., Lugo, G., Reeves, J., Vetter, R., & Ward, C. R. (2005). Developing a mobile learning environment to support virtual education communities. *Technological Horizons in Education Journal Online, 32*(8), 112–132.
Hegarty, M. (1992). The mechanics of comprehension and the comprehension of mechanics. In K. Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading*. New York: Springer-Verlag.
Hegarty, M. (2004). Dynamic visualizations and learning: Getting to the difficult questions. *Learning and Instruction, 14*(3), 343–351.
Hutcheson, T.D., Dillon, R.F., Herdman, C.M., & Wood, J. (1997). To animate or not to animate, that is the question. Paper presented at the *Proceedings of the Human Factors and Ergonomics Society 41st annual meeting* - 1997, Albuquerque.
Jacobsen, M. (2000). Excellent teaching and early adopters of instructional technology. In J. Bourdeau & R. Heller (Eds.), *Proceedings of world conference on educational multimedia, hypermedia and telecommunications 2000* (pp. 486–491). Chesapeake, VA: AACE.
Jayakanthan, R. (2002). Application of computer games in the field of education. *The Electronic Library, 20*(2), 98–102.
Jones, M.G., (1998, February 18–22, 1998). Creating Electronic Learning Environments: Games, Flow, and the User Interface. Paper presented at the *National Convention of the Association for Educational Communications and Technology (AECT)*, St. Louis, MO.
Just, M. A., & Varma, S. (2002). A hybrid architecture for working memory: Reply to MacDonald and Christiansen (2002). *Psychological Review, 109*(1), 55–65.
Ketelhut, D. J. (2006). Do students with higher self-efficacy exhibit greater and more diverse scientific inquiry skills: An exploratory investigation in "River City," a multi-user virtual environment. Unpublished dissertation, Harvard University.
Kindfield, A. C. H. (1994). Understanding a basic biological process: Expert and novice models of meiosis. *Science Education, 78*, 255–283.
Lewis, J., & Wood-Robinson, C. (2000). Genes, chromosomes, cell division and inheritance-do students see any relationship? *International Journal of Science Education, 22*, 177–195.
Lim, C. P., Nonis, D., & Hedberg, J. (2006). Gaming in 3D multiuser virtual environment: Engaging students in science lesson. *British Journal of Educational Technology, 37*(2), 211–231.
Linn, M. C. (2004). Using ICT to teach and learn science. In R. Holliman & E. Scanlon (Eds.), *Mediating science learning through information and communication technology*. London: Routledge Falmer.
Lowe, R. K. (1999). Extracting information from an animation during complex visual learning. *European Journal of Psychology of Education, 14*, 225–244.
Macedonia, M. (2000). Games soldiers play. *IEEE Spectrum, 39*(3), 32–37.
Malacinski, G. M., & Zell, P. W. (1996). Manipulating the "invisible." Learning molecular biology using inexpensive models. *The American Biology Teacher, 58*, 428–432.
Marbach-Ad, G. (2001). Attempting to break the code in student comprehension of genetic concepts. *Journal of Biological Education, 35*, 183–189.
Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38*(1), 43–52.
Moreno, R. (2002). Who learns best with multiple representations? Cognitive theory implications for individual differences in multimedia learning. Paper presented at the ED-MEDIA 2002 World Conference on Educational Multimedia, Hypermedia & Telecommunications, Denver, CO.
Morrison, J. L., & Aldrich, C. (2003). Simulations and the learning revolution: An interview with Clark Aldrich. *Vision*.
Munger, D. (2005). Can video games stimulate academic learning? [Electronic Version]. Cognitive Daily. Retrieved April 20, 2005 from http://scienceblogs.com/cognitivedaily/2005/04/can_video_games_stimulate_acad.php#more.
Nelson, B. C., & Ketelhut, D. J. (2007). Scientific inquiry in educational multi-user virtual environments. *Educational Psychology Review, 19*, 265–283.
Newell, A., & Simon, H. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice Hall.
Oblinger, D. G., & Oblinger, J. L. (2005). *Educating the Net Generation*.
Ota, K. R., & DuPaul, G. J. (2002). Task engagement and mathematics performance in children with attention-deficit hyperactivity disorder: Effects of supplemental computer instruction. *School Psychology Quarterly, 17*(3), 242–257.
Paas, F., Renkl, A., & Sweller, J. (2003a). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1–4.
Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003b). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist, 38*(1), 63–71.
Paivio, A. (1986). *Mental representations: A dual coding approach*. New York: Oxford University Press.
Peebles, P., & Leonard, W. H. (1987). A hands-on approach to teaching about DNA structure and function. *The American Biology Teacher, 49*, 436–438.
Ploetzner, R., & Lowe, R. K. (2004). Dynamic visualizations and learning. *Learning and Instruction, 14*(3), 235–240.
Prensky, M. (2001). *Digital game-based learning*. New York: McGraw-Hill.
Rickard, W., Oblinger, D. (2004, September 9–10, 2003). Higher education leaders symposium: Unlocking the potential of gaming technology. Paper presented at the *Higher Education Leaders Symposium*, Redmond, Washington.
Rieber, L. P., Tzeng, S.-C., & Tribble, K. (2004). Discovery learning, representation, and explanation within a computer-based simulation: Finding the right mix. *Learning and Instruction, 14*(3), 307–323.
Rotbain, Y., Marbach-Ad, G., & Stavy, R. (2006). Effect of bead and illustrations models on high school students' achievement in molecular genetics. *Journal of Research in Science Teaching, 43*(5), 500–529.
Schnotz, W. (2002). Towards an integrated view of learning from text and visual displays. *Educational Psychology Review, 14*, 101–120.
Shernoff, D. J., Csikszentmihalyi, M., Schneider, B., & Shernoff, E. S. (2003). Student engagement in high school classrooms from the perspective of flow theory. *School Psychology Quarterly, 18*(2), 158–176.
Squire, K. (2002). Cultural framing of computer/video games. *International journal of computer game research, 2*(1).
Srinivasan, S., & Crooks, S. (2005). Multimedia in a science learning environment. *Journal of Educational Multimedia and Hypermedia, 14*(2), 151–167.
Stewart, J., & Hafner, R. (1994). Research on problem solving: Genetics. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 284–300). New York: Macmillan.
Sweller, J., Merrienboer, J. J. G. V., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*, 251–296.
Taradi, S. K., Taradi, M., Radic, K., & Pokrajac, N. (2005). Blending problem-based learning with Web technology positively impacts student learning outcomes in acid–base physiology. *Journal of Advanced Physiological Education, 29*, 35–39.
Tobin, K. (1986). Student task involvement and achievement in process-oriented science activities. *Science Education, 70*(1), 61–72.
Treagust, D. F., Chittleborough, G., & Mamialo, T. L. (2002). Students' understanding of the role of scientific models in learning science. *International Journal of Science Education, 24*(4), 357–368.

Trotter, A. (2005). Despite Allure, Using Digital Games for Learning Seen as no Easy Task [Electronic Version]. *Education Week*, 25, 1–19. Retrieved November 3, 2005 from http://www.edweek.org/ew/articles/2005/11/02/10games.

Tsui, C.-Y., & Treagust, D. F. (2003). Genetics reasoning with multiple external representations. *Research in Science Education, 33*, 111–135.

Tsui, C.-Y., & Treagust, D. F. (2007). Understanding genetics: Analysis of secondary students' conceptual status. *Journal of Research in Science Teaching, 44*(2), 205–235.

Vygotsky, L. S. (1967). Play and its role in the mental development of children. *Soviet Psychology, 5*(3), 6–18.

Wilder, L. K., Black, Sharon. (2001). *Integrating Technology in Program Development for Children/Youth with E/BD*.

Winn, W. (2002). Current Trends in Educational Technology Research: The Study of Learning Environments. *Educational Psychology Review, 14*(3), 331–351.

Yee, N. (2006). The Demographics, Motivations, and Derived Experiences of Users of Massively Multi-User Online Graphical Environments. *Presence: Teleoperators and Virtual Environments, 15*, 309–329.

Yu, F. Y. (2001). Reflections upon cooperation-competition instructional strategy: Theoretical foundations and empirical evidence. *The National Chi Nan University Journal, 51*, 181–196.