RESEARCH ON LEARNING

Learning Outcomes Associated with Classroom Implementation of a Biotechnology-Themed Video Game

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Abstract

The educational video game Mission Biotech provides a virtual experience for students in learning biotechnology materials and tools. This study explores the use of Mission Biotech and the associated curriculum by three high school teachers and their students. All three classes demonstrated gains on a curriculum-aligned test of science content. Students from two of the classes showed gains on a standards-aligned test of content; students from the third class did not demonstrate statistically significant gains. This result is attributable to a ceiling effect. The results support the idea that video games can be useful in classroom contexts. No statistically significant changes were found when looking at how the game affected student attitudes toward science and science careers.

Key Words: *Video games; video game learning; virtual classrooms; biotechnology.*

Video gaming has become a pervasive component of American culture, poised to overcome and eclipse sales in traditional forms of media such as movies and music (NPD Group, 2009). Almost all adolescents will have played a video game by middle school, and most of these children will play them on a regular if not daily basis (Lenhart et al., 2008). Video gaming is more than just a leisure medium; it can be positioned as a powerful educational tool to support learning. Gaming technology is useful in education because it provides motivating contexts for sustained engagement that can lead to learning.

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Games that make use of science ideas and science settings have the potential to support student learning of science content and development of interest in the field (Annetta et al., 2010). When designed well, games can create opportunities otherwise inaccessible because of limitations of classroom resources, issues of safety, or simply because they are beyond the scope of a traditional classroom (Gee, 2003; Shaffer, 2006). Examples of this are having students work directly with ampicillin-resistant bacteria or creating micro-array chips. In the first instance it would be too dangerous for high school students to actually handle antibiotic-resistant bacteria, and the second example would be cost prohibitive for most schools. Gaming technologies have the potential to create new avenues for learning experiences for all students (Shaffer et al., 2005).

○ Mission Biotech: A Blended Approach to Video Game Learning in the Classroom

Mission Biotech (MBt) is an educational video game developed to immerse students in a virtual laboratory in order to provide a context for using fundamental biological concepts and for introducing modern biotechnology tools and processes. The game was designed by a collaborative team including biomedical scientists, science educators, biology teachers, and a game studio. MBt was built around the Unreal Engine, a 3D graphical environment commonly used as the foundation for many commercial video games. MBt is best described as a first-person science role-playing game. It allows students to play the role of a new researcher in a biotechnology laboratory. Players are able to interact with many in-game resources such as micropipettors, centrifuges, a thermocycler, a freezer with various patient samples, etc. These virtual objects can be manipulated in ways that mirror their functionality in actual laboratories. The game is framed around a backstory in which an unknown viral disease is spreading. Nonplayer characters within the game environment guide students through a process of identifying the spreading virus before the situation becomes an epidemic. Players explore symptoms and characteristics for many viruses, extract nucleic acids from virtual patient samples, conduct and analyze polymerase chain reaction (PCR) results, establish positive and negative controls for reactions, and, when necessary (depending on what viruses are being screened), set up reverse transcription reactions.

The goal of MBt is for students to use virtual laboratory experiences to provide key diagnostic insight into which viruses are causing each of four levels' epidemiological outbreak. The game introduces biotechnology protocols (such as DNA extraction, PCR,

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and reverse transcription) not just as content to be negotiated but as actual processes students can take part in virtually and use to make research-based conclusions.

Mission Biotech was designed for use in high school classrooms and was intended for students from 10th grade to early college. We also created a set of curriculum materials for teachers to use in concert with the game. The MBt curriculum includes a series of lessons, teacher resources, and assessments to scaffold the learning that occurs within the game. Suggested lessons within the curriculum incorporate small-group activities, laboratory exercises, and brief lectures, all of which are designed to reinforce the biology concepts that students experience during game play. The game can be downloaded along with installation instructions, free of charge, from http://www.mbt-download.com.

○ Video Games in the Classroom

Studies of the efficacy of video games in science classrooms have examined the consequences of gaming on development of computer-based or technical skills (Annetta et al., 2010) and social and collaborative interaction and group problem-solving skills among student peer groups (Kafai et al., 2010). Often video games are used to scaffold inquiry-based learning as an alternative to laboratory or experimental practice (Ketelhut et al., 2010). Games become an alternative to traditional lecture and laboratory. They offer students a way to learn from play (Annetta et al., 2010). When video games are designed and implemented with pedagogy in mind, they can offer more engaging, adaptable, and motivating experiences for students, many of whom come to the classroom already enculturated into gaming techniques and play styles (Trotter, 2005). Despite this potential for video games in the classroom, Mayo (2007) pointed out that only a few major studies have looked at the learning outcomes of video games when applied to classroom settings. Even fewer have been concerned with the effects of video games in biology education and the biology classroom. Although significant conceptual literature addresses the positive potential of video games in learning and classrooms (e.g., Bowman, 1982; Squire, 2003; Shaffer et al., 2005), the literature is underdeveloped with regard to questions such as what effects video games have on student learning. In the current standards-based climate of U.S. public education, these types of studies are necessary to build a case for video games in classroom contexts. If research cannot demonstrate positive effects of gaming on standardized test scores, there will be little incentive for schools to implement gaming within classrooms. Therefore, the lack of research that directly examines gaming in science classrooms and the effects of game play on science learning outcomes is problematic for those education researchers, teachers, and developers who have seen the benefits of the medium and have been trying to get video games into the classroom.

○ Purpose of the Study & Research Questions

The purpose of our study was to test the effectiveness of a biotechnology-themed video game, Mission Biotech, in Florida public schools. The goal of this paper is to answer two central questions regarding the influence of video games on student science learning. First, do learning experiences with the Mission Biotech video game and associated curriculum lead to positive gains in student understanding of related biology content knowledge? Second, what effect does the video game have on student attitudes toward science and scientific careers? A goal of science education is to increase student interest in science and scientific careers. Games are supposed to keep students interested in the topic and, therefore, it seems reasonable to assume that video games will not only keep students interested but also have positive effects on their attitudes toward science. Games may be a mechanism for inspiring a new generation of student scientists.

○ Research Design

Sample

Three Florida teachers (2 females and 1 male; labeled teachers I, II, and III) were recruited from a summer biotechnology professional development program at a major research university. Project staff introduced Mission Biotech and the associated curriculum to the teachers during the professional development workshop. Each of these teachers chose to implement MBt in their classrooms over a 2- to 3-week period (depending on the individual scheduling demands of their schools). During the implementation, the teachers devoted approximately half of the instructional time (5 to 7 hours) to student game play, with the remaining time used for other instructional activities guided by the MBt curriculum guide, including lectures, small-group activities, and related laboratory exercises. Two teachers each implemented MBt in one class period, and the other teacher used MBt over two class periods on two different days. A total of 90 students (48 girls and 42 boys) submitted informed consent forms and completed both pre- and posttests.

Instruments

The research questions call for the investigation of two primary variables: biological content knowledge and attitudes toward science and careers in science. For the assessment of content knowledge, we adopted a multilevel approach wherein we explicitly considered how closely related assessed content was to the curricular intervention (Hickey & Pellegrino, 2005). In order to assess material directly related to MBt, we designed and administered a "curriculum-aligned" test. This curriculum-aligned test can be considered analogous to unit tests frequently given by teachers following a particular unit of instruction.

A second instrument was created to assess student learning of biological principles aligned with and derived from the specific biotechnology curriculum. The design of MBt was based on several life-science content standards articulated within the Next Generation Sunshine State standards (Florida's new science standards). The research team collected a wide range of publicly released items from standardized tests, including international comparative exams (e.g., TIMSS), the National Assessment of Educational Progress, and state tests (e.g., TAKS). Each sampled item was related specifically to one of the standards used for the design of MBt. Pools of items were created for each of the four target standards. Ultimately, five items for each standard were randomly selected from among the item pools for the creation of a 20-item "standards-aligned" test. This standards-aligned test can be considered as a proxy for standardized tests used to measure student achievement.

The final measure targeted student attitudes toward science and careers in science. This 25-item Likert-scale instrument asked students to rate their interest in science learning and science careers. All three instruments were analyzed for face validity by a series of experts in biology, science education, and measurement. The instruments were also pilot tested with 129 high school biology students (similar to but independent of the sample explored in the main study). Following methods derived from classic test theory and item response theory, items were examined for difficulty, discrimination, and likelihood of guessing for the content tests. Confirmation factor analysis was used to test the extent to which items on the Likert-scale instrument were consistent with the proposed formulation of the attitudinal construct. These analyses led to the modification and eventual improvement of several items. Students who participated in our main study took all three tests prior to any interaction with the game and curriculum. Posttest assessments were given following the conclusion of the Mission Biotech curriculum block. Copies of the instrument can be downloaded at http://www.mbt-download.com.

Analysis

Dependent-measures t-tests were used to determine whether the curriculum materials and video game had an effect on the students' understanding and attitudes as measured by posttest scores compared with pretest scores on all three instruments. These statistical comparisons were made for each teacher's classes because of differences in student characteristics and teacher implementation effects (given the limited number of teachers, hierarchical modeling was not possible). Because this strategy of independent statistical tests increases the chance of Type I errors, we set the α value at 0.01 as a conservative benchmark for establishing statistical significance. Effect sizes were calculated using Cohen's d in order to measure the magnitude of change.

○ Results

The results of the pre- and posttests are presented in three tables: curriculum-aligned results (Table 1), standards-aligned results (Table 2), and attitudinal results (Table 3). Both descriptive statistics (mean, standard deviation [SD], and standard error measure [SEM]) are presented alongside the inferential statistics (t score, degrees of freedom, and p value). For clarity, the statistically significant results are marked with an asterisk.

On the curriculum-aligned test of content knowledge (i.e., the unit test), students of all three teachers scored statistically significantly higher on the posttest as compared with the pretest ($p < 0.001$ for teachers I, II, and III). On the standards-aligned test of content knowledge (i.e., the proxy for state achievement tests), students from two of the teachers demonstrated statistically significant changes. Effect sizes were medium for the curriculum-aligned content test (r = 0.63, 0.54, and 0.47 for teachers I, II, and III, respectively) and small for the standards-aligned instrument for the two classes that showed significant changes (r = 0.39 and 0.30 for teachers I and III, respectively).

Table 1. Results from curriculum-aligned assessment.

Classroom	Pretest	Posttest	t	df	p
Teacher I	10.57	15.63	8.9014	29	<0.0001*
SD **SEM**	2.85 0.52	3.26 0.60			
Teacher II	16.29	20.14	5.0138	13	0.0002*
SD **SEM**	3.34 0.89	2.60 0.69			
Teacher III	9.20	13.63	7.1368	45	<0.0001*
SD **SEM**	3.34 0.49	4.80 0.71			

*Statistically significant.

Table 2. Results from standards-aligned assessment.

Classroom	Pretest	Posttest	t	df	p
Teacher I	12.37	15.10	8.8035	29	<0.0001*
SD **SEM**	3.46 0.63	3.08 0.56			
Teacher II	17.79	17.64	0.2790	13	0.7846
SD **SEM**	1.67 0.45	2.21 0.59			
Teacher III	10.35	12.72	6.4118	45	<0.0001*
SD **SEM**	3.43 0.51	4.08 0.60			

*Statistically significant.

Table 3. Results from attitudinal assessment.

Classroom	Pretest	Posttest	t	df	p
Teacher I	76.83	74.77	2.0788	29	0.0466*
SD **SEM**	9.03 1.65	11.93 2.18			
Teacher II	72.93	75.36	1.7428	13	0.1050
SD **SEM**	12.69 3.39	11.98 3.20			
Teacher III	76.83	74.77	2.0788	45	0.0466
SD **SEM**	9.03 1.65	11.93 2.18			

*Statistically significant.

The second research question explored effects of MBt experiences on attitudes toward science and science careers. Data from the pre- and posttest administrations of the attitudinal instrument do not suggest statistically significant changes. In fact, despite design expectations that game play would likely increase student interest in science and science careers, the posttest scores on the attitudinal instrument were lower than the pretest scores; however, these differences were not statistically significant.

○ Discussion

Results of the curriculum-aligned tests indicate that students from all three teachers' classes learned biology content associated with the MBt intervention. All three classes demonstrated statistically significant gains with moderate effect sizes. These findings support the efficacy of this particular game as a teaching and learning tool. Given the close association between the curriculum-aligned test and the intervention, these results provide an indication of how much of the material presented in the learning environment students learned. We should expect any successful intervention delivered over 2 to 3 weeks to produce these kinds of positive results. The curriculum-aligned test did not measure how well students were succeeding at the game. Games in general require certain combinations of clicks or movements in response to prompts. A game-savvy student could succeed at the game by learning the right combinations without learning the content. However, these students would more than likely not be successful on curriculum-aligned tests. Just memorizing the correct responses would not be sufficient to perform well on the content tests.

Results from the standards-aligned tests offer a somewhat different picture with regard to the question of whether an intervention supports learning of content. The standards-aligned test was created with items related to the underlying standards-based content of the intervention, but the items were not related to the contexts in which students had originally experienced the content. If students were to apply new learning-based on their experiences within the intervention, they would have to process that knowledge as it was intended for the classroom and apply it in unfamiliar contexts, namely the standards-based test items. In short, it is far more challenging to affect learning such that changes become evident in standards-aligned assessments through a single unit of instruction as compared to curriculum-aligned assessments (Ruiz-Primo et al., 2002). These kinds of changes provide a good indication of meaningful learning that affects the way students think about issues in science and would be revealed on standardized tests of achievement (Klosterman & Sadler, 2010). Results indicate that students from two of the classes were able to successfully take ideas learned from the MBt learning environment and use them in response to different kinds of standards-aligned problems. The effect sizes for these changes were smaller than those observed for the curriculum-aligned test, but this is consistent with predictions provided by the multilevel assessment model underlying the study (Hickey & Pellegrino, 2005). The fact that students showed any significant gains on a standards-aligned test is noteworthy and certainly not the norm for intervention studies making use of a multilevel assessment framework (Ruiz-Primo et al., 2002).

Students in one of the three teachers' classes did not show significant gains on the standards-aligned test. This was an Advanced Placement class. The average pretest score for this group was 89%. From the start, there were not large gaps in the students' understanding of the core biology content. We believe that the lack of significant changes in this classroom was indicative of a test ceiling effect; this is a result that has been observed in other studies utilizing multilevel assessments with high-performing science learners (Barab et al., 2007). These students likely started the treatment with a deeper understanding of the standards-aligned content, as evidenced by their placement into AP Biology classrooms. However, they may not have had much instruction in biotechnology content and techniques. The standards-based tests were not related to the game in which students had originally experienced the content. The tests weren't covering what was in the class. They were aligned only to the state standards derived from the topic of the intervention. This could explain why this class showed no change in the standards-aligned content tests and substantial change in curriculum-aligned tests.

Taken together, these results and the associated interpretations support the contention that video games can effectively support learning of core biological principles. There is ample evidence in the literature that video games are popular among learners and that they can provide virtual exposure to a broad range of experiences that would otherwise be inaccessible. This study extends these insights on gaming by offering empirical evidence of student learning of important standards-based biology content associated with classroom-based implementation of an educational, biology-focused video game.

Findings related to the exploration of student attitudes toward science and careers in science did not support positive impacts of the gaming experience. We originally anticipated greater impacts on students' attitudes than content learning. Given the widespread popularity of games and the motivating effects of video game play, we expected MBt to create a sense of excitement toward science among student players (Shaffer, 2006). Data derived from the attitudinal instrument do not support this contention. In addition to the quantitative test data featured in this report, the project team conducted case studies of classroom implementations of MBt and collected interview data from students and teachers. It appears as though many learners became frustrated with some of the game play. In designing MBt, the project team prioritized a faithful representation of scientific processes. Players were required to be precise in their actions and decisions. Mistakes, if made, required players to redo many of the processes. The design team wanted to feature some of the challenges and uncertainties of the scientific process. Some students found these game features tedious and grew frustrated when they could not skip ahead and "get the answer." Features that the design team saw as important for an accurate representation may have been perceived negatively by the students and ultimately worked against the goal of generating interest in science. Designing games is a labor-intensive process. Our development cycle was not able to respond directly to all student input concerning the difficulty of learning how to manipulate game objects. It is very difficult to virtualize many elements of "real" laboratory science. Some students were bound to have problems negotiating game play, particularly students with little gaming experience. This is one possible explanation supported by some of the qualitative data collected by the team, but we certainly cannot rule out other explanations, including the possibility that the instrumentation was not sensitive enough to detect the kinds of attitudinal changes sought.

Using new and innovative technologies such as video games can help bridge the gap between the highly interactive leisure world of most adolescents and the expectations of today's classrooms. Given the nature of our data, it can be argued that educational video games with curricular supports can lead to meaningful learning. On the basis of our experiences in the game design process, observations of teachers implementing MBt, and analyses of the student data, we believe that the success of MBt in the classroom is not a product of the game itself but of how the game was situated in the context of the classroom and the other activities that helped students make biological sense of their experiences within the game. When done right, video games can provide fresh inquiry-based experiences for students that are both self-motivating and cooperative, providing continuous, just-in-time feedback that allows students to progress through traditional science content in a nontraditional way.

One of the most obvious hesitations to using games in schools is that they might inhibit or negatively influence students' abilities to succeed on standardized tests. This is a major concern, given the current standards-based climate in schooling. We have shown that using the video game MBt, designed not just as a game but as a complete curriculum package, did not inhibit the kinds of learning most valued in systems that prioritize standardized tests. The implementation of MBt had a positive effect on these scores. Therefore, using video games with curricular support designed around content standards can positively influence students' abilities to learn in the science classroom. However, these results may not hold for every game marketed as an educational video game. The burden of implementing video games in educational contexts remains on teachers; those teachers interested in bringing games into the classroom will need to exert judgment and find games that specifically address individual classroom needs. There should be no rush to bring games into the classroom just because they are popular among students. Many games are not appropriate for the classroom, and even the most creative teacher would be hard pressed to find a justification for their use. It is our belief that games must be constructed with sound pedagogy and curricular support in mind in order for them to be successful in academic settings.

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References

Annetta, L.A., Cheng, M.-T. & Holmes, S. (2010). Assessing twenty-first century skills through a teacher created video game for high school biology students. *Research in Science & Technological Education*, *28*, 101–114.

Barab, S.A., Sadler, T., Heiselt, C., Hickey, D. & Zuiker, S. (2007). Relating narrative, inquiry, and inscriptions: a framework for socioscientific inquiry. *Journal of Science Education and Technology*, *16*, 59–82.

Bowman, R.F. (1982). A Pac-Man theory of motivation: tactical implications for classroom instruction. *Educational Technology*, *22*, 14–17.

Gee, J. (2003). *What Videogames Can Teach Us about Literacy and Learning.* New York, NY: Hargrove.

Hickey, D.T. & Pellegrino, J.W. (2005). Theory, level, and function: three dimensions for understanding the connections between transfer and student assessment. In J.P. Mestre (Ed.), *Transfer of Learning from a Modern Multidisciplinary Perspective* (pp. 251–253). Greenwich, CT: Information Age Publishers.

Kafai, Y.B., Quintero, M. & Feldon, D. (2010). Investigating the "why" in Whypox: casual and systematic explorations of a virtual epidemic. *Games and Culture*, *5*, 116–135.

Ketelhut, D.J., Nelson, B.C., Clarke, J. & Dede, C. (2010). A multi-user virtual environment for building and assessing higher order inquiry skills in science. *British Journal of Educational Technology*, *41*, 56–68.

Klosterman, M.L. & Sadler, T.D. (2010). Multi-level assessment of scientific content knowledge gains associated with socioscientific issues-based instruction. *International Journal of Science Education, 32*, 1017–1043.

Lenhart, A., Jones, S. & Macgill, A.R. (2008). Video games: adults are players too. Available online at http://pewresearch.org/pubs/1048/.

Lenhart, A., Kahne, J., Middaugh, E., Macgill, A., Evans, C. & Vitek, J. (2008). Teens, video games, and civics. Available online at http://www.civicsurvey.org/PIP_Teens_Games_and_Civics_Report_FINAL.pdf.

Mayo, M.J. (2007). Games for science and engineering education. *Communications of the ACM*, *50*, 31–35.

NPD Group. (2009). More Americans play video games than go out to the movies. [Online.] Available at http://www.npd.com/press/releases/press_090520.html.

Ruiz-Primo, M.A., Shavelson, R.J., Hamilton, L. & Klein, S. (2002). On the evaluation of systemic science education reform: searching for instructional sensitivity. *Journal of Research in Science Teaching*, *39*, 369–393.

Shaffer, D.W. (2006). *How Computer Games Help Children Learn*. New York, NY: Palgrave Macmillan.

Shaffer, D.W., Halverson, R., Squire, K.R. & Gee, J.P. (2005). Video games and the future of learning. *WCER Working Paper No. 2005-4*.

Squire, K. (2003). Video games in education. *International Journal of Intelligent Games & Simulation*, *2*(1), 49–62.

Trotter, A. (2005). Despite allure, using digital games for learning seen as no easy task. *Education Week*, *25*, 1–19.

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