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Students Designing Video Games about Immunology: Insights for Science Learning

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Exposing American K–12 students to science, technology, engineering, and math (STEM) content is a national initiative. Game Design Through Mentoring and Collaboration targets students from underserved communities and uses their interest in video games as a way to introduce science, technology, engineering, and math topics. This article describes a Game Design Through Mentoring and Collaboration summer program for 16 high school students and 3 college student mentors who collaborated with a science subject matter expert. After four weeks, most students produced 2-D video games with themes based on immunology concepts from the educational science game Immune Attack. Findings from three groups that finished their games and one group with an uncompleted game are explored.

KEYWORDS video games, science, game design, educational games, STEM, peer mentoring, high school, students making games, Game Maker, Immune Attack

Concern over American students' scores on standardized math and science tests may arise from views that careers in science, technology, engineering, and math (STEM) are the gateway to ensuring competitiveness in the global economy (NGA, 2008). In the United States, women and minorities are particularly underrepresented in STEM fields. The call for introducing American students to STEM content and careers has been a strong one, and it has been

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answered by a multitude of initiatives occurring during the school day, after school, on the weekends, and during the summer. Researchers from George Mason University developed an innovative program, *Game Design through Mentoring and Collaboration* (GDTMC) that uses student interest in video game design as a means to increase motivation, achievement, and exposure to STEM content for traditionally underserved students (Sheridan, Clark, & Peters, 2009). In this article, the authors discuss one aspect of this program: collaboration with the Federation of American Scientists (FAS), where students played and designed games with the specific intention of integrating science content.

BACKGROUND

Highlighting STEM education is of national importance for American K–12 schools in order to foster future innovators for the 21st century workforce (NSF, 2009). Literacy in STEM content is beneficial to all students, helping them prepare for the competitive global economy and strengthening skills for college, even those who may not choose specific STEM career paths (NGA, 2008). This focus has led the way for a multitude of programs, both in school and after school, designed to encourage the interest of K–12 students in STEM content. In particular, the National Science Foundation has created the Innovative Technology Experiences for Students and Teachers (ITEST) program to support such research efforts. ITEST programs specifically aim to bring students closer to choosing careers in science, technology, engineering, and mathematics (NSF, 2009). George Mason University researchers have created the ITEST-funded GDTMC to encourage middle and high school students from underserved populations to increase motivation, achievement, and exposure to STEM content through video game design classes (Clark & Sheridan, 2010).

Video Games as an Educational Tool

Video games are a major part of life for the American teenager. A national survey from the Pew Internet and American Life Project (2008) found that 99% of boys and 94% of girls from ages 12–17 play some form of video game, whether on consoles, computers, or mobile devices. The level of engagement video games command, and the time and effort children devote to learning how to play the games, have generated interest in using them as tools for learning and teaching (Gee, 2007; Gros, 2007; Shaffer, Halverson, Squire, & Gee, 2005; Prensky, 2001). Playing games can develop skills in thinking, planning, and learning in specific environments that have rules and boundaries (FAS, 2006; Squire, Giovanetto, Devane, & Durga, 2005). Designing games gives children the opportunity to create their own rules and boundaries, work collaboratively, and exercise creativity (Kafai & Ching, 2001; Robertson & Howell, 2008; Roberston & Good, 2005; Tarouco, Cogo, Konrath, & Grando, 2006). Tapping into this interest in video games that young people already have and subtly using it as the foundation for new learning experiences can be an excellent way to encourage interest in STEM fields.

GDTMC

The GDTMC program attracts students who are interested in video games, typically those whose initial interests only lie in playing the games. Participants are often asked to envision ways to make the digital games they play better and to imagine their own versions of these games that they play, whether computer-based, downloaded from the Internet, or on video game consoles. In this way, students begin thinking about game design through their own experiences.

The program exposes students to STEM fields by learning 3-D computer modeling and animation, computer programming concepts, and video game design in a studio learning environment (Sheridan et al; 2009). Peer mentors that have already completed the game design program and/or are in college for technology-related fields are hired to assist instructors in carrying out the lessons. In one of the classes of learning basic game design, students create their own 2-D video games. In another, mathematics and steps for the scientific method are covertly incorporated into 3-D modeling and animation lessons. All classes that participants take to learn aspects of video game design are designed to be exercises in critical-thinking skills. Furthermore, the peer–mentor model is what makes this video game design class unique.

GDTMC was established to build upon and expand activities already taking place during a program that had been operating informally at an urban high school with a technology focus. During the school year, classes are held on Saturdays for two hours, in 10-week sessions during the fall and spring. These classes are held in labs equipped with cutting-edge computer hardware and software. Students voluntarily sign up for these classes, which include one hour for 3-D modeling and animation and one hour for video game design. Each class is run by an instructor, who plans the lessons and gives an overview to the class at the start of each session. The mentors, who have been familiarized with the lessons by the instructors prior to class, walk around the room and help the students as needed. The instructor also observes the class and keeps students on task by announcing the next steps that should be taken. The classes are designed so that students can work at their own pace; advanced students can move ahead when they are ready by elaborating on their projects to make them more complex. The students who are just beginning or do not catch on as easily as others can receive one-on-one time with a mentor, without needing to ask the instructor questions to hold up the rest of the class.

Summer sessions usually last for four weeks, four hours a day. Students from the fall and spring sessions who wish to become mentors go through a training session during this time. The participants of the summer program are smaller in number than the school-year sessions and may be given a stipend to attend. In addition to assisting the participants, mentors work on their own projects for their courses and personal development. The GDTMC project encourages both the students and mentors to develop STEM interests.

Collaboration with the Federation of American Scientists

Outreach to professionals in the STEM field is important for GDTMC researchers. In particular, introducing students to women and minorities working in STEM fields helps the students see the potential for their own careers. In the summer of 2009, George Mason researchers collaborated with the FAS on their educational science game: Immune Attack. Immune Attack teaches players about immunology and molecular processes involved in tracking bacteria (FAS, 2011). In this game, the player controls a nanobot, a miniscule machine that traverses the human body in order to repair the immune system. Immune Attack is currently being updated for a new version in which the nanobot cures a neurological disorder.

A trial program was launched where Immune Attack was used as the foundation for the students to create their own educational science games. The FAS program director for educational technologies became the science subject matter expert (S-SME). The S-SME assisted students participating in the GDTMC summer program with creating protoypes for the next Immune Attack game. GDTMC students learned how to program with the game software, Game Maker, while simultaneously learning about basic immunology and neurology in order to make a realistic educational game.

DESCRIPTION OF SUMMER PROGRAM

Students

Sixteen high school students and three student mentors (in college or entering college in the fall) participated in the summer class. The majority of these students were part of a city-wide youth summer program and the high school at which GDTMC operates was their work site. GDTMC was one of several work site programs housed at the high school from which students could choose. Summer students and mentors were paid through the city-wide youth summer program or by GDTMC. Of the students, there were 6 females and 10 males. Of the mentors, two were male and one was female. All participants were African American. All groups started out with four students.

Tools

The students used a software called Game Maker to create their games. Game Maker (http://www.yoyogames.com/gamemaker/) is a free software that allows for the creation of 2-D and 3-D games without the need to write code. Basic object-oriented programming concepts are emphasized as the students work with objects and create events and actions through the use of icons and drag-and-drop moves. Students are able to view the programming code created by their actions. Objects, events, and actions are all standard concepts in the programming languages used to create professional video games. In this workshop, students concentrated on creating 2-D games that took place on a single screen.

Game Design Workshop

Students in the Game Maker class met every day for four weeks, spending two to three hours each day working on their games. The class was directed by an instructor with game programming knowledge and three mentors, who were all former GDTMC participants. During the first week, the S-SME discussed the concept of the game Immune Attack and gave a brief overview on basic neurology, a subject that none of the students had yet been exposed to in their classes during the academic year. The S-SME presented four molecular processes that occur in neurons. Before she began describing the processes in detail, she asked the students to keep in mind the molecular process for which they might want to create a game. The introductory talk lasted over 60 minutes because students asked so many questions. The students divided themselves into four groups. Group One chose to create a game about the myelin sheath maintenance; Group Two chose DNA gene regulation; Group Three chose neurotransmitter receptor functions; Group Four chose signal integration which eventually morphed into growth factor signaling and carcinogenesis. After the four groups established their focus, the groups separated to design their games. Each group had one or two students that had taken a Game Maker class before, whether through the GDTMC project or through a high school curriculum, and the students varied in their technical skills. Meanwhile, the S-SME spent another 30 minutes with each group, asking pertinent questions about the molecular mechanisms involved.

Each group met with the subject matter expert individually on subsequent weeks, discussing their specific tasks. Together, they created an outline for the game, which included pictorial representations and diagrams. Each group posted their outlines at their workstations, to which they would later refer. Throughout the entire program student mentors rotated between groups to assist with the technical aspects of the games.

Data Collection

The findings are based on the observations of two graduate research assistants (GRAs) in the form of field notes of the summer program, the observations of the S-SME who worked with the students, and the observations of the principal and co-principal investigators. The S-SME shared onsite observations and communicated student progress both in person and via e-mail. The GRAs also held informal interviews with peer mentors and students to gauge their progress. These interviews were often conducted at the workstations so that students and mentors could reveal their games at various stages of completion. The final completed games were collected and analyzed as well.

The focus of the authors in this data collection was to document the process of implementation rather than to rigorously assess student learning, but insights on student learning were able to be drawn based on observations and initial analysis. To improve descriptive validity that these observations accurately represented the range of participants' activities and thinking in the program, a triangulation of types of data sources were used, including observations of students working processes at different points in the game design process, documentation of student interaction with the S-SME both in person and through e-mail, informal interviews with students about their designs, and documentation of the games at various stages of completion. To reduce the effects of researcher biases on the interpretations of the findings, member checks with the participants were conducted to assess whether the researcher interpretation of the students games and their design process aligned. The two researchers independently conducted observations and informal interviews, and reviewed and interpreted this data before discussing the full data with each other. At first, each individual game design group was considered on its own terms, looking at all the various data sources to document their individual process from start to completion. Then the researchers looked across these cases for patterns that seemed to emerge. From this discussion, the two researchers wrote memos that were shared with the broader interpretive community of the S-SME and the principal investigators, who introduced new questions for the data and potential alternative interpretations. Through this process, the initial themes proposed are presented as potential insights into student learning, and present evidence that illustrates how these elements were and were not present in each of the four game design groups observed. In the instances where the patterns do not seem to hold for all four groups, potential alternative interpretations are offered and the researchers suggest follow-up investigations to study these themes more thoroughly.

FINDINGS

Three of the four groups were able to complete their games. Group One created a game they called Myelin Sheath Restoration, demonstrating how glial cells come to adhere to the axon of the neuron. Group Two entitled their game Signal the DNA, which describes a complex relationship between neuronal signals, proteins, and DNA transcription. Group Three did not finish their game, as will be discussed in further detail. Group Four developed a game that they named Brain Chemistry. This group wanted to show how certain growth factors, which the group referred to as chemical signals, caused a normal neuron to become cancerous.

The video game design approach was primarily chosen for its interest and relevance to students-video games are well established as an engaging arena for youth. However, in addition to being an engaging route, three key learning processes were found that are highlighted by the game design approach to science learning. The key learning processes are:

1. Questioning one's own knowledge: Designing a game led students to notice gaps and question their own understanding of the science concepts and voluntarily seek avenues to fill in the gaps.
2. Ownership and responsibility: Designing a game created a sense of ownership and responsibility to make the game attractive, engaging, and scientifically accurate.
3. Articulating knowledge: While game design involves creating concepts in a visual format, students were able to articulate the purpose of their games and the science concepts behind them at the completion of the four weeks.

Questioning One's Own Knowledge

From at least as early as when Socrates confronted the Oracle in Plato's *Apology*, appreciating one's own lack of knowledge has been recognized as an important step of learning. The authors found that, when students had to design a game that taught others a scientific concept, the science areas about which they were most unsure became apparent. For instance, during a presentation by Group Two, one member began to explain how the proteins would bind to the DNA. She began to play her game as the nanobot pushed the proteins, depicted as balls on the screen, onto a DNA strand. When the S-SME asked her what these balls were made of, she could not answer. Yet she was able to explain how pushing these "balls" onto the DNA could affect the genetic code. Designing a game on a scientific concept is much like depicting a model of the scientific concept, which has been found to be an important way to get students to question their incorrect conceptions and gaps in knowlege (Gardner, 1991; Bruer, 1993; Schneps & Sadler, 1987).

In addition to the effect of having to design an explicit model of the concept, working in groups also helped student misunderstandings surface. As groups tried to map out what should come next in their game, they would realize what they did not understand certain aspects when they had to explain specific concepts to one another. One of the key factors identified in the correlation between cooperative learning and higher achievement outcomes is the greater role of student-generated explanations in the learning process (e.g., Brown & Palinscar, 1989; Sharan, 1990; Slavin, 1992). Sources of confusion would also be revealed as students tried to explain their games to the subject matter expert, the instructor, the mentors, or students in other groups. Sometimes students would be uncertain about a term or what the graphics in the game were supposed to represent, which made it clear to them, and to the researchers, instructors and mentors, that they had grown confused about their molecular process.

Ownership and Responsibility

When students design and create a product, there is a greater sense of ownership than other modes of demonstrating science knowledge, such as answering questions on a test, or even the more hands-on following prescribed steps of an experiment. In collaboration with the S-SME, each group of students was responsible for creating a game that is attractive, fun to play, and yet clearly and accurately teaches complex scientific concepts. Finding this balance was challenging to students. One student in Group Four remarked, "The very first problem was understanding what the teacher told us. Another problem was actually writing a story to the actual game and seeing what we were actually going to do." Despite the challenge, students took a personal responsibility to meet these goals. For instance, when the S-SME was not on site, students would try to problem-solve with a mentor, refer to their outlines, use the Internet for research, or communicate with the S-SME via e-mail. Participants were motivated to find answers to their questions using a variety of strategies and did not wait for their weekly meetings with the S-SME.

While three of the four groups reflected this sense of ownership and responsibility, our experience with one group showed a different learning path. Students in Group Three were unable to finish their game, even though they were the first group to complete their game for review by the S-SME. During the play and presentation of the game, the S-SME realized that the students did not fully understand the scientific concepts behind the game. She met with them again and gave them points to get back on track. While none of the four groups had a perfect attendance rate, two of the members of Group Three were consistently absent, and of the two remaining members, only one was noticeably active in redesigning the game. After several failed attempts, this student decided to help the three other groups with the programming of their games. One of the mentors remarked that this group was not unmotivated; they were discouraged. Another mentor decided to do research at home in a final attempt to help her group develop a game. This research, combined with direct communication between the mentor and the S-SME via e-mail, finally put the group in a place where they could develop their ideas. Unfortunately, this was at the end of the program and there was not enough time left for creating the game.

Even though this group did not complete a finished product, they were initially enthuasiastic about the game and this enthusiasm resurfaced toward the end of the program. The discouragement they felt at missing the science concepts in the beginning hindered the time they had to work on the project. While a number of factors contributed to Group Three's problems, they are a reminder that, even though the design approach seems to foster a sense of ownership and responsibility, there is a need for continued support for students who feel discouraged and want to walk away from a project, particularly when the discouragement stems from realizing their initial enthusiastic investment of energies were not successful.

Articulating Knowledge

While designing a workable, accurate game is a form of visual articulation of a concept, it was also important to us that students be able to verbally articulate their understandings of scientific concepts. At the end of the four weeks, the three groups finished their games and gave presentations. In order to demonstrate their work, students played their game while explaining what was happening on the screen so that everyone watching could understand the purpose of the game, which was driven by a particular scientific concept.

In Group One's Myelin Sheath Restoration game, two members of the group explained that the myelin sheath is a glial cell, and in the game it is weak and breaking off of the axon. The player controls the nanobot, whose job it is to repair the myelin sheath by pushing additional glial cells back onto the axon. Group Two's game, Signal the DNA, illustrated a complex neuronal process: The "signals" in this game are proteins that enter the nucleus in response to the neuron having received a signal from outside. These proteins would bind to/alter the activities of transcription factors on the DNA. In the game the signals are falling randomly and the nanobot is required to deliver the signals to the appropriate promoter regions of the DNA. In addition to describing how the game works, one of the group members discussed that these proteins can manipulate the DNA, activating or inactivating different genes, which can have lasting effects, such as altering one's memory, thus showing insight into why the concept matters. Group Four developed a game which they named Brain Chemistry. This group wanted to show how certain growth factors, which the group referred to as chemical signals, caused a normal neuron to become cancerous. In their game, these chemicals are falling onto a neuron and it is the player's role to use the nanobot to push them away. If too many chemicals touch the neuron, it then becomes cancerous.

These presentations showed that, despite having no prior knowledge of these neurological concepts, students were able to design reasonably accurate visual representations of the constructs and verbally describe the concepts. In future research, to more fully assess their understanding verbally, the researchers plan to engage them in more detailed questioning about their selected scientific concepts; however, the initial observations show that they were able to make this translation between the visual and the verbal.

DISCUSSION

These high school students, like many in American public schools, had not learned neurology during the academic year. Over four weeks during the summer, they grew accustomed to listening to the descriptions of the complex molecular processes. Their goal—to create video games—required them to be active listeners. Additionally, because the subject matter expert shared the same goal—the creation of the game—she encouraged the active listening and the frequent interruption with questions and ideas for demonstrating the molecular process in the game. Instead of only conveying information in lecture format, knowledge was constructed via active interaction and lively exchange between students and subject matter expert. The S-SME and mentors often reminded the participants that their games would be useful as prototypes when FAS develops other levels for Immune Attack. This combination of an interactive, constructivist approach to learning and the authentic and engaging task of designing a video game, can be seen as creating a learning environment where students are more likely to question their understanding, take ownership and responsibility for the quality of their work and the accuracy of the knowledge they represent in it, and be able to articulate their understanding both visually and verbally.

To be sure, other constructivist learning approaches have shown promise for students working with scientific concepts that are not particular to game design (e.g., Kolodner et al., 2003). However, the authors have seen that the game design goal provides an opportunity for students to make visible their scientific understanding in a technology-driven environment, allowing them to interact with their creations. In this way, students were involved in the collaborative creation of a visual art product—a video game—and also a scientific model. Through this process the development of artistic habits of mind, such as what Hetland, Winner, Veenema, and Sheridan (2007) highlighted as developing the habit to envision and reflect, and what Heath and Roach (1999) and Heath (2001) described as "Imaginative Actuality," the central function of imagining possibilities, making plans and bringing them to actuality in the arts (Sheridan, 2011). Development of scientific understanding is also seen as students begin to question their learning, surface misconceptions, and as they attempt to make their game scientifically accurate. This approach to learning suggests interesting possibilities in education that involves integration of artistic and scientific thinking.

FUTURE WORK

While this approach shows promise, the insights are only preliminary. More formal research is needed to understand how to support this integrative design and science learning, how to help students persist through the failures and discouragement they are likely to experience in this type of complex extended design project, and how to assess the learning demonstrated in students' visual and verbal articulations of the scientific concepts. This experience has informed the authors on how to design the next iteration of a summer workshop where students can integrate science content into their video game design. Further detailed research is planned to understand how the students take an active part in their learning and if their video game design experience has encouraged their interests in technology and science.

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